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Soil Fertility Management Strategies in Edible Yams and Aroids: A Review

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Abstract

Soil fertility as well as nutrient management of crops depends on the different processes of nutrient dynamics viz., nutrient flow/movement, nutrient transformation, nutrient utilization and its absorption, which in turn influences not only the crop yield but also the quality of the produce. The interaction among the nutrients leading to these processes usually takes place in the soil, rhizosphere and also in the soil-plant system. Any disruption in these processes will result in the manifestation of various nutritional disorders. These processes at the different sites are affected by native soil characteristics and other extraneous factors. In this review, a thorough documentation of the different processes leading to nutrient dynamics in three species of edible yams viz., greater yam (*Dioscorea alata*), white yam (*Dioscorea rotundata*) and lesser yam (*Dioscorea esculenta*) and edible aroids viz., elephant foot yam (*Amorphophallus paeoniifolius*), taro (*Colocasia esculenta*) and tannia (*Xanthosoma sagittifolium*), including the response of independent nutrients as well as combination of nutrients on yield and quality, index leaf tissues, critical concentration of nutrients for deficiency/sufficiency and the nutritional disorders have been done.

Key words: *Dioscorea alata, Dioscorea rotundata, Dioscorea esculenta, Amorphophallus paeoniifolius, Colocasia esculenta, Xanthosoma sagittifolium*, major, secondary, micronutrients, index leaves, critical nutrient concentration, nutritional disorders

Introduction

The soil - plant system is one of the most important components of agricultural and natural ecosystems. This system is influenced by the different processes responsible for nutrient dynamics viz., nutrient flow, nutrient transformation, nutrient availability and nutrient uptake. All these processes collectively defined as nutrient dynamics affect not only the crop production but also the quality of the produce. The major processes contributing to nutrient dynamics in the different sites of interaction viz., soil, rhizosphere as well as plant system (soil-plant system) can be listed as nutrient flow or movement, nutrient transformation and nutrient absorption and utilization. Any disruption in these processes can adversely affect the crop resulting in the manifestation of different types of nutritional disorders. Among the different factors contributing to these processes, interaction between nutrients in the soil-plant system is the most important, which in turn is affected by soil organic matter, crop residues, manures and fertilizers etc. In this paper, a detailed review on the research work carried out under the different processes of nutrient dynamics in edible yams (*Dioscorea* spp.) and edible aroids viz., elephant foot yam (*Amorphophallus paeoniifolius*), taro (*Colocasia esculenta*) and tannia (*Xanthosoma sagittifolium*) are documented.

A. Yams (*Dioscorea* spp.)

Yams are considered to be the most nutritious of the tropical root crops (Wanasundera and Ravindran, 1994) as these contain four times protein than cassava, are high in essential amino acids, good source of vitamin A, vitamin C, fibre and minerals, low in calcium and anti-nutritional factors like phytate and trypsin inhibitors. The most widely cultivated edible species of yams are white yam (*Dioscorea rotundata* Poir.), greater yam (*Dioscorea alata* L.) and lesser yam (*Dioscorea esculenta* (Lour.) Burk.).

I. Fertility status of soils

Yams in general prefer light friable sandy or gravelly, well drained soils rich in organic matter. But, white yam can come up well in heavy soils, can tolerate high clay content, but not water logged conditions. They prefer soils which are relatively rich in organic matter. The optimum pH is 6-7 and below pH 5.5, Al toxicity can occur (O' Sullivan, 2010). Survey conducted in the yam growing belts of Orissa in Dhankanal district indicated that 50% area is marginally deficient in Zn. Hagza et al. (2010) reported that *D. alata* has good adaptation to low soil fertility. Regarding the resistance of yam species to nutrient problems, *D. alata* was found to have somewhat tolerance to soil acidity (Abruna-Rodriguez et al., 1982).

II. Soil fertility management strategies

a. Nutrient movement/nutrient flow

The root architecture decides the nutrient movement in relation to application of fertilizers and absorption of nutrients under field situation. According to Melteras et al. (2008) and O'Sullivan (2008), yam roots radiate from the crown of the plant and remain just under the soil surface for some distance before branching and descending and hence on sandy soils, Nwinyi and Enwezor (1985) found that broadcasting of fertilizers was equally effective as banded or ring placement. Soil physical properties also influence the flow of nutrients and Agbede (2005) found that soil bulk density was negatively correlated with tuber length, leaf nutrient concentration and yield in yams.

b. Nutrient absorption and utilization

As yams are efficient scavengers of soil nutrients, adequate supply of nutrients can result in achieving good growth and yield potential. Rodriguez et al. (1989) and Irizarry et al. (1995) studied the nutrient uptake and utilization coefficients for fertilizers and soil nutrients in *D. alata*. Kabeerathumma et al. (1991) studied the absorption and utilization of major nutrients (N, P, K) at different growth stages of the three different species of yams and found that the maximum utilization of N and K by *D. esculenta* and *D. rotundata* was within 5-7 months after planting (MAP) whereas the demand for P by these species was found to continue with maturity of the crop. In the case of *D. alata*, the maximum utilization of all the three nutrients was found to be within 5 MAP. The concentration of these nutrients in the plant parts was the highest during the early stages of the growth (3-5MAP). The uptake of major, secondary and micronutrients are given in Table 1. According to O' Sullivan and Ernst (2007), a crop of yam producing 15 tonnes of tubers removed N, P, K, Ca, Mg and S to the tune of 30-76,0.7-8.7, 26-78, 0.5-3.3, 1-4.5, 0.2-21 kg ha^{-1} respectively and Na, B, Cu, Fe, Mn and Zn in the range of 1.5-2.7,10-14, 7.5-57, 21-270, 2.9-115 and 36-95 g ha^{-1} respectively. The amount of K removed from the soil by a yam crop is similar to the amount of N to the tune of K @ 12-25 kg t^{-1} of edible dry matter or 150-250 kg ha^{-1} dry matter for high yielding varieties (Sobulo, 1972; Obigbesan and Agboola, 1978; Kabeerathuma et al., 1991; Irizarry and Rivera, 1985; Irizarry et al., 1995). Irizzary et al. (1995) estimated a total removal of 25 kg N for each ton of edible dry matter in a well nourished crop of *D. alata*.

