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Diagnosis and confirmation of subsoil acidity induced multi nutrient disorders in Tannia (*Xanthosoma sagittifolium* L. Schott) grown in an Ultisol, Kerala, India

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Abstract

Aroids are a group of tropical tuber crops which includes taro, tannia and elephant foot yam. Tannia (*Xanthosoma sagittifolium* L. Schott) belonging to the family Araceae is considered as a remunerative intercrop in the partial shaded conditions of plantations. The tubers, consisting of corm and cormels as well as the leaves are edible, and have good nutraceutical properties, but many of them are yet to unravel. The leaves are rich sources of phytochemicals and minerals like P, Ca and K. Being a shade tolerant and acid sensitive crop, when it is grown in potentially acidic aluminium (Al) rich laterite soils, they are prone to the occurrence of some nutritional disorders which was suspected as subsoil acidity induced Mg, K and Ca deficiency. Experiments conducted in the nutrient omission pot trial gave the inference of the same which was further confirmed through soil and plant analysis. More confirmation on the occurrence of the antagonistic effect of excess K on the deficiency of Mg and Ca too was evolved by conducting experiments in lysimeter tanks followed by the analysis of the soil filled in lysimeter tanks and the symptomatic leaf samples. Though both experiments were done to confirm the susceptibility of the crop to potential acidity manifested in the form of interveinal chlorosis, typical of Mg deficiency, and associated K and Ca disorders. The growth and yield data of the crop recorded indicated the need to replenish the soil with required quantities of nutrients viz., K, Ca and Mg at an application rate of K_2O @ 100 kg ha^{-1} along with lime@1 t ha^{-1} and $MgSO_4$ @100 kg ha^{-1}. Since acidity being the primary cause and K being the crucial nutrient in affecting the yield, further experiments conducted revealed dolomite as the best soil ameliorant @ 1 t ha^{-1} and K_2O @ 150 kg ha^{-1}.

Keywords: Tannia, Nutrient disorder, Subsoil acidity, Nutrient deficiency, Lysimeter

Introduction

Tropical tuber crops form the secondary staple in many parts of the globe primarily due to their higher biological efficiency manifested in terms of very high tuber productivity. Aroids are a group of tropical tuber crops which includes elephant foot yam (*Amorphophallus paeoniifolius*), taro (*Colocasia esculenta*) and tannia (*Xanthosoma sagittifolium*). Tannia is an unexplored crop with respect the research and development though it is one of the most important tuber crops which fetch moderately good income throughout the year. It is shade

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tolerant and found as a suitable intercrop in plantations especially coconut. Though the cultivation of this crop is very limited nationally in an area of around one lakh hectare (Susan John et al., 2013), globally it is a very important crop of Southeast Asia, West Africa and Central Americaand grown as a commercial crop in countries like Ghana, Nigeria, and PNG islands. In India, it is grown in Kerala, Maharashtra, Tamil Nadu, Karnataka, West Bengal and Northeastern states. The tuber (mother corm and cormels) and leaves are consumed as vegetable. The leaves are rich in minerals especially potassium, phosphorus and calcium compared to tubers which in turn contain relatively large starch granules having potential in the production of industrial starch.

In Kerala, this crop is usually grown as an intercrop in coconut gardens, banana, rubber and arecanut plantations and to some extent as a monocrop in lowland situations. When this crop is grown in the laterite soil types which are the predominant one in Kerala, the crop is seen affected by yellowing of the foliage around 3-4 month stage of the crop and later the entire crop is found destroyed with complete decay of the roots. Hence, even the package of practices (PoP) recommendation of the crop could not be evolved. In these circumstances, a preliminary observational trial conducted gave some clues of the foliage problem as Mg deficiency and the root damage as due to the Al toxicity of this soil having a pH 4.5-5.0. Based on these inputs, further elaborate studies were undertaken to diagnose and confirm this disorder of tannia which in turn was found very crucial in affecting the growth and yield of the crop. The primary aim of this study was to observe, diagnose and confirm the symptoms in tannia in the absence of the nutrients, to study the antagonism among the identified nutrients to arrive at a nutrient management strategy.

Materials and Methods

In order to achieve these objectives, the following experiments were conducted:

Nutrient omission pot (NOP) experiment: To identify the critical nutrients affecting the growth and yield of tannia.

