MINERAL NUTRITION OF TARO (*COLOCASIA ESCULENTA*) WITH SPECIAL REFERENCE TO PETIOLAR PHOSPHORUS LEVEL AND PHOSPHATE FERTILIZERS

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SUMMARY

Soil and plant analyses can serve as guides for taro fertilization but care must be exercised in interpretation. Composition of taro leaf blades and petioles changes with advancing age so that plant age at sampling must be standardized. Leaf blades are more stable in composition than petioles. Luxury nutrition can be detected from petiole analyses but probably not from leaf blade analyses. Petioles sampled at about 8 months of age will serve as sensitive tissue for indicating the phosphorus status of taro. Petiole composition at 8 to 9 months ranges from 0.10 to 0.48% P, depending on levels of available soil phosphorus.

A leaf petiole phosphorus content of 0.23% at about 9 months age, and a soil solution concentration of about 0.16 ppm P are suggested as reasonable levels for good phosphorus nutrition of taro. Two soils developed from highly weathered alluvium required 500 to 600 kg/ha P to attain these levels.

RESUME

On peut se baser sur les analyses pédologiques et végétales pour fertiliser le taro, mais il faut que l'interprétation soit faite avec précaution. La composition des limbes foliaires du taro et des pétioles change à messure que l'âge avance, ce qui nécessite que l'âge des plantes soit standardisé au moment de l'échantillonnage. Les limbes foliaires ont une composition plus stable que les pétioles. On peut déceler une nutrition de haute qualité à partir d'analyses des pétioles mais probablement pas des analyses de limbes foliaires. Des pétioles échantillonnés à l'âge de 8 mois environ serviront de tissus sensibles pour indiquer le statut du phosphore du tarot. La composition des pétioles de 8 a 9 mois va de 0.10 à 0.48% de P, en fonction des niveaux du phosphore disponible dans le sol.

Une teneur de 0.23% en phosphore de pétiole foliaire de 8 mois environ, de même qu'une concentration de solution du sol d'environ 0.16 de ppm P sont considerés comme des niveaux acceptables pour une bonne nutrition du tarot en phosphore. Deux sols développés à partir d'alluvion soumis aux effets d'intempéries ont besoin de 500 a 600 kg de P/ha pour atteindre ces niveaux.

RESUMEN

Los análisis de suelos y plantas pueden servir como una guía para la fertilización de la malanga pero debe tenerse cuidado en su interpretación. La composición de los limbos de hojas y pecíolos cambia con la edad, de manera que debe estandarizarse la edad a la que se muestrean. Los limbos de las hojas son mas estables que los pacíolos en su composición. La nutrición superflua puede detectarse a partir de análisis del pecíolo pero probablemente no, a partir de análisis del limbo de la hoja. Los pecíolos muestreados alrededor de los ocho meses de edad servirían como un tejido sensible para indicar el estado del fósforo en la malanga. La composición de los pecíolos a los 8–9 meses varía de 0.10 a 0.48% P, dependiendo de los niveles de fósforo dipenible en el suelo.

Se sugiere un contenido en el pecíolo de la hoja de un 0.23% a los ocho meses de edad – approximadamente – y una concentración de la solución del suelo de cerca de 0.16 ppm P, como niveles raxonables para una buena nutrición fosfórica de la malanga. Dos suelos desarrollados a partir de aluvión altamente intemperizado requirieron 500 a 600 kg/ha P para alcanzar esos niveles.

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INTRODUCTION

Taro is widely cultivated in the tropics and subtropics. Common names for taro vary from one culture to another. In West Africa, it is known as cocoyam, whereas in the Philippines it is known as gabi or aba. Records of its cultivation date back to 400 B.C., thus making it one of man's oldest food crops[4]. Taro can be cultivated both on upland and lowland, waterlogged conditions because of its ability to transport oxygen from the leaves to the roots[2,5]. Taro can be grown under other adverse conditions, thus making it a good subsistence crop for underdeveloped areas. In Egypt, it has been used as the initial crop for reclaiming salt-affected sandy soils[10].