c. Crop response to nutrients

Yams are reported to be highly efficient in the utilization of native and applied nutrients from soils. Hence, continuous cropping of yams may lead to severe depletion of essential nutrients from the soil (Onwueme, 1978). Supplementing the soil with plant nutrients overcomes this problem to a great extent. Obiagwu (1997) raised grain legumes as intercrops to supplement N and on a sandy river basin soil in Nigeria, yam responded positively to NPK@ 15:15:15 applied at 30-90 kg ha^{-1} and to intercropping with cowpea or yam bean. Intercropping with cowpea and yam bean was found equivalent to applying 48 and 26 kg ha^{-1} NPK respectively.

i. Effect of N on yield, yield attributes and quality

Yam crop removes considerable amount of N from the soil. Chapman (1965) obtained 30% increase in tuber yield in *D. alata* when the application of N fertilizers was delayed until 3 MAP. Preliminary trials conducted

Table 1. Nutrient requirement of yams

Dioscorea species	Tuber yield (t ha^{-1})	Nutrient uptake (kg ha^{-1})								
		N	P	K	Ca	Mg	Zn	Cu	Fe	Mn
D. alata	19	114	15	141	25.07	11.30	0.327	0.29	3.62	1.76
D. esculenta	18	112	15	93	23.54	12.00	0.531	0.18	3.83	2.19
D. rotundata	29	117	17	123	23.84	9.91	0.460	0.33	4.29	1.81

Source: Kabeerathumma et al. (1991)

at Central Tuber Crops Research Institute (CTCRI) to find out the effect of different levels of N on the yield of *D. alata* (Singh et al., 1973a) clearly showed that N levels up to 60 kg ha^{-1} had a significant influence on tuber yield and resulted in highest tuber yield of 33.1 t ha^{-1} and dry matter content of 33%.

According to Enyi (1972), N application increased tuber number per plant, mean tuber bulking rate and tuber yield in *D. esculenta*. At CTCRI, Singh et al. (1973b) confirmed substantial yield response in *D. esculenta* to N application and arrived at an economic dosage of 80 kg N ha^{-1}. Rao et al. (1975) reported that N significantly increased tuber yield linearly up to 300 kg ha^{-1}. Koli (1973) found that N rates up to 67.2 kg ha^{-1} increased tuber yields by 22.1% in *D. rotundata* at Northern Ghana. At Nigeria, Umanah (1977) recorded significant increase in yield of *D. rotundata* by applying N @ 33.6 kg ha^{-1}, but a higher dose of 67.3 kg ha^{-1} could not increase the yield further. Though Aduayi (1979) estimated insignificant correlation between tuber yield and leaf N concentration in *D. rotundata*, tuber yield was the highest at 200 kg N ha^{-1} (Aduyi and Okpon, 1980). Significant response of *D. rotundata* to 90 kg N ha^{-1} has been reported at International Institute of Tropical Agriculture (IITA), Nigeria (Kpeglo et al., 1980).

Kayode (1985) reviewed the fertilizer responses of yams in West Africa and concluded that a small response to N was usually obtained on previously cropped sites with soil N below 0.1%, but not on newly cleared sites with soil N above 0.3%. Irizarry et al. (1995) recorded no response of *D. alata* to fertilizer on a site having a soil N status of 0.18-0.22% despite a very high fresh tuber yield of 58 t ha^{-1} and N removal by the crop of 214 kg ha^{-1}. A similar experiment on the same soil using *D. rotundata* (Irizzary and Rivera, 1985) recorded a significant response to high application rates of combined fertilizer containing 224 kg ha^{-1} N.

A few reports indicate that N had no effect on dry matter content of edible yam species viz., *D. esculenta* (Singh et. al., 1973b), *D. alata* (Irizarry et al., 1995) and *D. rotundata* (Umanah, 1977). In contrast, Singh et al. (1973a) noticed that dry matter, starch and sugar contents of tubers were appreciably high at 60 kg N ha^{-1} in *D. alata*. Further, additional dosages of N had no significant impact on dry matter or starch content of tubers. Singh et al. (1973b) reported maximum crude protein at 80 kg N ha^{-1}, maximum starch and total carbohydrate at 40 kg N ha^{-1} in *D. esculenta*. The protein content of tuber was found to be enhanced by N application in *D. esculenta* (CTCRI, 1976). On the other hand, Gbedelo (1986) stated that application of N fertilizers can result in tubers of low organoleptic quality.

ii. Effect of P on yield, yield attributes and quality

Yams can efficiently utilize soil P and its response to phosphatic fertilization is generally poor (Coursey, 1967; Umanah, 1977; Koli, 1973; Lyonga, 1982). Phosphorous application resulted in either no response (Irving, 1956) or even depressed tuber yield (Coursey, 1967; Umanah, 1977) in certain instances. Zaag et al. (1980) studied the P requirement of yam in detail and explained that the external P requirement of yams ranged from 0.005 to 0.02 ppm P in solution. All the three species of yams viz., *D.esculenta, D. alata* and *D. rotundata* efficiently utilized P at low concentrations in the soil solution. In general, the response of yams to P fertilization is reported to be very little, partly because P is not a limiting nutrient to yams in view of its low requirement (Kabeerathumma et al., 1991) and partly due to the association of the mycorrhizal fungi which help yam roots to absorb P effectively from the soil (Potty, 1978; Zaag et al., 1980).

According to Irizarry et al. (1995) one third of the P present in tubers comes from senescing leaves.