Controlled condition experiment in lysimeter tanks: To confirm the identified nutrients and the antagonistic effect among the nutrients to arrive at the rate and time of application of the nutrients identified from the previous NOP experiment.

Nutrient omission pot (NOP) experiment

The optimum nutrient rate for tuber crops growing upland and low land soils was standardized using preliminary rate trial (PRT) and nutrient omission pot trial (NOPT) with maize as indicator crop based on the methodology proposed by Asher and Grundon (1991). In PRT, different levels of 'ALL' treatment *viz.,* 0 ALL, 0.5 ALL, 1 ALL, 2 ALL, 4 ALL were given for both upland and lowland soils in pots grown with maize crop to arrive at the optimum nutrient rate for both soil situations. The 'ALL' treatment consisted of nutrients *viz.,* N, P, K, Ca, Mg, S, B, Zn and Mo @ 100, 30, 80, 35, 30, 25, 2, 4, 0.4 kg ha^{-1}. The trial conducted with tuber crops growing upland and lowland soils indicated the optimum nutrient rate as 2 ALL and 4 ALL respectively (Susan John and Suja, 2012). These levels were taken as optimum for conducting the NOPT with tannia under upland and lowland soil types to find out the limiting nutrients for tannia. The experiment was conducted in fibre glass pots of 50 cm diameter containing 15 kg soil from both upland and lowlands and grew tannia for 6-8 months taking 2 ALL and 4 ALL as optimum for upland and lowland soil types respectively. There were 10 treatments by omission of different nutrients from optimum as below:

T1: Optimum (2 ALL for upland and 4 ALL for lowland), T2: Optimum- N, T3: Optimum – P, T4: Optimum– K, T5: Optimum – Ca, T6: Optimum – Mg, T7: Optimum – S, T8: Optimum – B, T9: Optimum – Zn, T10: Optimum – Mo

The experiment had two replications for each soil type, conducted in CRD, and the tannia variety used was a local one. The quantity of nutrients added in the optimum for upland (2 ALL) and lowland soils (4 ALL) are shown in Table 1.

Table 1. Quantity of nutrients added in pots under optimum treatment

Nutrient	Rate (kg ha^{-1})		Name of salts	Rate of application of salt (mg per pot)	
	Upland	Lowland		Upland	Lowland
N	200	400	NH_4NO_3	1042	2084
P	60	120	$NaH_2PO_4.2H_2O$	628	1256
K	160	320	KCl	586	1172
Ca	70	140	$CaCl_2$	358	716
Mg	60	120	$MgCl_2.6H_2O$	910	1820
S	50	100	Na_2SO_4	404	808
B	4	8	H_3BO_3	41.4	82.8
Zn	8	16	$ZnCl_2$	30.2	60.4
Mo	0.8	1.6	$(NH_4)_6 MO_7O$	18.74	37.48

The observations recorded were the nutritional status of the soil filled in the pots before planting tannia, occurrence of nutritional disorders in tannia due to the omission of various nutrients, confirmation of the nutrient disorder through soil and plant tissue analysis.

Controlled condition experiment in lysimeter

The objective of this experiment was to arrive at the rate of the split dose and time of application of the constraint nutrients which was identified from NOPT. This experiment was conducted in lysimeter (cement tanks of 1m^3 volume) using both upland and lowland soils. The treatments included different levels of the limiting nutrients arrived from NOPT. The tannia crop was raised for 9-10 months (till harvest). The limiting nutrients identified were K, Ca and Mg. As the severity was more for Mg, the experiment was designed in split plot where the main plot treatments (4) were the rate and time of application of K and Ca and the sub plot treatments (3) were levels of Mg. The experiment was replicated for both lowland and upland soils. The rates for the main plot treatments were arrived at by keeping the adhoc recommendation of taro (NPK @ 80:50:100 kg ha^{-1}) followed for tannia. The rate of application of Ca through lime was 1t ha^{-1}. Hence, the basic rate of application of K and Ca were 100 kg ha^{-1} K_2O applied through MoP and lime @ 1 t ha^{-1}. The main plot treatments were:

M1 : Full Ca, Mg, K as basal at the time of land preparation

M2 : Full Ca, ¾ K and Mg each as basal, and the rest ¼ K and Mg each at one month after planting

M3 : Full Ca, ½ K and Mg each as basal and the rest ½ K and Mg each in two splits at one month interval within 2 months of basal application

M4 : Full Ca, ¼ K and Mg each as basal and the rest ¾ K and Mg each in three splits (at one month interval up to 3 months after basal @ ¼ each K and Mg)

The sub plot treatments were:

S1 : $MgSO_4$@100 kg ha^{-1}, S2: $MgSO_4$@ 150 kg ha^{-1}, S3: $MgSO_4$@ 200 kg ha^{-1}.