As a food crop, taro compares favourably in nutritional value with other root crops as cassava, yams, sweet potato and other edible aroids[12]. In Africa, Samoa, and other parts of the world, taro leaves are cooked as a vegetable and contain relatively high amounts of Ca, P, Fe, K, Vitamin A and ascorbic acid. The protein of the leaves has most of the essential amino acids[12]. Taro flour can be used for making bread and cookies, while slices can be baked or made into chips. The staple food of ancient Hawaiians was poi[5]. This has unique characteristics as food for babies.

Published information on the mineral nutrition of taro is limited, but the few available publications suggest that it responds well to fertilization, particularly when it is grown on highly leached tropical latosols[5,8]. Most of the published investigations have been done in Hawaii. The aim of this paper is therefore to bring together the scattered pieces of available literature, and to discuss some new fertilizer developments in the crop, especially with regard to phosphorus.

EFFECTS OF MANAGEMENT SYSTEMS

Response of taro to fertilization varies with the type of management practice. In Hawaii, for instance, lowland taro responds most to N, while the upland crop responds most to P and then to N[12]. Thus, with N, P and K at 400, 600 and 300 kg/ha respectively in lowland conditions under sprinkler, furrow and flood irrigation, Exumah[6] observed no effect of the method of irrigation on the concentrations of N, P, K, Ca, Mg, Fe and Mn in petioles at three months of age. At six months however, all elements studied were significantly higher in petioles under sprinkler and furrow irrigation than under flood irrigation. A similar trend was observed in main corms at seven months. This phenomenon is attributed to a redistribution of the elements from the rapidly declining top to the steadily growing corms, and to dilution effects of better yields under flooded conditions[5,6]. Plucknett *et al.*[12] stressed the significant role of fresh water in taro not only for maintenance of maximum vegetative growth and leaf production in the period of starch storage, but also because most taro cultivars are more susceptible to root rot in warm stagnant water.

Ezumah[6] has also reported an increase in amounts of N, K, Fe and Mn in taro at three months of age under ridged culture, although ridging had no effect on concentration of all elements in corm at seven months, and on Ca and Mg in petioles at all ages.

Other investigations[4] were also conducted on the island of Kauai, on effects of N, P, and K on growth and nutrient uptake of taro under upland and wetland conditions. Fertilizer rates used were: 0, 280, 560 and 1120 kg/ha of each element. Also N, P, and K treated plants received 280 kg/ha of each: P and K; N and K; and N and P respectively. Control plants received no fertilizer.

EFFECTS OF FERTILIZERS ON LEAF NUTRIENT COMPOSITION

Reports from several workers[3,6,10], indicate increased N content with N fertilization, but the dilution effect of increased growth decreased P and K foliar percentages. Fertilization with P increased P content in the leaves but decreased K percentage, particularly when the crop was grown on highly weathered upland soils. Application of K significantly increased K content in both upland and lowland taro leaves, and also increased total N in the upland crop. Production of sugar in leaf blades and starch in corms has also been associated with K application[12]. Because of competition among the cations Ca^{++}, Mg^{++}, K^{+} and NH_4^{+} for uptake by plants, decreased Ca and Mg percentages of leaves of upland and lowland taro should be expected when K fertilizers are applied. Effects on N uptake will depend upon the form of N being taken up. Ammonium is nutrified slowly in some highly weathered soils of Hawaii[15]. Contents of K of lowland taro leaves are consistently higher than upland taro regardless of treatment. This is associated with high amounts of K and Mg in the lowland soils[3].

EFFECTS OF FERTILIZERS ON CORM DEVELOPMENT, DRY MATTER AND ROOTS

Corms begin to make significant growth about three months after planting and continue to grow until maturity. Nitrogen applications increase corm weights of both lowland and upland crops whereas application of K seemed to increase corm weight of lowland crop only[3]. Concentrations of N, P, K, Mg, and Fe at seven months have been reported[6] to be significantly higher in sprinkler irrigated than in flooded plots, but levels of K and P in corms were equal under sprinkler and furrow irrigation. Phosphorus applications apparently increased specific gravity, and hastened corm maturity as shown by yield decrease of dryland taro occurring when harvesting was delayed from ten to fifteen months. When upland taro depends upon rainfall, a short drought may accelerate maturation and starch storage but late rains may cause renewal of growth with hydrolysis of stored starch in the corms leading to reduce corm quality and starch content[10]. Furthermore, corms assume a dumb-bell shape when rains are erratic, globular at time of active vegetative growth but constricted at maturation. Bowers, Plucknett and Younge[1] report a direct correlation between poi recovery and specific gravity of corms, and de la Pena[3] indicated correlation coefficients of 0.626** and 0.68** respectively for specific gravity with percentage dry matter of apical and basal parts of dryland main corms, and 0.76** for sucker corms. In potted plants, both N and P increased corm dry matter, whereas in the absence of P, there was no response to N beyond the 400 kg/ha application.