Zaag et al. (1980) tested several varieties of *D. esculenta, D. rotundata* and *D. alata* for response to P application and found that only the highest yielding varieties of *D. alata* responded to additional P of up to a soil solution concentration of 0.02 ppm. But Halavatau (unpublished) recorded a positive response to P fertilization by *D. alata* on a soil testing 8 ppm but not on soils testing 18 ppm or above. The amount of P removed by the crop is around 1.3-2.2 kg P t^{-1} of edible dry matter equivalent to 12-25 kg ha^{-1} of P (Sobulo, 1972; Obigbesan and Agboola, 1978; Irizarry and Rivera, 1985; Kabeerathumma et al., 1991; Irizarry et al., 1995). However, on P binding soils, 50-100 kg ha^{-1} of P may be needed to maximize the yield response when P is placed in a concentrated band in the mound (Halavatau, unpublished).

iii. Effect of K on yield, yield attributes and quality

Enyi (1972) reported that K application resulted in greater leaf area and leaf area duration and exerted a profound influence in diverting greater proportion of dry matter into tubers than N and increased the dry matter accumulation in tubers, tuber size, tuber number and tuber yield. The increase in tuber yield due to K was attributed partly to its effect in bringing about slightly earlier tuber initiation and partly to an increase in bulking rate. According to Singh et al. (1973b), for *D. esculenta*, the economic dose of K_2O was 120 kg ha^{-1}. Maximum starch and total carbohydrate were obtained at 120 kg ha^{-1}. Obigbesan (1973) stated that *D. rotundata* continued to respond to additional supply of K up to 78.4 kg ha^{-1}, *D. esculenta* responded highly to K application up to 165.76 kg ha^{-1}, while the yield of *D. alata* was unaffected by K fertilization. In contrast, Umanah (1977) noticed that in *D. rotundata*, the effect of K application on yield was inconsistent. Investigations on the effect of K on tuber yield of three *Dioscorea* spp. undertaken at University of Ibadan, Nigeria (Obigbesan et al., 1977) revealed that the highest tuber yield of *D. cayenensis* and *D. rotundata* (variety Aro) was produced at 30 kg K_2O ha^{-1}, whereas *D. alata* and *D. rotundata* (variety Efuru) gave optimum performance at 60 kg K_2O ha^{-1}. It also appeared that yams will not respond to K fertilizers when the level of exchangeable K was greater than 0.15 meq 100 g^{-1} soil on newly cleared land. It was also suggested that K fertilization raised the percentage of marketable tubers. At Orissa, Behura and Swain (1997) indicated that *D. alata* responded up to 60 kg K_2O ha^{-1}.

The dry matter content of tubers was not much affected by K fertilization. Crude protein and sugar contents did not show any regular trend. K application increased starch and dry matter contents in *D. rotundata*, whereas studies at CTCRI (CTCRI, 1976) could not find any effect of applied K fertilizers on the starch content of *D. alata*. Shyu and Chang (1978) observed gradual reduction in crude protein content in *D. alata* with increased K levels.

iv. Combined effect of NPK on growth, yield and quality

It has been demonstrated quite early that yams grown in soils with less than 0.1% N, 10 ppm P and 0.15 meq 100 g^{-1} exchangeable K responded well to fertilizer application (Young, 1976; Obligbesan et al., 1977). Positive yield response of yams to fertilizer application, particularly in soils where N, P and K levels were low has been reported (Rouanet, 1967; Gooding and Hoad, 1967; Lyonga, 1976; Kpeglo et al., 1980). The magnitude of response to fertilizers was found to vary with *Dioscorea* species (Kabeerathumma and Mohankumar, 1994). Apparently higher response to applied N and K has also been confirmed (Lyonga, 1982; Kabeerathumma et al., 1987). Detailed investigation on the management of different resources for *D. rotundata* intercropped in coconut garden in the red loam soils of Kerala indicated that application of coir pith compost @ 5 t ha^{-1} along with NPK @ 80: 60: 80 kg ha^{-1} favoured soil physico-chemical properties and maintained higher yield to the tune of 24.61 t ha^{-1}(Suja et al., 2000; Suja et. al., 2003; Suja et al., 2004a; Suja et al., 2004b).

III. Index leaf tissues and critical nutrient concentration

In the selection of index leaves for nutrient content analysis, there are several reports regarding sampling of leaf blades of all leaves (Sobulo.1972; Gaztambide and Cibes, 1975; Irizarry and Rivera, 1985; Irizarry et al., 1995) and young mature leaves (Obigbesan and Agboola, 1978; Zaag et al., 1980). Later, on understanding the fact that leaf position was a source of considerable variability in leaf nutrient concentrations and a well defined index tissue was essential to make valid comparisons with reference to critical concentrations, O'Sullivan (2010) conducted separate experiments for each disorder varying the supply of one nutrient to induce either deficiency or toxicity at a range of intensities. She further established the relationship between plant dry matter yield and leaf nutrient concentrations at various leaf positions on the vine to arrive at the index leaf and critical concentration of deficiency and toxicity.

The index leaves and its critical nutrient concentration for different yam species in an Ultisol were established by Kabeerathumma et al. (1987). According to the study, in all the three species of *Dioscorea*, the first fully mature leaf could be taken as the index leaf and that produced at 3 MAP in the case of lesser yam and 4 MAP in greater yam and white yam could be taken for tissue analysis.

Table 2. Critical nutrient concentrations (CNC) in the index leaf tissues of *Dioscorea* species

Nutrient concen-tration	Unit	*D. alata*	*D. esculenta*	*D. rotundata*
N	%	1.86	1.85	1.94
P	%	0.20	0.18	0.16
K	%	2.27	1.46	2.02
Ca	%	0.26	0.22	0.27
Mg	%	0.65	0.47	0.54
Fe	$\mu g\ g^{-1}$	449	691	339
Cu	$\mu g\ g^{-1}$	532	390	657
Mn	$\mu g\ g^{-1}$	85	92	81
Zn	$\mu g\ g^{-1}$	24	21	22

Source: Kabeerathumma et al. (1987)

The critical nutrient concentration (CNC) in the index leaves of these species is given in Table 2.