The time of application of $MgSO_4$as given in the main plot treatments is as per the rate given in the subplot treatments.

Organic manure in the form of FYM and neem cake was applied @ 12.5 t ha^{-1}and 1 t ha^{-1} respectively based on the rmoreof the observational trial conducted which in turn indicated the need to apply more of organic manures. Moreover, organic manure in the form of neem cake and coir pith compost and nutrient efficient biofertilizers especially K solubilizers was applied to confirm its effect in rectifying the foliage disorder and also to see whether the problem is due to soil born/seed born organisms. The observations recorded were nutritional status of the soil filled in the lysimeter (pH, organic carbon, available N, P, K Ca, Mg, Fe, Mn, Zn) before planting tannia, growth characters (number of leaves, length of petiole, breadth of leaf, length of leaf)at4 months after planting (MAP) and at harvest, number of cormels, cormel weight and corm weight at harvest, occurrence of nutritional disorders, confirmation of nutrient disorders through soil and plant tissue analyses. The chemical analysis of the soil samples for pH, organic carbon, available nutrients *viz.,* N, P, K, Ca, Mg, S, Fe, Cu, Mn and Zn were done as per the standard analytical procedures (Jackson, 1973) and plant analysis for nutrients like N, P, K, Ca, Mg following Piper (1966). Statistical comparison of the different treatments was done following GenStat version 2.0.

Results and Discussion

The results emanated from the two experiments for identifying and confirming the soil factors are summarized below:

Nutrient omission pot experiment

Initial nutrient status of the soil filled in fibre glass pots

The nutrient status of the soil filled in fibre glass pots before planting tannia is given in Table 2. It is seen that there was not much variation in soil chemical properties between the upland and lowland soils. Both were strongly acidic in soil reaction revealing the presence of Al^{3+} ions in the deeper layers (subsoil acidity) contributing to potential acidity. Hence, the basic factor causing the problem was apprehensively taken as sub soil acidity.

According to Loneragan, (1970), nutrient omission pot experiments are useful in identifying the limiting nutrients in the fields. Dowling et al., (1996) conducted NOP experiment with maize in different soil types of Aiyura and the Eastern highlands of Papua New Guinea to identify the nutrients deficient in these soils.

The data on organic carbon, available N, P, K of both soil types indicated that these soils are low in N and K and medium in organic carbon and available P. According to

Table 2. Nutrient status of the soil used for NOPT in tannia (Mean values)

Soil type	pH	Organic Carbon	Available			Exchangeable		Available			
			N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
		(%)	(kg ha^{-1})			(meq 100g^{-1})		(μg g^{-1})			
Lowland	4.69	0.703	179.48	22.32	167.36	1.321	1.321	0.71	32.15	25.97	1.51
Upland	4.82	0.643	164.32	18.49	192.80	1.284	0.643	0.57	29.68	24.54	1.29

Sanchez and Logan (1992), the infertility of acidic soil is a major problem throughout many tropical regions as they are characterized by many soil constraints. Sanchez (1976) stated N as the most frequently deficient nutrient in tropical soils. Widdowson (1992) explained the severe P deficiencies of these soils as due to the combination of strong P fixation and poor supply of P from parent materials. Poor K availability can be due to leaching loss from high rainfall and the high soil acidity either retarding the release of K or favouring its fixation. While exchangeable Ca was low in both soils, exchangeable Mg was found high in lowlands. Micronutrients are found sufficient in both soil types. Macdonald (1948) attributed the increased solubility of micronutrients at low pH as the reason for the satisfactory availability of micronutrients in these soils.

