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Polyhalites (Polysulphates): Best Soil Ameliorant for Cassava (*Manihot esculenta* Crantz) in the Ultisols and Entisols of Kerala

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Abstract

Among the tropical tuber crops, cassava is important due to its higher biological efficiency, larger area under cultivation both for edible and industrial uses, ability to withstand biotic and abiotic stresses, quality starch in the preparation of many value added products including ethanol and biodegradable plastics. In India, cassava is cultivated mainly in Kerala, Tamil Nadu, Andhra Pradesh, Maharashtra and North Eastern States. In Kerala, it is grown as an edible crop and more than 90% of the soils under cassava are acidic (Ultisols), deficient in nutrients like K, Ca, Mg and B. Polysulphate, a natural mineral product containing 18.5% S,13.5% K_2O, 5.5% MgO and 16.5% CaO was evaluated in agro-ecological unit (AEU) 3, AEU 8 and AEU 9 in Kerala for two seasons in five farmers' fields and one at on station since June 2018 to explore its possibility as a good soil amendment by studying its effect on tuber yield, tuber quality and soil physico-chemical properties. Polysulphate application can be done either as half lime and half dolomite as per lime requirement along with 1-2 t ha^{-1} polysulphate which resulted in a tuber yield of 53.33 t ha^{-1} on par with full dolomite along with polysulphate (50.32 t ha^{-1}) and polysulphate alone (49.24 t ha^{-1}).The yield increase with polysulphate application over PoP, and lime together with dolomite was to the tune of 17.10% and 15.55% respectively. Polysulphate improved bulking of tubers in good form with better quality in terms of cooking, improvement of starch and lowering of bitterness. Though there is no substantial improvement in soil pH, the exchangeable soil K, Ca, Mg and S showed an increase of 80.93, 91, 2.54 and 59.84% over initial compared to 17.84, 90, -11, -0.66% under PoP and 42.39, 82, 18.95 and -3.28% under lime along with dolomite respectively for these nutrients.

Key words: Laterites, Onattukara sandy loam, tuber yield, cyanogenic glucosides, starch, soil chemical properties

Introduction

Tuber crops are the third most important food crops of man after cereals and grain legumes. Among the tropical tuber crops, cassava (*Manihot esculenta* Crantz) is the most important with respect to higher biological efficiency, area under cultivation, acceptability as a secondary staple, ability to thrive under marginal soil and environmental conditions, tolerance to pests and diseases, sustainability for continuous cultivation (Susan John et al., 2015, 2016), quantity and quality starch and its excellent physico-chemical and biochemical properties for the preparation of value added products.

Among the different states of India, extensive cultivation of these groups of crops are in Kerala, Tamil Nadu, Andhra Pradesh, Bihar, Chhattisgarh, West Bangal and NEH States. In Kerala, cassava is cultivated on a large scale for edible purpose in the laterite soil which constitute more than 80% of the total area of Kerala. In addition, sandy soils of the Onattukara is also famous for tuber crops especially as intercrops in coconut plantations. In both these soils, acidity coupled with high P, deficiency of K, Ca, Mg and B are the important soil chemical constraints for crop production (Rajasekharan et al., 2014). However, all the tuber crops grow well in these soils with proper soil and crop nutrition.

The experience from the long term fertilizer experiment (LTFE) still in progress at ICAR-CTCRI since 1977 reveals the strong positive response of cassava to manures and fertilizers (Susan John et al., 2005). Farmers are managing these crops mostly through an integrated approach with organic manures and NPK fertilizers. The secondary nutrients like Ca, Mg and S and micronutrients like Zn and B, though essential for these crops are not used regularly as fertilizer nutrients. It is understood from the LTFE that, there is drastic depletion of secondary and micronutrients under continuous cultivation of cassava especially under NPK fertilization without organic manures (Kabeerathumma et al., 1993, Susan John et al., 2005). Though cassava did not respond significantly to lime application, as cassava is Al tolerant and Ca efficient by nature and liming is not usually practiced (Susan John and Venugopal, 2006). However, application of lime @ 2 t ha^{-1} has been recommended taking into account the extreme acidic condition of laterite soil having pH ranging from 4-5.5.

For tropical tuber crops, K is considered as the key nutrient as it is important for both tuber productivity and quality (Imas and Susan John, 2013). As regards to quality, K contributes to reduction in cyanogenic glucoside (HCN) content responsible for bitterness of tubers and increase in starch through its moderating effect on starch synthatase enzyme. Moreover, the K content in the laterite and sandy soils of Kerala are low to medium in the range of 150-250 kg ha^{-1}. Mg depletion was severe under cassava when grown continuously in the same field without Mg application and hence a dose of Mg as 20 kg ha^{-1} $MgSO_4$ has been recommended (Kabeerathumma et al., 1993) .

The present study was undertaken to see the suitability of a multi nutrient natural product by name polysulphate/ polyhalite containing K_2O, CaO, MgO and S to the tune of 13.5, 16.5, 5.5 and 18.5% as a soil ameliorant for cassava in the major cassava growing agro ecological units (AEU) of Kerala *viz.,* AEU 3 (Onattukara sandy plain) AEU 8 (Southern laterites) and AEU 9 (South central laterites).

Materials and Methods

The experiment was conducted in five farmers' fields of AEU 3 and AEU 9 in addition to one at on station at ICAR-CTCRI for two seasons. The cassava variety used was Sree Pavithra. The plot size was 4.5 x 4.5 m with 16 outer and 9 inner plants. The experiment consisted of nine treatments replicated thrice in RBD. The treatments were as follows:

- T_1. Package of Practices (POP) recommendation for cassava (NPK @100:50:100 kg ha^{-1}+ FYM @12.5 t ha^{-1})
- T_2. Soil test based recommendation of NPK and FYM
- T_3. POP + lime@full lime requirement (LR) + polysulphate@ 2 t ha^{-1}
- T_4. POP + lime@1/2 LR+polysulphate@ 2 t ha^{-1}
- T_5. POP + dolomite @full LR+ polysulphate@ 2 t ha^{-1}
- T_6. POP + dolomite @1/2 LR+ polysulphate@ 2 t ha^{-1}
- T_7. POP + polysulphate@ 2 t ha^{-1}
- T_8. POP + lime @1/2 LR + dolomite@1/2 LR + polysulphate@ 2 t ha^{-1}
- T_9. POP + lime @1/2 LR + dolomite@1/2 LR

Observations were recorded mainly on growth characters of the crop, tuber yield, tuber quality parameters *viz.,* starch and HCN and nutrient build up with respect to K, Ca, Mg and S over the initial status.