Experiments conducted by O'Sullivan (2010) at Australia using solution culture identified the index leaves for D. alata and *D. rotundata* as leaf blades from the 5^{th} and 6^{th} nodes from the tip and for *D. esculenta*, as 7^{th} and 8^{th} leaves from the tip. The critical nutrient concentration for deficiency and toxicity of mineral nutrients for the three species of *Dioscorea* according to her experiments is presented in Table 3.

Table 3. Critical nutrient concentrations (CNC) for deficiency and toxicity of mineral nutrients in *Dioscorea* species

Nutrient	Unit	*D. alata*	*D. rotundata*	*D. esculenta*
Deficiency				
N	%	2.90-4.00	Lower	2.00-2.60
P	%	0.21-0.37	0.21-0.37	0.21-0.37
K	%	2.10-3.90	2.2-2.8	2.10-2.60
Ca	%	1.00-1.50	0.5-0.9	0.50-0.90
Mg	%	0.10-0.14	0.10-0.14	0.10-0.14
S	%	0.10-0.14	0.10-0.14	0.10-0.14
Fe	$\mu g\ g^{-1}$	25-45	25-45	25-45
B	$\mu g\ g^{-1}$	9-20	9-20	9-20
Mn	$\mu g\ g^{-1}$	10-15	10-15	10-15
Zn	$\mu g\ g^{-1}$	15-35	15-35	4-6
Cu	$\mu g\ g^{-1}$	2.0-3.6	2.0-3.6	2.0-3.6
Mo	$\mu g\ g^{-1}$	< 0.8	Lower	Lower
Toxicity				
Na	$\mu g\ g^{-1}$	400	-	-
B	$\mu g\ g^{-1}$	220-300	220-300	-
Mn	$\mu g\ g^{-1}$	5000-7000	5000-7000	-
Zn	$\mu g\ g^{-1}$	280-400	280-400	-
Cu	$\mu g\ g^{-1}$	20-30	20-30	-

Source: O' Sullivan (2010)

IV. Nutritional disorders

Shiwachi et al. (2004) developed nutrient deficiencies in *D. alata* and *D. rotundata* in nutrient solutions using nutrient omission pot trials. O'Sullivan and Jenner (2006) studied nutrient deficiencies of major, secondary and micronutrients following a modified programmed nutrient addition method in greater yam. Gaztambide and Cibes (1975) studied nutritional deficiencies of yams (*Dioscorea* spp.) and related effects on yield and leaf composition.

O'Sullivan et al. (2001) and O'Sullivan and Jenner (2006) conducted preliminary work on nutrient omission experiment and solution culture technique to document symptoms of a range of deficiencies to establish nutrient profiles in leaves of varying position on the vine. O'Sullivan (2010) established the nutritional disorders of all the three species of yams both under sand culture as well as under field experiment including the deficiency symptoms, critical concentration, index leaves and management aspects. In the case of K, the key nutrient for yams, it was seen that both *D. rotundata* and *D. esculenta* leaves contained less K than *D. alata* when grown on the same site (Obigbesan and Agboola, 1978; Zaag et al., 1980). Ekpete (1978) concluded that yams appeared to be tolerant to marginal soil K levels compared to other crops. However, soil tests have not been calibrated for yam response to K.

O'Sullivan and Earnst (2007) reported that *D. rotundata* appeared to have a greater tolerance to low tissue Ca levels showing less growth reduction despite lower tissue concentrations than *D. alata* when grown at deficient Ca levels. *D. esculenta* also tended to have lower Ca levels than *D. alata* when grown at the same site and concentrations as low as 0.95% was associated with healthy growth. In *D.esculenta*, Mg deficiency symptoms with interveinal chlorosis of older leaves were very common especially when continuously grown in low fertile soils (Susan John et al., 2006a).

Sotomayor-Ramirez et al. (2003) reported that poor growth in yams at Puerto Rico responded strongly to a foliar spray containing a mixture of micronutrients. Concentrations of DTPA extractable Mn less than 4 ppm were considered potentially deficient for a range of root and vegetable crops, but concentrations of DTPA extractable Mn above 45 ppm were considered potentially harmful to root crops such as potato and carrot (CFL,1983). Sotomayor-Ramirez et al. (2003) recorded Zn concentrations of 35 and 22 ppm in leaves from the middle of the vine in *D. alata* and *D. rotundata* respectively on a Zn deficient soil.

As regards to the effect of soil salinity on yam growth and production, salt affected yam plants tended to be pale with a uniform light green colour on young leaves becoming increasingly interveinal with leaf age. In a solution culture experiment, *D. alata*, suffered 50% yield reduction at 4 dS m^{-1} with a significant growth decline at 1dS m^{-1}.

In the case of tolerance to soil acidity, yam (especially *D. alata*) was found to be very sensitive to soil acidity when compared to other tropical tuber crops (Abruna-Rodriguez et al., 1982). They further stated that in soils having a pH below 4.5, Al was likely to severely reduce yam production. It was also found that in *D. alata*, yield was significantly reduced when Al saturation was only 10% of the effective cation exchange capacity (ECEC) of the soil and only 15-30% of maximum yield would be obtained when Al saturation was 40%.

B. Aroids

1. Elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson)

I. Fertility status of soil

The crop prefers a deep loamy, well drained sandy loam to sandy clay loam soil with a pH of 6 - 7 rich in organic matter. Swamy et al. (2002) conducted a survey in the elephant foot yam growing areas of North Eastern hill regions of India comprising of Assam, Nagaland and Meghalaya and revealed that the elephant foot yam growing soils in this region was acidic with pH lower than 5.5 indicating the predominance of exchangeable Al^{3+}. The soil organic carbon content was high in all areas, except Assam, where it was moderate. The slow rate of mineralization due to the low temperature indicated low to medium status of available N in these soils. The available P was low in the soils of Nagaland, but low to high in Assam and Meghalaya soils. Approximately in 78% of the soils, the P availability was low or moderate. The available K content was low in Nagaland, moderate in Assam and high in Meghalaya. The Ca status of the soil was low in all the states.