Observation on the occurrence of nutritional disorders

The general stand of the crop was poor with some nutritional disorders in all the treatments. The major symptom noticed was interveinal chlorosis of the lower leaves, typical of Mg deficiency in the Opt-Mg pots and yellowing and drying the margins of lower leaves in some cases, typical of K deficiency/toxicity seen in Opt-K pots, there was crinkling and curling of the upper leaves, characteristic of Ca deficiency in Opt-Ca pots. The characteristic symptoms observed in this trial specific to nutrients *viz.,* K, Ca and Mg corroborates to the symptoms observed in sweet potato (O' Sullivan et al., 1996) and yams (O'Sullivan and Jenner, 2006).

Confirmation of the nutritional disorder through plant analysis

The leaf samples showing the symptoms in both upland and lowland soils were analyzed and compared with their respective critical levels for K, Ca and Mg. It clearly revealed, the symptom manifestation is mainly due to the deficiencies of the above nutrients as the levels of these nutrients during the symptom expression were below their respective critical levels Table 3and 4.

The NOPT clearly indicated that the contents of all omitted nutrients as less than their respective critical levels as well as the antagonistic and synergistic effect of nutrients either in lowering or in increasing the nutrient contents as per the reports of Ohno et al., (1985) and Skinner and Matthews (1990). The leaf nutrient analytical data in Table 3 confirmed that, the typical symptoms observed in field condition characteristic of K, Ca and Mg deficiency was the one seen in this trial where these nutrients were omitted. The results of chemical analysis of the lamina and petiole at different stages of symptom manifestation are presented in Table 4.

The data showed that K, Ca and Mg concentrations in the different leaf parts at the different stages of symptom expression were low compared to their respective critical

Table 3. Nutrient content in the leaves under NOPT

Treatments	P		K		Ca		Mg	
	(%)							
	Lowland	Upland	Lowland	Upland	Lowland	Upland	Lowland	Upland
ALL	0.718	0.610	1.020	0.756	0.535	0.756	0.824	0.503
All-N	0.451	0.421	2.512	2.990	0.896	0.990	1.191	0.802
ALL-P	0.349	0.465	2.106	2.538	0.705	0.538	0.770	0.882
ALL-K	0.286	0.228	0.528	0.486	0.349	0.486	0.969	0.855
ALL-Ca	0.718	0.523	1.782	1.390	0.389	0.390	0.540	0.963
ALL-Mg	0.614	0.473	2.572	1.498	0.551	0.698	0.205	0.414
Critical Level	0.50		2.30		0.900		1.30	

Table 4. Nutrient content in the symptomatic leaves of tannia (Mean of upland and lowland soils)

Leaf portion	N	P	K	Ca	Mg
	(%)				
Petiole (Initial stage)	1.6	0.581	0.238	0.763	0.711
Petiole (Middle portion)	1.8	0.573	0.380	1.00	0.737
Leaf blade (Initial stage)	-	0.448	0.234	0.615	1.185
Leaf blade (Slightly severe)	-	0.469	0.65	0.565	0.260
Dried leaf blade		0.676	0.55	0.513	0.223
Symptom (Very severe)		0.485	0.98	0.416	0.635
Critical level	3.2	0.500	2.3	0.900	1.30

levels. The nutrient concentrations of K, Ca and Mg in the leaf parts of the nutrient omitted treatments of both lowland and upland soils as well as the deficiency symptoms characteristic of each nutrient observed agrees with the fact that, the problem is linked to the abnormalities in the proper absorption of K, Ca and Mg by tannia and is associated with soil acidity. This is partially in conformity with the report of O' Sullivan et al. (1996) that in acidic soils like Ultisols, which are extremely acidic, the potential acidity due to Al^{3+} ions can be toxic to roots causing injury and hindering the uptake of water and nutrients especially Ca and Mg.