Growth of roots was considerably less in non-flooded than flooded treatments regardless of P fertilizer rates. Thus limited root development rather than a lack of nutrients may account for the superior growth of flooded taro as compared with upland taro.

YIELDS

In Hawaii, N, P and K applications increased yields of upland taro significantly. Dryland taro yields of 40 tons/ha harvested at 15 months using 560 kg/ha P applications have been reported from the Kauai Branch Station, Hawaii by Plucknett[10]. These yields are also greatly superior to those reported from Malaya, Trinidad, India and West Africa where yields are usually about 7–9, 4.5, 22–31 and 3–8 metric tons/ha respectively.

However, only N and P applications increased flooded taro yields significantly. In one of de la Pena's investigations[3], the greatest yield, 58 metric tons/ha of flooded taro, was obtained by the use of 1120 kg/ha N. The yield was 33 tons/ha for 0 kg/ha N. In contrast, the greatest yield of the upland taro achieved was only 26 tons/ha, and this was obtained by the use of 250 kg/ha application of N. No N under comparable conditions gave 9.8 tons/ha and 1120 kg/ha N gave 17 tons/ha. Imbalance among nutrients which may occur with heavy use of single nutrients on soils of low initial fertility, such as highly weathered upland soils, may be responsible for decreased yields of the heavily, as opposed to moderately, N fertilized plots.

INTERNAL AND EXTERNAL PHOSPHORUS REQUIREMENTS OF FLOODED TARO

There has been a tendency to neglect the phosphorus nutrition of paddy crops since it has been generally believed that the reducing conditions will solubilize iron phosphates and keep existing phosphorus available to the crop. The process may be inadequate to provide sufficient phosphorus if the parent alluvium is derived from a highly weathered land surface. Such alluvia usually have capacities to absorb much phosphate with little change in the availability of soluble phosphate.

Taro in Hawaii is often heavily fertilized with phosphate[11]. This suggests that the crop has a high requirement for phosphorus in solution (external requirement). Work is now in progress to determine the external phosphorus requirement of taro in comparison with rice. At the same time, leaf and petiole analyses are being made to arrive at the internal phosphorus requirement. The plots used are being monitored through several crop cycles to measure long-term phosphate fertilizer requirements and residual effects of phosphate fertilizer.

Field experiments are being carried out at the Paddy Crop Experiment Station, Hawaii Agricultural Experiment Station, Wailua, Kauai. The soil, Hanalei silty clay, is a poorly drained alluvium with a watertable at about 40 cm but an impervious layer in the soil which effectively restricts water transfer into the surface soil from the watertable. The soil is classified as Typic Tropaquept. The source of alluvium was the highly weathered upland of Kauai. Minerals are predominantly hydrated iron and aluminum oxides.

Ten levels of phosphate in the soil were established by adding concentrated superphosphate in amounts designed to give 0.003, 0.006, 0.012, 0.025, 0.05, 0.1, 0.2, 0.4 and 1.6 ppm phosphorus in solution. Amounts of phosphate required to establish the various concentrations of phosphorus were taken from a phosphate absorption curve based on equilibrating the original soil with several concentrations of phosphate in 0.01 M $CaCl_2$ for 6 days (Fig.1). The plots were initiated in July 1970 with corn as the initial crop, which however was destroyed by flooding. The soil was allowed to dry and new phosphate adsorption curves were contructed using data from fresh soil samples. In this exercise no evidence could be found of residual effects from the previously applied phosphate (Table 1). These results have important implications for alternate uses of paddy soils.

Phosphate was reapplied and rice was seeded. Yields of IR-8 and IR-22 rice were about 65% of maximum when no phosphate was added and were about 95% of maximum when phosphate was added to give 0.012 ppm P in solution equilibrated with the oxidized soil. (This gives about 0.07 ppm P in solution under strongly reduced conditions in the field).