The growth characters studied included plant height, stem girth, number of fallen and retained leaves at 3, 6 and 9 months after planting (MAP). Tuber yield harvested at 9-10 MAP was recorded from inner plants and converted on per hectare basis. The HCN content in fresh tubers immediately after harvest was determined following Indira and Sinha (1969) and starch in the dry tuber as per Chopra and Kanwar (1976) and expressed on fresh weight basis. The soil chemical properties estimated included pH, available N, P, K, Ca, Mg, S following standard analytical procedures (Page et al., 1982).

Results and Discussion

The initial soil analytical data on pH, organic carbon, available N, P, K, Ca, Mg and S of the six locations are presented in Table 1.

Table 1. Initial soil chemical properties of the six experimental sites (CTCRI)

Locations	AEU	pH	Organic Carbon	Available N	Available P	Available K	Available Ca	Available Mg	Available S
			%		kg ha^{-1}		meq 100g^{-1}		ppm
1	9	6.07	1.26	94.08	131.3	237.7	2.427	1.80	5.95
2	9	4.62	2.34	243.04	157.0	174.0	1.858	2.47	15.14
3	3	4.76	0.69	59.58	148.2	87.6	0.639	1.16	7.03
4	3	5.75	1.29	98.78	116.6	137.8	0.896	1.63	8.11
5	8	4.15	1.68	203.84	447.5	278	0.724	1.79	16.76
6	8	4.52	0.36	43.90	15.4	120.4	0.355	1.16	7.57

In general, the soil is acidic, organic carbon low to high, available N low except in location 5, available P very high, available K low to medium, available Ca, Mg and S ranged from low to high, high and high to very high respectively.

Based on the organic carbon, available P and K, the soil test based fertilizer (STBF) recommendation arrived for the six locations as per Aiyer and Nair (1985) and Susan John et al., (2010a) are given in Table 2. The need for resorting to soil based nutrient management was emphasized by many researchers (Cassman, 1999; Motsara, 2007; Susan John et al., 2010a).

The mean data of the three AEU's on growth characters, tuber yield, tuber quality and soil nutrient build up are discussed below:

1. Growth characters

The mean data on the characters viz., plant height, stem girth, number of fallen and retained leaves taken from the sample plants (Fig. 1) of the different locations of AEU 3, 8 and 9 at 3 months interval since 3MAP till harvest for the two seasons did not show any significant effect of the treatments. However, over PoP including soil test based application, comparatively higher values as T_2 (199 cm), T_4 (8.74 cm), T_6 (103) and T_3 (126) were recorded for plant height, stem girth, fallen and retained leaves respectively. Pellet and El-Sharkawy (1993) reported a significant increase in aerial and total biomass production in cassava due to balanced application of essential nutrients.

Table 2. Soil test based INM recommendation evolved for the six locations

Locations	FYM (t ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
1	5	78	0	60
2	2.5	54	0	83
3	7.5	84	0	106
4	5	63	0	94
5	2.5	71	0	48
6	12.5	97	41.5	94
Mean	6.33	75	7	81

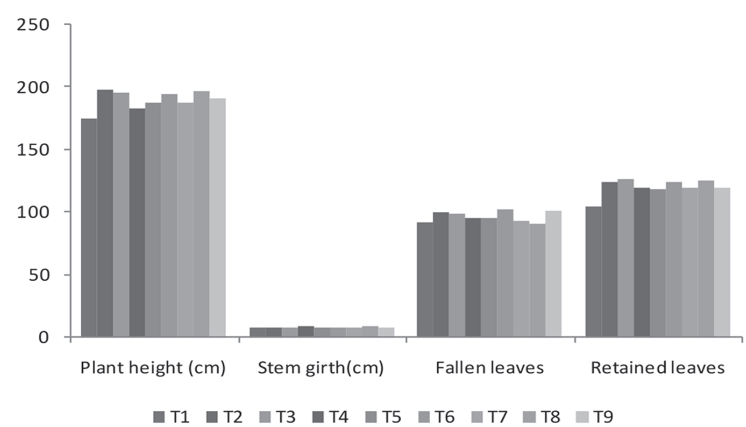

Fig.1. Effect of treatments on biometric characters of the plant (mean of 2 years)

2. Tuber yield

The mean tuber yield data of the two seasons over six locations of the three AEU's are presented in Table 3.

The pooled data on tuber yield of the six locations indicated T_8 (half dolomite and half lime along with the polysulphate) resulted in the highest yield (53.33 t ha^{-1}) on par with T_5 (full dolomite

Table 3: Effect of treatments on tuber yield at different locations (Mean over 2 years)