At harvest, the plants showed some visible symptoms in the foliage, not as serious as the previous and the samples were again analyzed for K, Ca and Mg and the results revealed, K as toxic and Ca and Mg as deficient when compared with their respective critical levels (Table 5)

Table 5. Nutrient content in the leaf at harvest

Treatments	Lowland (%)			Upland (%)		
	K	Ca	Mg	K	Ca	Mg
ALL-K	6.32	-	-	3.60	-	-
ALL-Ca	-	0.258	-	-	0.321	-
ALL-Mg	-	-	0.633	-	-	0.674
Critical level	2.300	0.900	1.300	2.300	0.900	1.300

The analytical results of the leaves at harvest too clearly indicated that the typical deficiency symptoms observed in the Ca and Mg omitted treatments are due to their levels in soils well below their critical levels. The high content of K observed in both upland and lowland soils during harvest can be attributed to the conjoint effect of coir pith compost and nutrient efficient biofertilizers especially K solubilizers (added during the symptom manifestation) in augmenting the release of K in the soil solution for plant uptake.

Controlled condition experiment in lysimeter

Initial nutrient status of the soil filled in lysimeter

The soil is moderately acidic (pH : 5.78), organic carbon is medium (0.731%), available N (119.95 kg ha^{-1}), P (90.256 kg ha^{-1}), K (0.299 meq 100 g^{-1}) and exchangeable Ca (5.197 meq $100g^{-1}$) and Mg (1.475 meq $100g^{-1}$)is low, very high, low, very high and sufficient respectively with acation exchange capacity of 21.967 cmol $^{(+)}$ kg soil. The results of the initial nutrient status of the soil filled in lysimeter tanks corroborates to the report of Rajasekharan et al., (2014) that the laterite soils of Peninsular India are highly acidic with high Al^{3+} ions in soil solution affecting the plant roots, with low available N due to slow mineralization of organic carbon under high acidic soils, high to very high soil available P due to dissolution of fixed P in acidic environment, low K due to the nature of highly weathered laterite soils and the tropical humid climate and the same situation accounts for the general low availability of exchangeable Ca and Mg in these soils. There are also reports by Koshy and Thomas (1972) and Kerala State Planning Board (2013) supporting the results of the initial nutrient status of the soil.

Growth characters of the crop

The growth characters of the plant recorded at 4MAP on number of leaves, length of petiole, length and breadth of leaves showed no significant effect of treatments. However, T5 (M2S2) recorded the highest values with respect to these characters (Fig.1). In this treatment, the entire lime, 75% K and Mg each was applied as basal and the remaining 25% each K and Mg was applied one month after planting. The Mg applied was @ 100 kg ha^{-1} as $MgSO_4$. Biometric observations recorded at harvest on the crop attributes did not show any significant effect of treatments. However, T1 (M1S1) with entire lime, K and Mg as $MgSO_4$ @ 50 kg ha^{-1} applied as basal at the time of land preparation recorded the highest plant height and leaf number (58) and T11 resulted in lengthy petiole with longest and broadest leaves (Fig. 1). The total number of leaves at harvest included the total number of leaves the crop produced from sprouting till harvesting and was taken by counting the number of rings in the mother corm. At harvest, T11 (M4S2) comprising of entire lime, 25% each K and $MgSO_4$ as basal with rest 75% K and Mg in three splits resulted in better leaf production with lengthy petiole, lengthy and broader leaves. Asokan and Nair (1984) in taro and Pushpa kumari et al., (1999) in tannia could not find any significant effect of nutrients on growth characters like plant height and number of leaves per plant.