II. Soil fertility management strategies

a. Nutrient flow and nutrient loss

In elephant foot yam, the flow of nutrients from top to bottom to a depth of up to 90 cm was studied under three different levels of N, P and K (James George, 2004). It was found that only 40% N and 50% K was retained in the top layer indicating higher mobility of these nutrients, whereas 75% of P accumulated in the surface layer. However, slightly higher mobility of P was observed when fertilizers were applied along with FYM, but no such definite trend was seen in the case of N and K movement. The data on nutrient losses indicated higher loss of N (12.4 -16.5 kg ha^{-1}) and K (5.28-12.12 kg ha^{-1}) through leaching. The loss of N through volatilization ranged from 2.44 - 4.96 kg ha^{-1} (James George, 2004).

b. Nutrient absorption and utilization

i. Major nutrients

Under controlled condition, the uptake of nutrients N, P and K was studied under three different levels of N, P and K alone and along with FYM and the mean uptake of N, P and K was 26.89, 4.23 and 36.63 g m^{-2} respectively. A crop of elephant foot yam producing a tuber yield of 43 t ha^{-1} removed 124 .8 kg N, 26.1 kg P and 222.4 kg K respectively (Kabeerathumma et al., 1987).

Kabeerathumma et al. (1987) studied the N, P and K utilization pattern of elephant foot yam during different growth stages of the crop and found a progressive increase in the uptake of these nutrients with increase in the age of the crop. The rate of uptake of N and P was found to be maximum between 3-5 MAP. After 7MAP, no conspicuous increase in N and P uptake was noticed. Though K uptake was maximum during 3-5 MAP, it continued to increase with the age of the crop with the highest during the tuber bulking period. Pushpakumari and Sasidhar (1996) studied the uptake of N, P, K by elephant foot yam under shade and found that N and P uptake decreased with increasing shade intensities and K uptake was uniform at shade levels from 0-50%, but significantly higher at 75% shade.

Further studies on the N, P and K content of different plant parts at various growth stages revealed that the nutrient content changes with increase in age of the crop. The N and K contents in the foliage of elephant foot yam were the highest after 5 MAP and thereafter it decreased with maturity. The N content of root, tuber and pseudo-stem decreased towards maturity of the crop. Among the different plant portions, leaf was the richest in N (2-4%) and pseudo-stem had the highest K content (> 4%). The K content of tuber was maximum during tuber initiation which decreased towards bulking. The P content was maximum in leaves with maximum concentration during the early growth stage and further declined towards the maturity stage.

Nair and Mohankumar (1991) found that among the different growth stages, the concentrations of N, P and K were maximum during the active growth phase (2-4 MAP). They studied the critical growth period in elephant foot yam where the dry matter as well as NPK concentration in the plant part was maximum and found that the above nutrients were maximum during the active growth phases (2-4 MAP). The dry matter in the above ground portion increased up to 6 MAP and then decreased till harvest. In the underground portion, the dry matter accumulation continued up to 10 MAP .The crop growth rate (CGR) increased with increased N and K application up to 100 kg N and 150 kg K_2O ha^{-1}. P nutrition had no significant effect on CGR. The CGR increased with age of the crop up to 10 MAP.

Verma et al. (1995) studied the growth, tuber formation and uptake of N and K as influenced by the rate and methods of application of N and K in a field experiment in West Bengal and reported maximum growth, dry matter production, tuber yield and N and K uptake with N and K @ 150 kg ha^{-1} each applied in two splits. The N and K contents were the highest in shoots at 120 DAP and in corms at 150 DAP. In a field trial in the sandy loam soils of West Bengal, Verma et al. (1994) studied the performance of elephant foot yam as affected by N levels and reported that concentration of N in shoots and corms decreased with growth stage and increased with N application rate. Ashokan et al. (1988) studied the absorption of radioactive P (^{32}P) by an intercropping system comprising of cassava, banana, elephant foot yam and groundnut and the uptake of radioactive P by elephant foot yam was found to be negligible.

ii. Secondary nutrients

The absorption and utilization of both Ca and Mg increases with age of the crop. Maximum Ca utilization was seen at 3-5 MAP whereas Mg showed the highest uptake during 5-7 MAP. The ratio of Mg to Ca utilization was 1:2.19 indicating a higher Ca requirement for the crop. The requirement of Ca was more during the active vegetative growth stage whereas Mg utilization was higher during tuber bulking stage. This information suggests the need to apply these nutrients at respective growth stages to increase the yield (Kabeerathumma et al., 1987).

As regards to the nutrient content in the plant parts during different growth stages, leaves had the highest concentration of Ca and Mg during all growth stages. The Mg content in the leaf showed a slight decrease at 5MAP and then increased with maturity. But in the pseudo-stem, Mg content increased with the age of the crop. The root and tuber had higher Mg in the early growth stage which decreased towards maturity.

iii. Micronutrients

Among the micronutrients, Fe was removed by the crop in larger amounts to the tune of 7.38 kg ha^{-1} followed by Mn (1.78 kg ha^{-1}). The uptake of Zn and Cu was very meagre in the range of 490 and 112 g ha^{-1} respectively. The depletion of these nutrients from the soil through tuber was as 81-82% Zn and Cu, 30% Mn and 53% Fe. The concentration of Fe and Mn in the different plant parts increased with age and the tuber contained more Fe and Mn. The Zn and Cu content in the different plant parts decreased with maturity (Kabeerathumma et al., 1987).

c. Crop response to nutrients

Nair and Mohankumar (1991) found that elephant foot yam required a fertilizer dose of 100: 50:150 kg N, P_2O_5 and K_2O ha $^{-1}$. The optimum NPK as per the response surface fitted was 107:47:147 kg ha^{-1}. Ravindran and Kabeerathumma (1990) studied the impact of manures and fertilizers in elephant foot yam under partial shade of coconut with bushy cowpea as intercrop and found that vegetable cowpea could be successfully grown as intercrop in elephant foot yam without reducing its yield and the fertilizer dose could be reduced to 27:20:33 kg N, P_2O_5 and K_2O. Sethi et al. (2002) studied the effect of different levels of NPK on the yield of elephant foot yam at different locations of Orissa for two seasons and found that application of NPK@ 125:50:125 kg ha^{-1} produced the highest yield of 35.29 t ha^{-1}.