		Tuber yield (t ha^{-1})						
Treat No	Treatment Description	CTCRI	AEU 3(1)	AEU 3(2)	AEU 9(1)	AEU 9(2)	AEU 8	Pooled
T_1	PoP	42.80	34.5	46.5	41.2	32.5	48.80	41.05
T_2	STBF	48.14	38.9	47.0	43.3	34.3	48.69	43.39
T_3	PoP+ LF+PS	56.36	48.0	49.2	41.7	37.7	51.40	47.39
T_4	PoP+1/2 L+PS	51.25	37.7	45.3	48.9	27.4	46.86	42.90
T_5	PoP+ DF+PS	60.44	49.5	49.4	56.5	37.0	49.08	50.32
T_6	PoP+1/2D+PS	57.49	42.9	42.4	43.9	30.9	53.92	45.25
T_7	PoP+ PS	60.63	42.3	44.4	53.8	41.1	53.20	49.24
T_8	PoP+1/2L+1/2D+PS	63.07	50.1	56.1	57.3	37.7	55.73	53.33
T_9	PoP+1/2L+1/2D	50.36	42.2	30.6	43.2	33.1	50.12	41.60
	Mean (Locations)	54.5	39.6	44.5	66.7	36.4	50.9	46.05
	CD (Treatment)	5.32	4.68	6.18	4.16	3.84	4.29	4.75
	CD (Location)	10.94						
	CD (Treatment × Location)	NS						

along with polysulphate) (50.32 t ha^{-1}) and T_7 (polysulphate alone)(49.24 t ha^{-1}) (Table 3). The tuber yield data under the different treatments are presented in Fig.2. A comparison of yield with and without polysulphate under PoP, STBF, lime and dolomite together are presented in Fig.3. The yield increase calculated with polysulphate application over PoP, STBF and lime together with dolomite was to the tune of 17.10, 10.79 and 15.55% respectively. The pooled data indicated significant effect of locations too with significantly the highest tuber yield (66.7 t ha^{-1}) at AEU 9(1). This was followed by CTCRI (54.50 t ha^{-1}) which in turn was on par with AEU 3(2) (44.5 t ha^{-1}) and AEU 8(TVM) (50.9 t ha^{-1}). The other two locations *viz.,* AEU 3(1) and AEU 9(2) had the lowest tuber yield to the tune of 39.6 and 36.4 t ha^{-1} respectively. The significantly high yield associated with polysulphate alone or in combination with lime or dolomite can be attributed to the effect of nutrients *viz.,* K, Ca, Mg and S in affecting the potential productivity of the crop as reported by Susan John et al., (2010b, 2013) in the case of K, Bari et al., (2001) for potato for nutrients like Mg and S and Mohan Kumar and Nair (1985) for Ca and S and Anju et al., (2020) for all these nutrients.

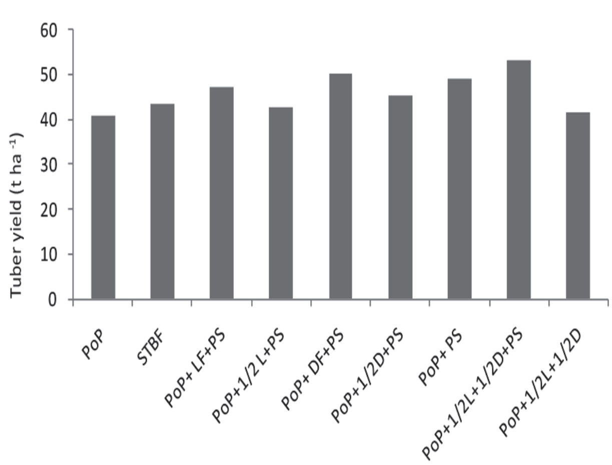

Fig. 2. Effect of treatments on tuber yield (t ha^{-1}) (Pooled data)

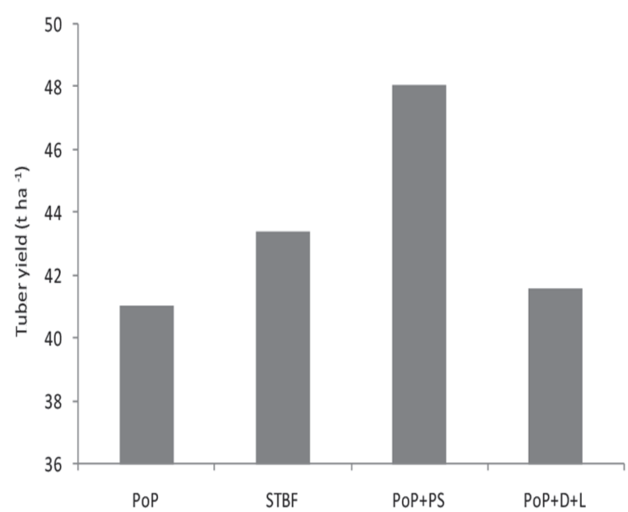

Fig.3. A comparison of tuber yield (t ha^{-1}) with and without polysulphate application (Pooled data)

3. Tuber quality parameters

The mean data on HCN content in tubers of the three AEU's for the six locations for two seasons and the data on starch over six locations are presented in Table 4. An analysis of the data in Table 4 clearly revealed that, T_3 with full lime and polysulphate resulted in the lowest HCN content in tubers (30.22 ppm) on par with T_1 (39.54 ppm), T_6(34.40 ppm) and T_8 (34.07 ppm). The highest content of tuber cyanogen was recorded in T_4 (half lime along with polysulphate) (79.72 ppm) which was on par with T_7(polysulphate alone) (64.93 ppm). However, there was significant effect of polysulphates in reducing the bitterness of cassava tubers. Over PoP (39.54 ppm), there was reduction in HCN under T_3 (30.22 ppm), T_6(34.40 ppm) and T_8 (34.07 ppm). In locations *viz.,* AEU 9 and AEU 3, though there was no significant effect of treatments on HCN, treatments T_8 (20.2 ppm) had the lowest HCN followed by T_4 (27.0 ppm) where polysulphate was applied along with lime and dolomite. In these locations among the different treatments, T_9 without application of polysulphate resulted in the highest HCN (74.3 ppm). At AEU 3, the HCN content was found comparatively higher compared to the other two sites. Here, polysulphate along with half dolomite resulted in the lowest cyanogen (T6) (46.9 ppm) and full dolomite along with polysulphate had the highest HCN(148.2 ppm).