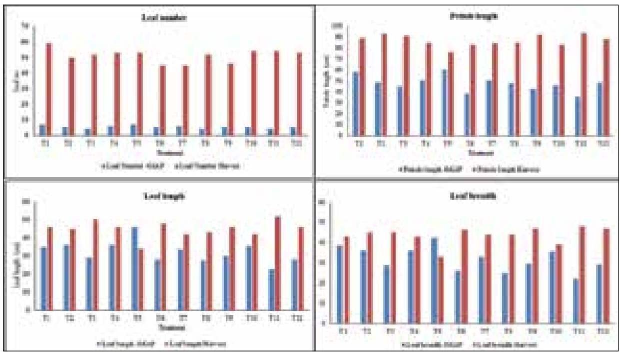

Fig. 1. Growth characters of tannia under the influence different treatments

Observation on the occurrence of nutritional disorders

As regards to the occurrence of nutritional disorders in the crop under this trial, it is found that, at the 4-5th month growth stage, the lower leaves of the plant started showing some visual symptoms as yellowing of the tips and margins followed by its drying and withering, typical of K toxicity. Later, the newly emerging as well as the younger leaves also started showing some disorder as crinkling, curling, deformity of the leaf causing complete growth cessation of the plant, typical of Ca deficiency. Interveinal chlorosis in the lower leaves coupled with yellowing, drying and withering the tips and margins of the leaves causing complete devastation of the crop too was noticed during this stage. The visual symptoms as observed above were found characteristic of the deficiency of nutrients *viz.,* K, Ca and Mg. The characteristic symptoms observed due to K, Ca and Mg adhere to the reports of O' Sullivan et al., (1996) for root crops grown in South Pacific. Moreover, according to Grimme (1983) and Susan John et al., (2006), Mg deficiency observed in tannia can be the result of Al toxicity due to strong acidity under a pH of 4.5-5.0 which was manifested as Mg deficiency since tannia is an indicator plant for Mg deficiency as per Cable (1996). The K toxicity in leaves can be due to the continuous application of K in the lysimeter which is a controlled condition situation. The antagonistic effect of K in reducing the availability of Ca and Mg in soil solution might have resulted in the expression of the characteristic symptoms of Ca and Mg deficiencies. Rhodes et al., (2018) reported that application of K can reduce the leaf Ca and Mg contents much stronger than vice versa and hence soil K need to be taken into account while determining the Ca and Mg threshold levels.

Confirmation of the nutritional disorder through soil and plant analysis

Confirmation of the above disorders through the analysis of leaf samples showing these symptoms at 4MAP indicated their N, P, K, Ca and Mg contents as 2.274-3.551, 0.438-0.670, 6.32-8.35, 0.416-1.00 and 0.682-1.351 with mean values as 2.913, 0.554, 7.335, 0.708, 1.017 % respectively clearly indicating the problem as K toxicity coupled with Ca and Mg deficiency due to the antagonistic effect of excess K on the deficiency of Ca and Mg. This type of antagonism in many plants was reported (Garcia et al., 1999; Grunes et al., 1992).

No severe characteristic symptoms were observed during harvest except for drying the margins of older leaves. The chemical analysis of petiole as well as the lamina samples of tannia at this stage indicated that, K, Ca and Mg are deficient in both petiole and lamina with their levels below their critical levels (Table 6). Though no symptoms specific to the shortage of these nutrients were observed at the harvest stage, the existence of K, Ca, Mg antagonism was found still existing and similar trend was reported by Meyer (2013) who in turn found that, leaf K suppressed Ca and/or Mg content in the leaves.

Table 6. Nutrient content (%) in the leaves showing the disorder at harvest

Nutrient	Lamina	Petiole	Critical level
K	1.042	0.879	2.300
Ca	0.584	0.461	0.900
Mg	0.687	0.307	1.300

The analytical results of soil samples at harvest indicated the average pH, organic carbon, available N, P ,K, Ca and Mg content of the soil as 6.55, 0.957%, 193.22, 38.52, 439.23 kg ha^{-1}, 21.96 and 3.29 meq 100g^{-1} respectively. The soil analytical results at 4 MAP and at harvest (Table 7) for pH, organic carbon, available N, P, K, Ca and Mg indicated that, these soils during both intervals were sufficient with respect to all nutrients especially the marginal nutrients *viz.,* K, Ca and Mg identified for tannia and have a reasonably high pH also. The data further reveals that though the soils are sufficient at 4 MAP and at harvest with respect to Ca and Mg, the plants were deficient and expressed the symptoms due to it. The increase in pH and subsequent better availability of marginal nutrients like K, Ca, and Mg had not sufficiently improved the leaf status of nutrients during these two intervals. Similar effect in many crops were reported as decreased uptake of Ca and Mg with K fertilization due to cationic antagonism (Gosnell and Long, 1971) and K depresses root uptake of Mg when rhizosphere K levels are high (Marschner, 1995). The antagonistic effect of these three marginal nutrients in tannia were further explained as per the reports of Karlen et al., (1978) and Wilkinson et al., (2000) that increased K concentrations depress Mg translocation from roots to shoots, leading to low leaf Mg as well as the 'dilution effect' in response to