Sen and Mukherjee (2002) investigated the effect of different levels and methods of application of N and K on corm production in elephant foot yam and application of the highest dose of N and K each @ 150 kg ha^{-1} in three splits produced the maximum corm yield of 54 t ha^{-1}. In a field experiment at West Bengal, Kundu et al. (1998) determined the effect of NPK fertilizer dose on plant biomass, corm yield and total yield and indicated that NPK @ 200:100:100 kg ha^{-1} was the optimum fertilizer dose for elephant foot yam. In a trial conducted at Kalyani, West Bengal, Sen et al. (1995, 1996) reported satisfactory corm production (58.90 t ha^{-1}) by applying N and K @ 150 and 75 kg ha^{-1} respectively.

Henpithaska (1993) tried different organic manures in Thailand and found that corm yield in elephant foot yam increased by organic amendments viz., cattle manure, maize cobs, castor meal, black rice hulls, coir and rice hulls. Patel and Mehta (1987) found that the corm yield in elephant foot yam increased by applying FYM @ 30 t ha^{-1} and N @ 150 kg ha^{-1}. Mukhopadhyay and Sen (1986) reported that application of N @ 150 kg ha^{-1} along with K @ 50 kg ha^{-1} could increase corm weight, corm bulking rate and yield in elephant foot yam. Patel and Mehta (1984) reported an increase of 15.5% in corm yield with 30 t ha^{-1} FYM and 6.5 % increase with 150 kg ha^{-1} N in elephant foot yam.

The impact of nutrition viz., major, secondary and micronutrients on the quality (delineating the acridity of tuber) has not yet been explored. Patel and Mehta (1987) reported an increase in P, K and silica content in corms with FYM application, but had no effect on starch and N contents. Further, application of N increased the N, P, K, starch and silica contents of the corms. Mukhopadhyay and Sen (1986) reported that quality of corms improved with increasing levels of both N and K.

Table 4. Critical nutrient concentration (CNC) in the index leaf tissues of elephant foot yam

Nutrient	Unit	CNC
N	%	4.05
P	%	0.55
K	%	3.82
Ca	%	0.33
Mg	%	0.65
Fe	$\mu g\ g^{-1}$	689
Cu	$\mu g\ g^{-1}$	14
Mn	$\mu g\ g^{-1}$	238
Zn	$\mu g\ g^{-1}$	121

Source: Kabeerathumma et al. (1987)

III. Index leaf and critical tissue concentration

The leaf blade at 3rd month of planting was generally taken as the index leaf and the critical tissue concentration is given in Table 4 (Kabeerathumma et al., 1987).

IV. Nutritional disorders

Deficiency symptoms of N were usually noticed in poor soils low in organic matter. Wide spread chlorosis or yellowing of the foliage was the characteristic symptom which later resulted in drying and withering of the whole plant. Deficiency of K was characterized by yellowing, curling inward and drying of the margins and tips of the leaflets which later caused complete drying of the whole plant (Susan John et al., 2006a).

2. Taro (*Colocasia esculenta* (L.) Schott.)

I. Fertility status of soil

Taro can be grown in all types of soils but it prefers deep well drained, friable loams particularly alluvial loams for its better growth and productivity.

II. Soil fertility management strategies

a. Nutrient absorption and utilization

The peak demand for N and K for taro was during 3 MAP of the crop. The P content in the plant part was maintained almost constant up to 3 MAP (Kabeerathumma et al., 1984). In the case of micronutrients, the peak demand for Fe and Mn was during 2-3 MAP and the demand for Zn and Cu was around the maturity stage. All the micronutrients showed a tendency to accumulate in the root with advancement in the growth stage of the crop (Kabeerathumma et al., 1985). Miyasaka and Barthholomew (1979) reported about Ca nutrition of taro.

b. Crop response to nutrients

Cattle manure or compost @ 3-4 t ha^{-1} is recommended along with NPK @ 80:60:80 kg ha^{-1} for most parts of India. However, for Orissa, application of NPK @ 100:80:80 kg ha^{-1} was found to be the optimum (Misra et al., 2005). Recommended NPK rates for taro was NPK @ 60-140, 25-125, 80-340 kg ha^{-1}(de Gues, 1967). According to Mohankumar and Sadanandan (1989) and Mohankumar et al. (1990) a fertilizer rate of 40-80 kg N, 10 kg P and 40-80 kg K per hectare with split application of N and K has been recommended for Kerala. In Hawaii, higher rates of fertilizer ie., NPK as 515: 250: 670 kg ha^{-1} have been recommended (Silva et al., 1990; Sato et al., 1990).

III. Index leaf and critical nutrient concentration

The second youngest open leaf blade could be selected as the index leaf which often corresponded to the youngest fully expanded blade that will be the larger leaf 1 and 2. The tentative critical concentration and adequate concentrations in this leaf tissue as suggested by O' Sullivan et al. (1996) is given in Table 5.