The pooled data of the three locations showed significant effect of treatments, locations and the interaction of treatments and locations. T_8 resulted in the lowest cyanogen content of 38.89 ppm on par with all treatments except T_5, T_7 and T_9. Among the locations, AEU 9 had the lowest (43 ppm) on par with AEU 8 at ICAR-CTCRI. The effect of treatments on the HCN content of cassava tubers are presented in Fig. 4. Though the effect of polysulphate on HCN and starch content of cassava tubers are not much evident and appears to be random, the reduction in HCN and increase in starch recorded in some ploysulphate treatment especially along with dolomite can be attributed to the moderating effect of nutrients *viz.*, K, Mg and S in affecting the linamarase enzyme responsible for cyanogen synthesis and starch synthatase enzyme in affecting the starch synthesis (Nair and Aiyer, 1986; Susan John et al., 2005; Mohan Kumar and Nair, 1985).

The effect of polysulphate on starch content of cassava tubers on fresh weight basis is presented in Fig. 5. The starch content of cassava tubers analysed for one location at ICAR-CTCRI indicated significant effect of

Table 4. Effect of polysulphate on cassava tuber quality

Treat No.	Treatment Description	Cyanogenic glucosides HCN (ppm) AEU 8	AEU 9	AEU 3	Pooled	Starch (% fresh weight basis) Mean over 3 AEU's over 6 locations
T_1	PoP	39.54	44.0	50.1	44.57	26.17
T_2	STBF	56.90	43.7	75.5	58.72	30.65
T_3	PoP+ LF+PS	30.22	52.4	73.0	51.86	23.45
T_4	PoP+1/2 L+PS	79.72	27.0	64.6	57.11	23.56
T_5	PoP+ DF+PS	59.47	35.4	148.2	81.01	31.69
T_6	PoP+1/2D+PS	34.40	52.1	46.9	44.47	28.50
T_7	PoP+ PS	64.93	37.9	92.3	65.04	27.01
T_8	PoP+1/2L+1/2D+PS	34.07	20.2	62.4	38.89	28.15
T_9	PoP+1/2L+1/2D	52.40	74.3	69.4	65.36	23.34
	Mean (Locations)	50.18	43.00	75.83		
	CD (Treatment)	16.44	NS	NS	22.79	2.820
	CD (Location)	13.16	-			
	CD (Treatment X Location)	39.47	-			

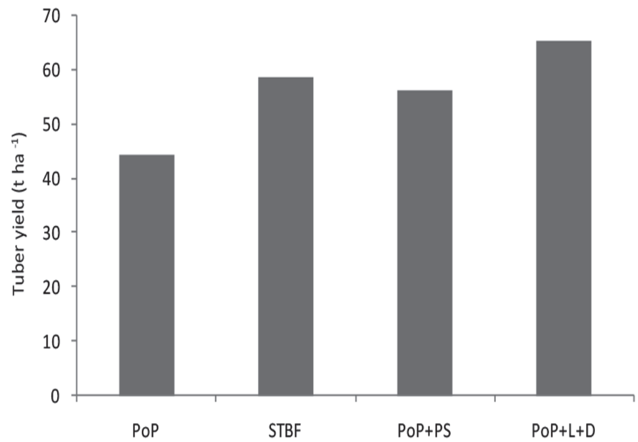

Fig 4. Effect of treatments on HCN(ppm) content of tubers

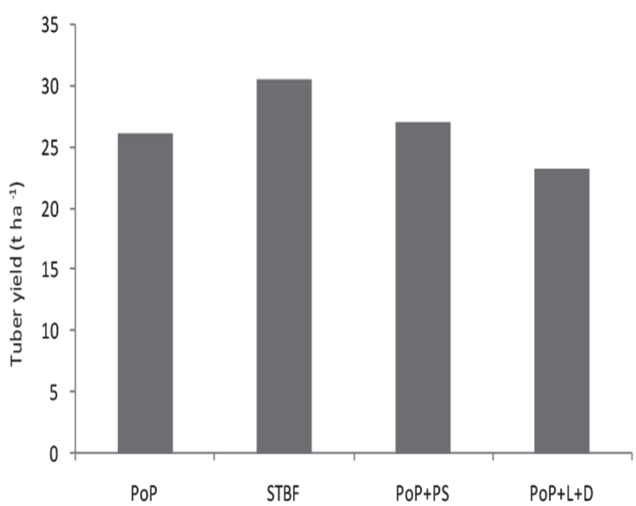

Fig.5. Effect of treatments on starch (% fresh weight basis) content of tubers

*PoP: Package of practices, STBF: Soil test based fertilizer recommendation, PS: Polysulphate, L: Lime, D: Dolomite

treatments. The highest starch content on fresh weight basis was obtained for T5 (full dolomite along with polysulphate) (31.69%) which was on par with STBF (30.65%).

5. Soil chemical properties

The soil chemical properties studied were pH, organic carbon, available N, P, K, exchangeable Ca, Mg and S. In fact, the build up of the nutrients over the initial status with respect to nutrients mainly K, Ca, Mg and S were the main focus. Here, the increase over initial status (Table 5) in terms of numerical value as well as percentage increase was determined.

a. *pH*

The pooled data over the six locations indicated the maximum rise in pH under T_7 (0.81 units) where polysulphate alone was applied along with PoP (16.88%). Over the initial pH (before the start of the experiment), the percentage increase in pH calculated with treatments *viz.,* PoP, STBF, PoP along with polysulphate and PoP along with lime and dolomite together revealed the highest increase in pH under STBF (14.57%) (Fig. 6). Though the treatment wise data indicated significant percentage increase in pH under polysulphate alone application (Table 5), the mean over the treatments did not result in significant increase in pH with polysulphate and other liming materials like lime or dolomite within a short span of two years time. It is known that, for soils having extreme acidity with pH to the tune of 4-5, raising pH significantly with soil amendments containing Ca or Mg is gradual and the presence of S in the polysulphate may have an acidifying effect too. Temesgen et al., (2017) also reported the slight increase in soil pH to the tune of 0.48, 0.71, 0.85 and 1.1 units after liming @ 0.55, 1.1, 1.65 and 2.2 t ha^{-1} revealing the fact that, pH increase of extremely acidic soil through liming for short period is not substantial.

b. Organic carbon

Among the treatments, T_8 with half each of dolomite and lime along with polysulphate resulted in the maximum increase in organic carbon followed by T_7(polysulphate alone) and T_6 (half dolomite along with polysulphate) (0.9%). The pooled data indicated the highest increase with T_5 (full dolomite along with polysulphate) (0.416%) (Table 5).