Plots were kept flooded after the rice was harvested; ceramic filter candles were embedded in each plot; and, after several days of equilibration, solutions were withdrawn for phosphate analyses. A large syringe fitted with a small bore plastic tube was used to withdraw a 25 ml sample. The first samplings were discarded. The solution was injected below the surface of molybdate-sulphuric solutions. Phosphomolybdate blue colour was developed immediately in the field. Residual effects from the previously applied phosphorus fertilizers were now evident. The original phosphate adsorption curve was used to calculate amounts of phosphate fertilizer to re-establish phosphorus concentrations. Taro was planted in July 1972.

Plant tissue samples and soil solution samples from the filter candles were taken in March 1973. Residual phosphate fertilizer clearly increased phosphate concentrations in soil solutions eight months after fertilizer was applied (Fig. 2). Results were reasonable considering that only one filter candle was sampled per plot. The phosphorus range in fertilized plots was about 0.04 to 0.4 ppm – a much narrower range than was originally hoped for. Actual concentrations were higher than intended except for the two highest phosphorus levels. Solutions from the plot which received no phosphate fertilizer contained about 0.02 ppm phosphorus while the adsorption curve based on soil sampled taken before flooding (oxidized soil) indicated that the no P treatment should equilibrate at about 0.002 to 0.010 ppm P.

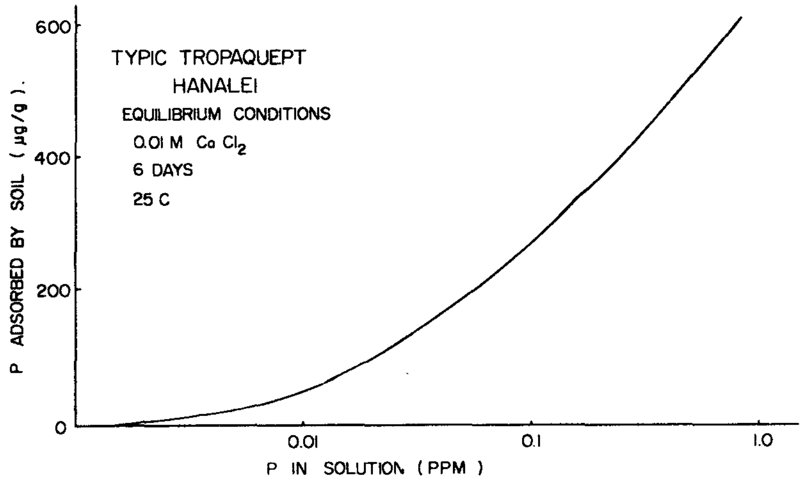

Fig 1. Phosphate adsorbed by the Hanalei soil in relation to phosphorus concentrations in equilibrated solutions. The soil had been drained for several years before this isotherm was constructed.

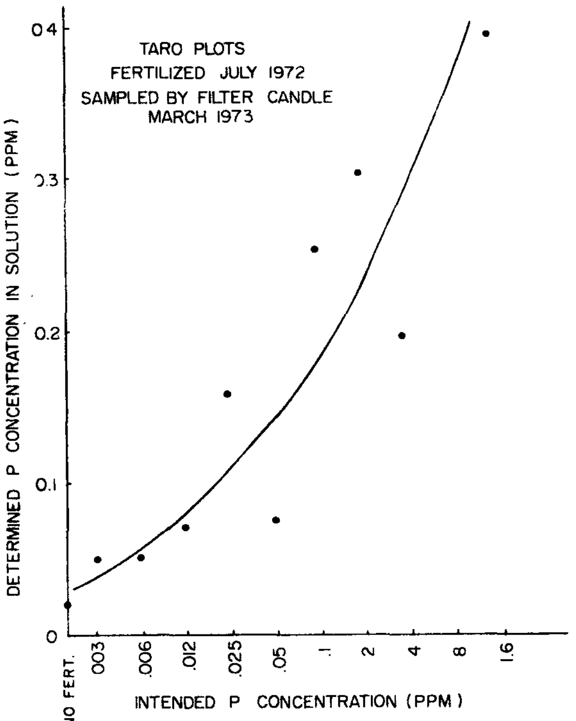

Fig 2. Phosphate concentrations of soil solutions extracted from field plots by means of filter candles in relation to intended concentrations of phosphate established by fertilizing 8 months earlier according to the phosphate adsorption curve illustrated in figure 1.