Table 5. Critical nutrient concentration in the index leaf tissues of taro

Nutrient	Unit	Critical concentration	Adequate range
N	%	3.70	3.9-5.0
P	%	0.33	0.5-0.9
K	%	4.60	5.0-6.0
Ca	%	2.00	2.6-4.0
Mg	%	0.15	0.17-0.25
S	%	0.26	0.27-0.33
Fe	μg g^{-1}	56.00	68-130
B	μg g^{-1}	23.00	26-200
Mn	μg g^{-1}	21.00	26-500
Zn	μg g^{-1}	22.00	22-50
Cu	μg g^{-1}	3.80	5.8-35

Source: O' Sullivan et al. (1996)

IV. Nutritional disorders

Miyasaka et al. (2002) reported nutrient deficiencies and toxicities in taro. The response of taro to different levels of Fe in hydroponic solution was studied by Ares et al. (1996). Austin et al.(1994) studied the effect of Mg on early taro growth. Miyasaka and Webster (1994) found Mn toxicity symptoms in taro as yellowing of leaf blades and brown spots between the veins and at the leaf margins and older leaves became deformed and cup shaped. Hill et al. (2000) studied the effect of excess Cu in taro and the threshold for young taro was fixed as 1.2 μM. The toxic concentration reduced dry matter, leaf area, root length, root dry weight ratio and impaired the synthesis and accumulation of cation in leaf blade. Hence, they stated that leaf Cu concentration could not be used as a diagnostic indicator of Cu.

Cable (1996) studied the mineral nutrition aspects of taro with thrust on soil sorption studies, solution culture and Integrated Plant Nutrient Supply. Sullivan et al. (1996) indicated the diagnostic criteria for nutritional disorders due to major, secondary and micronutrients in taro by conducting solution culture as well as field trials and described the visible symptoms of both deficiency and toxicity along with the critical tissue concentration.

Blamey (1996) recommended the use of mulch material like *Erythrina* leaves @ 60 t ha^{-1} to rectify the nutritional disorders in addition to the use of liming materials, organic manures and chemical fertilizers. Poihea et al. (1996) studied the response of taro to P fertilizer in some selected soils of Western Samoa and found that broadcast application of P as triple super phosphate along with lime or *Erythrina* mulch increased tuber yield. Sivan et al. (1996) studied the effect of K on drought tolerance in taro and indicated that plants with sufficient K restricted water loss and maintained a favourable water balance in the leaf tissue.

3. Tannia (*Xanthosoma sagittifolium* (L.) Schott.)

I. Fertility status of soil

Tannia can be grown on a wide variety of soils, except hard clay or pure sands. But for optimum yields, they require a deep well drained, nutrient rich soil, preferably with a pH ranging from 5.5 to 6.5. Tannia are intermediate between yams and cassava in their tolerance to soil acidity and yield about 60% of maximum yield in soils with 50% Al^{3+} saturation of the soil CEC. Foliar composition of tannia was not affected by soil acidity levels except for Ca content which decreased with decreasing soil pH and increasing Al^{3+} saturation. High yield of tannia was obtained at about pH 4.8 with 20% exchangeable Al^{3+} (Ramesh et al., 2007).

II. Soil fertility management strategies

a. Nutrient movement/Nutrient flow

The movement of nutrients at different depths under tannia was studied along with the nutrient loss through volatilization and leaching. The total loss of N and K accounted to 22-45 and 29-41 kg ha^{-1} respectively. As regards to nutrient flow, about 45%, 30% K and 63% P were retained in the top layer (James George, 2004).

b. Nutrient absorption/utilization

Total nutrient uptake by well-fertilized tannia cv. Morada (*X. violaceum*) plant was found to be maximum close to harvest time, with average values of 125, 15, 156, 48 and 25 kg ha^{-1} for N, P, K, Mg and Ca respectively. From planting to harvest, uptake of N and K increased rapidly but that of P was very slow. Uptake of Mg and Ca increased steadily up to 5-6 MAP, after which it fluctuated considerably (Ramesh et al., 2007). Leaf weight increased rapidly during the first 6 months, then decreased and remained fairly constant until harvest. The leaf lamina of well fertilized tannia plant contained on dry weight basis about 3.2% N, 0.25 % P, 2.3% K and 1.3% Ca (Chandler et al., 1982). At CTCRI, Kabeerathumma et al. (1987) reviewed the nutrient uptake/removal of tannia with respect to macro and micronutrients.

c. Crop response to nutrients

Tannia responds well to organic and chemical fertilization (Karikari,1971; Giacometti and Leon, 1994). The leaf growth and cormel yield increased due to fertilizer application and high fertilization reduced the time required for cormels to reach the maximum size (Wilson, 1984). Split application at planting and at 2, 4 and 6 MAP was usually adopted if harvesting was done at 9-12 MAP (Giacometti and Leon,1994). Organic manure such as FYM @ 20-40 t ha^{-1} is often recommended if available. In India, application of 12.5 t ha^{-1} of animal manure or compost is advocated at the time of land preparation. However, intercropping with green manures such as *Crotolaria juncea, Sesbania*, Lablab, *Purpurea* in Cuban red ferralitic soils reduced the yield of tannia (Alvarez et al., 1996).

There is little precise knowledge about inorganic fertilizer use despite the fact that tannia can tolerate poor soils. The requirement varies according to the soil, climate and method of planting. In India, the adhoc recommendation for taro ie., NPK @ 80:50:100 kg ha^{-1} is also recommended for tannia (Mohankumar and Kabeerathumma, 1994). In Puerto Rico and Pacific Islands, N and K @ 100 kg ha^{-1} each in split application gave good results. Although very responsive to application of mulch, farmyard manure and mineral fertilizer, little is known about the nutritional requirements of tannia under varied climatic and soil conditions.