It is seen that, there was an increase in organic carbon in all locations and can be attributed to the luxuriant vegetative growth of the crop under the different treatments.The leaf fall and consequent decomposition and incorporation might have improved the organic carbon status of the soil. The pooled data indicated the mean increase as 15% over the initial. The same trend as in the case of increase was noted for percentage increase in organic carbon with polysulphate alone resulted in the highest, followed by half dolomite along with polysulphate, PoP and half each of dolomite and lime along with polysulphate. The pooled data showed the highest percentage increase with T_5 (24%). The

Table 5. Increase/decrease in pH and organic carbon over initial (mean over treatments, over locations and seasons)

Treat No	Treatment Description	pH			Organic carbon (%)		
		After II season	Increase over initial after II season	% Increase over initial after II season	After II season	Increase over initial after II season	% Increase over initial after II season
T_1	PoP	5.15	0.33	7.36	1.96	0.222	13
T_2	STBF	5.55	0.73	14.57	1.97	0.234	13
T_3	PoP+ LF+PS	5.06	0.24	5.46	1.99	0.254	15
T_4	PoP+1/2 L+PS	5.24	0.42	8.58	1.92	0.182	10
T_5	PoP+ DF+PS	5.21	0.39	9.67	2.16	0.416	24
T_6	PoP+1/2D+PS	5.04	0.22	4.95	1.94	0.196	11
T_7	PoP+ PS	5.62	0.81	16.88	2.05	0.31	18
T_8	PoP+1/2L+1/2D+PS	5.03	0.22	5.82	2.12	0.378	22
T_9	PoP+1/2L+1/2D	4.93	0.11	2.60	1.96	0.218	13
	Initial	4.82	-	-	1.74		
	Mean (Locations)	5.20	-	8.43	NS		
	CD (Treatment)	0.442	-	-			
	CD (Location)	0.329	-	-			
	CD (Treatment X Location)	NS	-	-			

increase in organic carbon content of the soil due to polysulphate application over other treatments is evident from the Fig. 7. The increased soil organic carbon content seen under polysulphate over control can be attributed to the lime induced increases in root and shoot growth and thus organic residue inputs to soil as per the reports of Briedis et al., (2012) and Bronick and Lal, (2005).

c. Available N

The pooled data also showed significant difference among treatments with T_8 recording the highest (244.09 kg ha^{-1}) on par with T_1,T_3, T_7 and T_9. The pooled data also indicated T_8 had resulted in the maximum percentage increase in available N (77%) over initial. A comparison of the effect of polysulphate over other treatments on the available soil N content is depicted in Fig. 8. It is seen that, polysulphate application did not produce significant difference in soil available N compared to PoP and STBF as well as application of lime and dolomite (Table 6). Though there are reports (Garbuio et al., 2011) revealing increased nutrient availability due to liming through increased microbial activity resulting in increased

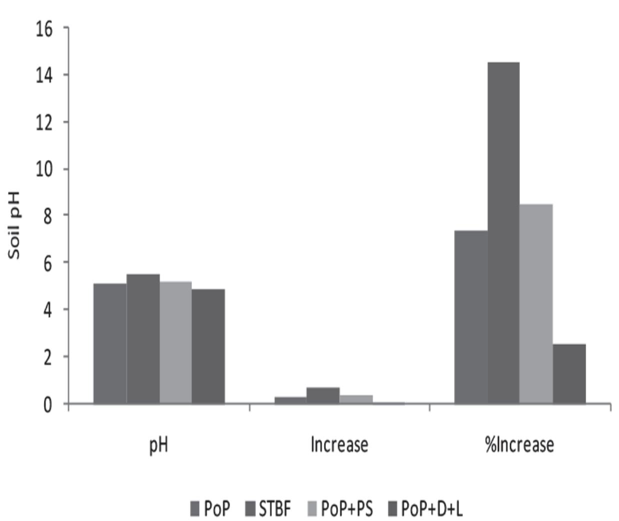

Fig.6. A comparison of the pH change due to polysulphate application in cassava (Pooled data)

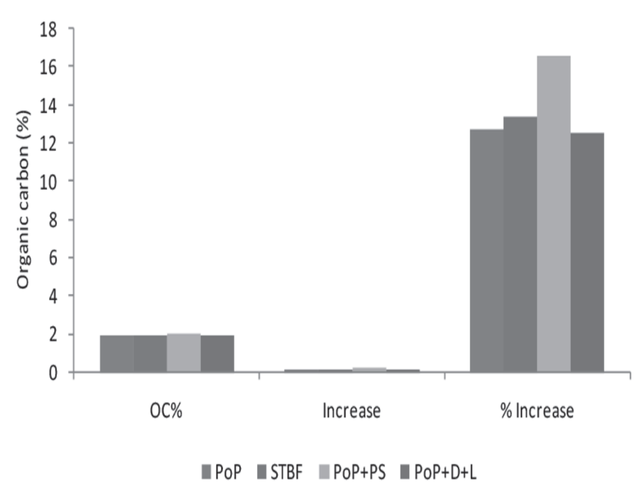

Fig.7. A comparison of the change in soil organic carbon due to polysulphate application in cassava (Pooled data)

decomposition of resident soil organic matter, Jezile et al., (2009) and Pawlett et al., (2009) indicated either no effect or a decreased microbial activity in highly acidic soils. The results of the present study with respect to insignificant effect of liming either through lime, dolomite or polysulphate can be attributed to the above findings.

d. Available phosphorus

The treatments did not significantly influence the available P content of the soil in any of the locations. But there was tremendous increase in available P over the initial year in all treatments.The pooled data also indicated the highest increase over initial P in the case of T_3 where full lime was applied along with polysulphate. The percentage increase ranged from 79-258% in the different experimental sites. The pooled data showed the highest under T_3 (158%). A comparison of the change in soil available P due to polysulphate application is given in Fig. 9. It is seen that, there is no substantial difference in soil available P due to polysulphate application (Table 6). The increased soil P availability due to continuous cultivation of cassava for two seasons can be due to the low uptake of P by the crop as well as the solubility of fixed P under low pH.There are reports indicating no response to liming especially under high P in acid soils with high lime. Rahman et al., (2002) reported high lime amounts can lead to reducing P availability and in high P soil. Rastija et al. (2014) could not find any increase in P availability under acid soil pH.