These data confirm the solubility effects of a reducing environment on phosphate. They also demonstrate that intensity of phosphorus nutrition from flooded alluvial soils can be inadequate. Not all flooded soils will equilibrate at such low phosphate concentrations. Soils in which 2:1 type clays predominate and in which soluble Si is high usually adsorb relatively much less phosphate than the soil investigated here. It follows then that phosphate released upon flooding should be more effective in increasing the phosphorus concentration of soils with 2:1 type clays.

Phosphate fertilization increased the phosphorus percentage of both leaf blades and petioles (Table 2). Leaf blades were less influenced by phosphate fertilization than were petioles which suggests that if foliar diagnosis is to be used, then petioles will be a superior indicator tissue for evaluating the adequacy of phosphorus nutrition. Visual observations of growth at 8 months indicate that most of the response from applied phosphate was attained with the treatment that was originally designed to give .006 ppm P in solution. The data suggest that the internal P requirement for taro vegetative growth is about 0.42% in the leaf blade or 0.16% in the petiole. This treatment was associated with about 0.05 ppm P in the soil solution 8 months after the taro was planted.

The foliar P data presented in Table 2 are in general agreement with composition of petioles and leaf blades of upland taro which have been previously determined on Kauai (Table 3). The data for flooded taro demonstrate that petioles can accumulate phosphorus. The data on flooded taro presented in Table 3 evidently represent luxury phosphorus consumption at the 6 and 9 month sampling dates since high concentrations of phosphorus in the petioles were associated with elevated phosphorus contents of leaf blades as well.

The upland taro clearly responded to phosphate fertilization while there was little if any response to phosphate by flooded taro growing on Hauula Paddy soil (Table 3). Based on these results a value of 0.23 percent P in petioles at nine months age should indicate adequate phosphorus nutrition. This level was attained by adjusting phosphorus to 0.1 ppm according to the isotherm for oxidized soil (Table 2). The actual concentration of phosphorus in solution after flooding was probably about 0.16 ppm.

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TABLE 1

Phosphate added to plots in 1970 and 1971 before adjusting P levels and planting taro in 1972

Intended P concentration	(P added Kg/ha) 1970	1971
--	0	0
.003	26	36
.006	54	72
.012	116	113
.025	224	268
.05	358	274
.1	510	507
.2	698	752
.4	896	932
1.6	1434	1164

TABLE 2

Phosphorus content of taro leaves in relation to established levels of phosphate in soil solutions*

Treatment No.	Assumed P concentration in soil solution (ppm)	Leaf P (% dry weight) Leaf blade	Leaf petiole
1	No P added	.35	.11
2	.003	.36	.10
3	.006	.42	.16
4	.012	.41	.16
5	.025	.41	.16
6	.05	.42	.17
7	.1	.45	.23
8	.2	.39	-
9	.4	.46	.25
10	1.6	.42	.25

* Treatments 4 to 7 were replicated 3 times. All other treatments were unreplicated.

TABLE 3

Influence of phosphate fertilization on the yield and phosphorus composition of taro grown as upland and flooded crops*

P added (kg/ha)	Yield (t/ha)	Leaf blades				Petioles			
		Age in months							
		3	6	9	12	3	6	9	12
Upland (Hanamaulu)									
0	15	.23	.25	.24	.27	.12	.13	.12	.16
280	21	.34	.28	.29	.30	.16	.16	.28	.28
560	40	.34	.29	.31	.32	.24	.14	.23	.31
1120	30	.41	.28	.32	.38	.31	.15	.24	.46
Flooded (Hauula paddy)									
0	39	.49	.53	.36	.34	.33	.67	.42	.29
280	44	.46	.52	.38	.32	.38	.64	.48	.34
560	38	.48	.56	.39	.33	.37	.67	.47	.30
1120	49	.46	.57	.37	.34	.37	.64	.43	.29

* Unpublished data of Ramon de la Pena.