In traditional tannia cultivation in Africa, Central America and in the Pacific Islands, very little or no mineral fertilizer is used, especially when the crop is grown on land that has just been cleared from bush-fallow. However, some fertilizer recommendation as N, P_2O_5, K_2O and CaO @ 76, 115, 285 and 154 kg ha^{-1}

respectively was proposed (Milian et al., 1992). The effect of fertilizer application on tannia yields has been reported by several authors. In Ghana, yield of cormels increased with application of up to 100 kg each of N and P and 50 kg ha^{-1} K. Karikari (1974) established a positive linear correlation between leaf area and cormel production. The NK combination also caused significant variation in tuber yield and the treatment combination $N_{60}K_{125}$ gave the highest yield and net return (Pushpakumari et al., 1999).

i. Nitrogen (N)

Cormel yields increased up to 8.42 t ha^{-1} due to application of 50 lb acre^{-1} N as compared to 7 t ha^{-1} in plots which received no N, but decreased to 6.67 and 6.23 t ha^{-1} by application of 100 and 200 lb N acre^{-1} respectively. The response to N was affected by photosynthetic photon fluxes. According to Valenzuela et al. (1990) a significantly higher efficiency of N application was observed under non shaded situations. Nutrients like N which can leach will often be taken up in substantial quantities from deep soil but strong root proliferation is not required for this. Split application of N at planting and 3 months after planting are recommended to improve the efficiency of N and yield in most of the countries including India.

ii. Phosphorus (P)

Large increases in corm/cormel yields were reported following the application of P as triple-super phosphate (Ramesh et al., 2007). The effects were further enhanced by green manure and lime applications as reported by Poihega et al. (1996). The effects of P fertilizer (as triple super phosphate), *Erythrina* green manure and lime on corm yields of taro and tannia were reported from field experiments in Western Samoa during 1993 to 1995. Large increase in corm yield was observed by applied P and the effects were enhanced by green manure and lime (Poihega et al., 1996).

iii. Potassium (K)

The supply of K increased tolerance of tannia to water stress. Improved stomatal control when evaporative demand was high enabled the plants to restrict water loss and to maintain a higher leaf water potential (Sivan et al., 1996). Potassium also promotes the assimilation, translocation and accumulation of water during the growth and development of the crop.

iv. Calcium (Ca)

Tannia shows tolerance to soil acidity. Salas et al. (1996) carried out investigations in very acid Ultisol having a pH of 4.4 and found that tannia yielded 58% higher under lime treatment (4 t ha^{-1} limestone). However, root growth responded significantly to calcium hydroxide application in highly acid soils. Sub soil acidity in strongly acid soils with pH 4-5 was identified as the most important problem limiting tannia production in Kerala (CTCRI, 2010).

v. Sodium (Na)

Potassium nutrition and high K requirement of tropical root crops may be affected by their Na status, as has been observed in a number of plant species (Ivahupa et al., 1996). Solution culture was used to study the effects of K and Na supplies in tannia. At low K supply, Na ameliorated symptoms of K deficiency and increased growth of tannia (Ramesh et al., 2007). Differences in response to Na were attributed to differences in Na translocation to plant tops. At maximum Na supply, the Na concentration in index leaves averaged 1.82% in tannia. An increase in the supply of Na resulted in a shift in the critical K concentration to deficiency (90% of maximum yield) in index leaves from 2.9% to 1.2% in tannia. To overcome this problem in tannia for determining the critical concentration relevant to a leaf sample of unknown K status, the relationships between the critical K concentration to the concentration of Na in the index leaves was also established.

III. Index leaf and critical nutrient concentration

The 3rd or 4th leaf at 4 MAP was recognized as the index leaf in tannia and the critical nutrient concentration as suggested by Kabeerathumma et al. (1987) is given in Table 6.

IV. Nutrient deficiency symptoms

Tannia is a nutritious tuberous vegetable, very susceptible to Mg deficiency and hence considered as an indicator plant for Mg deficiency (Cable, 1996). In the acid laterite soils, the crop does not grow well because of the occurrence of a multi- nutrient disorder. The problem is so severe that the fertilizer recommendation for this crop could not be evolved till now. Since both the tubers

Table 6. Critical nutrient concentration in the index leaf tissue of tannia

Nutrient	Critical nutrient concentration (%)
N	3.2
P	0.5
K	2.3
Ca	0.9
Mg	1.3

Source: Kabeerathumma et al. (1987)

and leaves of this crop are very tasty having substantial amounts of minerals and fetching a fair price in the market, farmers are growing this crop on a large scale. Studies to evolve an integrated nutrient management strategy for the crop is in progress and the preliminary studies viz., Preliminary Rate Experiment (PRT) and Nutrient Omission Pot Experiment (NOPT) indicated that subsoil acidity was the primary cause inducing the multi - nutrient interactions of K, Ca and Mg leading to secondary problem of deficiency and toxicity of these nutrients causing complete devastation of the crop by 5 MAP (Susan John et al., 2006a; Susan John et al., 2006b; Susan John and Suja, 2006; Susan John and Suja, 2007; Ramesh et al., 2007). Dolomite was identified as a suitable liming material to rectify the problem (CTCRI, 2010).

In a pot culture study to find out the effect of K supply on drought tolerance in tannia, it was observed that K deficiency and water stress reduced leaf area, root and total plant weight, but there was no interaction between K and water stress (Sivan et al., 1996). Spence and Ahmad (1967) and Johnston et al. (1996) conducted solution culture experiments in tannia and induced nutrient deficiency symptoms of N, P, K, Ca, Mg and Mn as described in Table 7.

Conclusion and future strategies

The above detailed review on the various aspects of soil fertility and nutrient management in edible yams and aroids clearly depicts the need to further explore the unresearched area of nutrient dynamics in these crops. Among these, the pattern of nutrient flow and movement in taro as well as the critical nutrient concentration of micronutrients in tannia needs to be further investigated.

Table 7. Nutrient deficiency symptoms in tannia

Element	Symptoms
Nitrogen	Stunted growth, small pale-green lamina and short petioles
Phosphorus	Symptom similar to N, but lamina colour is not affected
Potassium	Slight reduction in growth, older leaves show necrosis of the lamina tips and edges
Calcium	Stunted growth, thick leathery younger leaves, distorted young leaves with necrotic and chlorotic patches and rapid senescence of leaves and the entire plant
Magnesium	Bright orange coloration between lamina veins, starting at the apex and spreading throughout the entire leaf (rapid senescence of leaves) (Interveinal chlorosis)
Manganese	Interveinal chlorosis of the young leaves, which extends into new and/or old leaves depending on the species

Source: Spence and Ahmad (1996)

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