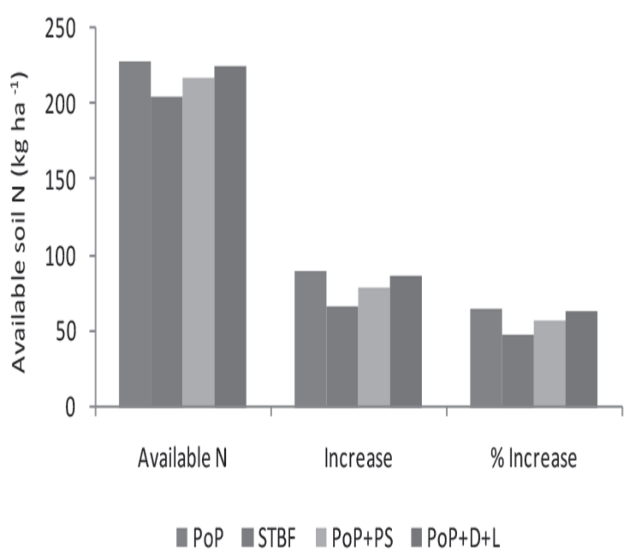

Fig.8. A comparison of the change in available soil N (kg ha^{-1}) due to polysulphate in cassava (Pooled data)

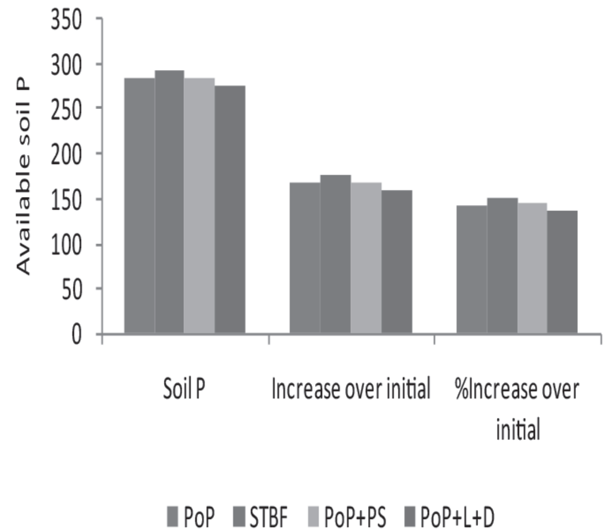

Fig.9. A comparison of the change in available soil P (kg ha^{-1}) due to polysulphate under (Pooled data)

e. Exchangeable potassium

In all polysulphate applied treatments, there was an increase in K status of the soil over the initial.The pooled data of the six locations showed the maximum increase with T_4 (101.74 kg ha^{-1}) followed by T_6 (95.69 kg ha^{-1}) and the least with STBF (9.04 kg ha^{-1}) and PoP (17.84 kg ha^{-1}) (Table 7).The pooled data showed the highest percentage increase of 151.37% under T_4 and the lowest under STBF(13.44%). A comparison of the treatments *viz*., PoP, STBF, lime and dolomite with polysulphate is presented in Fig. 9 and is very clear that, polysulphate resulted in highest exchangeable K increase compared to other treatments (Fig.10). Vigovskis et al., (2017)reported an increase in available K with liming. Since polysulphate contains K as K_2O to the tune of 13.5%, there will be an increase in soil available K due to its application.

e. Exchangeable calcium

The pooled data of the six locations indicated drastic increase in exchangeable Ca status over the initial with T_7 recording the maximum (1.28 meq 100 g^{-1} soil) followed by T_8. STBF resulted in the least increase (Table 7). It is seen that, application of polysulphate could result in the improvement of soil exchangeable Ca in the polysulphate applied treatments. The percentage increase in soil exchangeable Ca over the initial soil Ca status is depicted in Table 7 and Fig. 10 and 11. The increase as well as the percentage increase over the initial followed

Table 6. Increase/decrease in available N and P over initial (Mean over treatments, locations and seasons)

Treat-ment No	Treatment Description	Available N (kg ha^{-1})			Available P (kg ha^{-1})		
		After II season	Increase over initial after II season	% Increase over initial after II season	After II season	Increase over initial after II season	% Increase over initial after II season
T_1	PoP	228.60	90.60	65.65	284.56	167.62	143.34
T_2	STBF	205.49	67.49	48.90	294.03	177.09	151.44
T_3	PoP+ LF+PS	222.13	84.13	60.96	301.80	184.86	158.08
T_4	PoP+1/2 L+PS	206.13	68.13	49.37	289.65	172.71	147.69
T_5	PoP+ DF+PS	207.74	69.73	50.53	275.61	158.67	135.68
T_6	PoP+1/2D+PS	207.54	69.54	50.39	297.18	180.24	154.13
T_7	PoP+ PS	219.30	81.30	58.91	282.36	165.42	141.46
T_8	PoP+1/2L+1/2D+PS	244.09	106.09	76.88	266.52	149.58	127.91
T_9	PoP+1/2L+1/2D	225.43	87.43	63.35	277.37	160.43	137.19
	Initial	138.00	-	58.33	116.94	-	144.10
	Mean (Locations)	218.50	-	65.65	-	168.51	143.34
	CD (Treatment)	27.16	80.49	48.90	NS		
	CD (Location)						
	CD (Treatment X Location)						