Table 7. Nutrient status of the soil of the lysimeter at 4 MAP and harvest

Nutrient	Mean		Range	
	4 MAP	Harvest	4 MAP	Harvest
pH	7.37	6.548	6.65- 8.02	5.616 - 7.478
Organic carbon (%)	0.731	0.957	0.533 -1.009	0.743 - 1.343
Available N (kg ha^{-1})	119.95	193.217	111.96 -191.92	157.90 - 249.31
Available P (kg ha^{-1})	41.85	38.52	25.37 -60.71	17.73 - 75.66
Available K (meq 100g^{-1})	0.417	0.206	0.083-0.897	0.092-0.432
Exchangeable Ca (meq 100g $^{-1}$)	2.26	1.098	1.76 – 2.80	0.924- 2.139
Exchangeable Mg (meq 100g $^{-1}$)	1.71	3.293	1.06 - 4.27	2.504 - 4.831

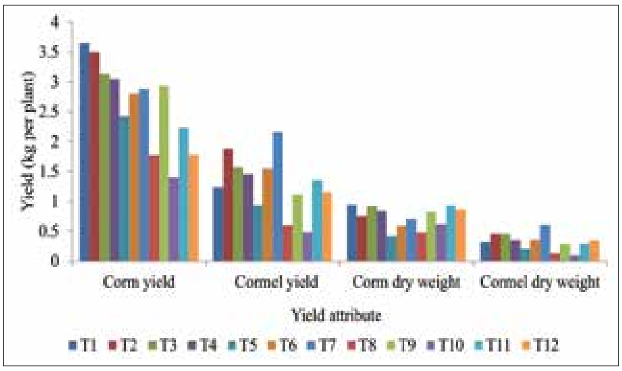

Fig. 2. Yield and yield attributes at harvest (kg plant^{-1})

K application (Dibb and Thompson, 1985).

Yield and yield attributes at harvest

As regards to the yield and yield attributes at harvest, there was significant effect of treatments on cormel yield and cormel dry weight where treatment T7 (N, P, K @ 80:50: 100 kg ha^{-1} along with $MgSO_4$ @ 50 kg ha^{-1}) recorded the highest values of 2.16 and 0.605 kg plant^{-1} respectively (Fig. 2). Though Suja et al., (2009) and Jayapal et al., (2020) reported organic nutrition resulted better tuber yield in tannia, Milan Morales et al., (1992) proposed a fertilizer recommendation of N, P_2O_5, K_2O and CaO @ 76,115, 285 and 154 kg ha^{-1} for tannia cultivation in Africa, Central America and Pacific Islands. In Kerala, Pushpakumari et al., (1999) suggested N and K_2O @ 60 and 125 kg ha^{-1} respectively.

Conclusion

Tannia, though an unexploited aroid under tropical tuber crops, is recommended as a profitable crop to grow especially as an intercrop in plantations. However, limited studies are available in this crop both nationally and internationally. The sensitivity of this crop to low pH especially in the acidic laterite soils hindered the studies in many times and in many locations. The preliminary trials could elucidate the fact that, extreme acidity due to Al^{3+} ions in soils of pH<5.0 as a critical factor to overcome in undertaking studies in this crop. Further studies therefore were to observe the symptoms manifested due to the absence of some critical nutrients induced by subsoil acidity and confirmation of the same through soil and plant analysis. Experiments like nutrient omission pot trials conducted both in fibre glass pots and big lysimeter tanks clearly established the effect of subsoil acidity in the manifestation of the symptoms, characteristics of K, Ca and Mg which were found critical both in soil and plants. Simultaneously, the antagonistic effect among these three nutrients too could be revealed which in turn was very prominent in this crop. The elucidation of these facts and hence the diagnosis and correction of these nutrients paved way to correct the same through the identification of a best soil amendment for tannia in this soil followed by the evolution of an integrated nutrient management (INM) strategy for the crop. The INM developed comprised of a suitable liming material and N, P, K. In the case of N, the application through chemical fertilizer was minimized to 25% and the rest was recommended through different organic manures like farmyard manure, green manuring *in situ* with cowpea, neem cake and N efficient biofertilizers. Application of P was found inevitable for this crop as the subsoil acidity due to Al^{3+} could be reduced through the formation of insoluble aluminium phosphate. K being the critical nutrient for tuber crops, it must be applied as per the recommended dose. However, this crop needs better exploitation of its nutraceutical properties especially of the leaves as it is a very rich source of phytochemicals particularly minerals.

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