Table 7. Increase/decrease in exchangeable K and Ca (pooled mean) over initial locations and seasons

Treat-ment No	Treatment Description	Available K (kg ha^{-1})			Available Ca (meq $100g^{-1}$)		
		After II season	Increase over initial after II season	% Increase over initial after II season	After II season	Increase over initial after II season	% Increase over initial after II season
T_1	PoP	175.33	17.84	26.55	1.14	0.5398	90
T_2	STBF	162.22	9.04	13.44	0.98	0.3798	63
T_3	PoP+ LF+PS	263.54	77.13	114.76	1.16	0.5598	93
T_4	PoP+1/2 L+PS	300.15	101.74	151.37	1.07	0.4698	78
T_5	PoP+ DF+PS	257.98	73.40	109.20	1.15	0.5498	92
T_6	PoP+1/2D+PS	291.15	95.69	142.37	1.08	0.4798	80
T_7	PoP+ PS	243.07	63.37	94.29	1.28	0.6798	113
T_8	PoP+1/2L+1/2D+PS	259.27	74.26	110.49	1.15	0.5498	92
T_9	PoP+1/2L+1/2D	211.85	42.39	63.07	1.09	0.4898	82
	Initial	148.78	-	26.55	0.6002	-	
	Mean (Locations)						
	CD (Treatment)	NS			NS		
	CD (Location)						
	CD (Treatment X Location)						

the same trend as that of the increase resulted due to different treatments in the various locations.

f. Exchangeable Mg

The effect of polysulphate application on soil Mg content after two years experimentation did not reveal much increase in exchangeable Mg content of the soil. The pooled data over the six locations indicated increase in soil exchangeable Mg over the pooled initial mean in treatments T_3, T_7, T_8 and T_9 where T_9 resulted in the highest increase (Table 8). A comparison of PoP, STBF, PoP+ PS and PoP+ lime + dolomite showed the soil exchangeable Mg was highest under PoP along with lime and dolomite. But over the initial, PoP and STBF indicated a decrease and the increase was maximum under PoP + lime + dolomite (Fig.12, 13). Peevy (1972) reported an increase of exchangeable Mg from 32 to 57 ppm per ton of liming material applied.

Table 8: Increase/decrease in exchangeable Mg and S (pooled mean) over initial locations and seasons

Treat-ment No	Treatment Description	Exchangeable Mg (meq $100g^{-1}$)			Available S (ppm)		
		After II season	Increase over initial after II season	% Increase over initial after II season	After II season	Increase over initial after II season	% Increase over initial after II season
T_1	PoP	0.2318	-10.91	-0.0284	8.17	Pooled	-0.054
T_2	STBF	0.2564	-1.46	-0.0038	9.62	-0.66	1.404
T_3	PoP+ LF+PS	0.2837	9.03	0.0235	12.71	17.08	4.482
T_4	PoP+1/2 L+PS	0.2614	0.46	0.0012	15.84	54.53	7.624
T_5	PoP+ DF+PS	0.2594	-0.31	-0.0008	13.57	92.75	5.352
T_6	PoP+1/2D+PS	0.2555	-1.81	-0.0047	10.33	65.11	2.106
T_7	PoP+ PS	0.2757	5.96	0.0155	12.33	25.62	4.108
T_8	PoP+1/2L+1/2D+PS	0.2651	1.88	0.0049	14.06	49.98	5.84
T_9	PoP+1/2L+1/2D	0.3095	18.95	0.0493	7.95	71.05	-0.27
	Initial	0.26452	2.42	0.0063	8.22	-3.28	8.22
	Mean (Locations)	0.2602	-			41.35	
	CD (Treatment)	NS			3.93		

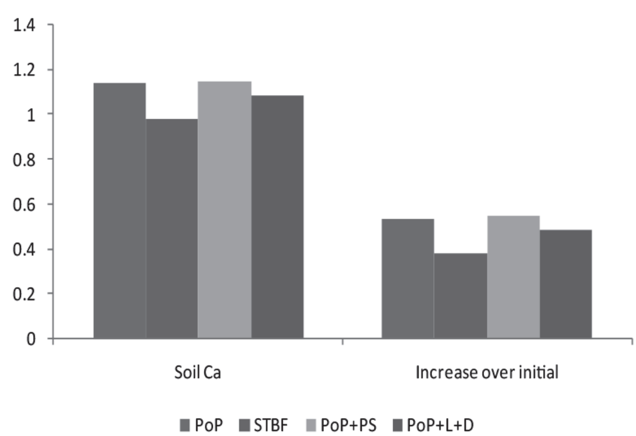

Fig. 10. A comparison of the change in soil exchangeable Ca (meq $100g^{-1}$) under different treatments

g. Available Sulphur

The pooled data indicated significant difference among treatments with T_4 followed by T_8 having the highest. These treatments were on par with T_3, T_5 and T_7. Treatments *viz*., T_1, T_2, T_9 without application of polysulphate resulted in the lowest available S content in the soil (Table 8, Fig. 14). The pooled data of the six locations showed decrease over the initial in T_1 and T_9. Among the polysulphate applied treatments, T_4 followed by T_5 had the maximum increase. STBF too resulted in comparatively a small increase in soil available S (Table 8 Fig.15). El-Kholy et al., 2013 found high sulfur solubility in soil and hence its high availability due to application of sulfur containing fertilizers.

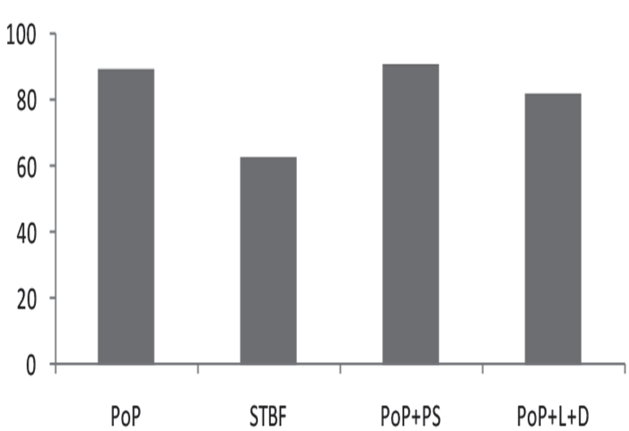

Fig. 11. A comparison of the percentage change in exchangeable Ca due to polysulphate in cassava

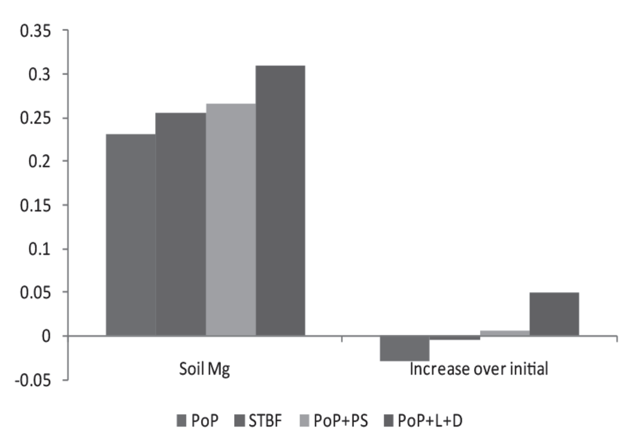

Fig. 12. A comparison of the soil exchangeable Mg under different treatments

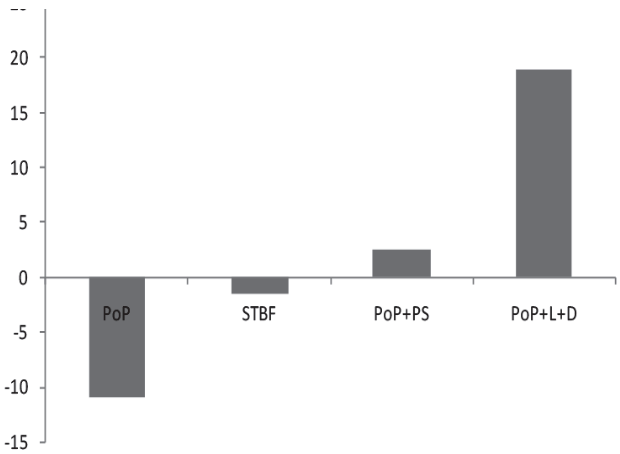

Fig. 13. A comparison of the percentage change in soil exchangeable Mg under different treatments

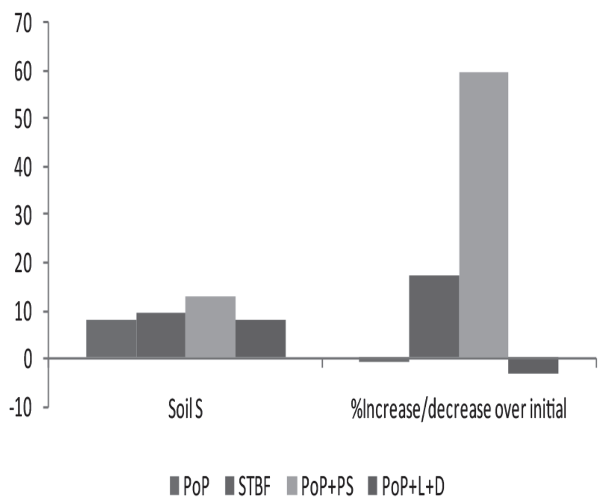

Fig. 14. A comparison of the soil available S under different treatments

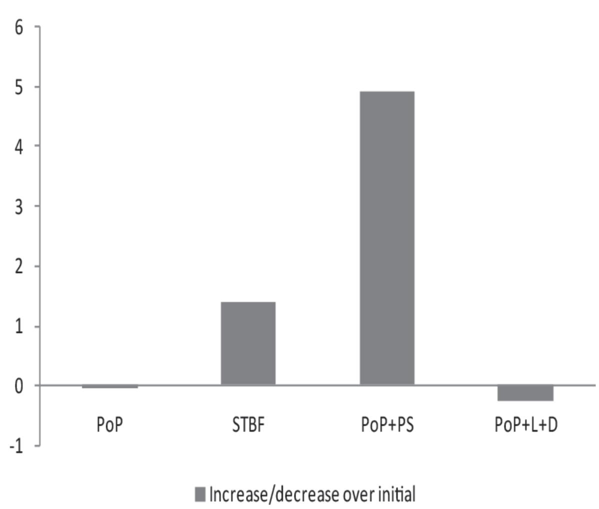

Fig.15. A comparison of the percentage change in soil available S under different treatments

Conclusion

The experiment conducted for two seasons in the three major agro ecological units of Kerala clearly revealed polysulphate as a good soil amendment for cassava. Among the nine treatments comprising of PoP, STBF, application of full and half dolomite and lime alone and together with PoP in combination with polysulphate and half dolomite and half lime without polysulphate, the best treatments were identified as those having half each of lime and dolomite in combination with polysulphate @ 2 t ha^{-1} followed by PoP along with polysulphate @2 t ha^{-1}. Polysulphate application resulted in improvement in quality of cassava tubers including cooking quality, increase in starch and reduction in HCN (bitterness) of cassava tubers. The soil chemical properties especially, K, Ca, Mg and S were improved in the soil due to polysulphate application in all locations. Hence, this can be recommended and popularized as a good soil amendment for cassava in Kerala. As regards to the economics of using polysulphate, the cost of a kg is presently Rs. 15/- which in turn give K, Ca and Mg , the very essential nutrients for acid soils at low cost. Though the N and P fertilizers cannot be reduced, there is a possibility to save K fertilizers while using polysulphates in addition to supply of Ca and Mg.

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