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EFFECTS OF DIFFERENT LEVELS OF N, P, AND K FERTILIZATION ON THE GROWTH AND YIELD OF UPLAND AND LOWLAND TARO (COLOCASIA ESCULENTA (L.) SCHOTT, VAR. LEHUA).

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EFFECTS OF DIFFERENT LEVELS OF N, P, AND K FERTILIZATION ON THE GROWTH AND YIELD OF UPLAND AND LOWLAND TARO (<u>COLOCASIA</u> <u>ESCULENTA</u> (L.) SCHOTT, VAR. LEHUA)

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By

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Finally, to my wife, Enriqueta, and children, Joy, Ramon, Jr. and Raynard Don without whose unceasing love, patience, and encouragements this work would have not been completed.

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ABSTRACT

Nitrogen, phosphorus and potassium were applied separately from 0 to 1120 kg/ha to upland and lowland taro. A 2 x 2 x 2 N-P-K interaction experiment was also conducted in pots using 0 and 15 grams of each element per plant.

Nitrogen fertilization increased the N contents of the taro leaves but decreased both the P and K contents. Applications of P fertilizer increased the P content in the leaves but decreased the K content. Potassium fertilization increased K and decreased Ca and Mg contents of the taro leaves. The N content of upland taro leaves increased with K fertilization but the N content of the lowland taro leaves decreased. Potassium in the leaves of lowland taro regardless of treatments was lower than the K content of upland taro due to the higher Ca and Mg contents of the lowland soil. Both upland and lowland taro plants exhibited luxurious P and K consumptions. The N, P, and K contents of the leaves, regardless of treatments, decreased with age.

The total N content of the soils was negatively related to the N fertilization, while soluble P and exchangeable K were directly related to the rates of P and K fertilizers applied.

Yields of both upland and lowland taro were significantly increased by N and P fertilization. Potassium fertilization increased the yields of upland taro only. Delayed harvesting up to

15 months increased the yields of lowland taro, while yields of the upland taro at 12 to 15 months old did not differ significantly. In the lowland taro, the significant yield increase due to fertilization was attributed to the increase in number and weight of the sucker corms. In the upland taro, however, yield differences among fertilized plots were attributed to the main corms.

Nitrogen fertilization decreased the density of both upland and lowland taro corms significantly. Phosphorus fertilization did not have significant effects on the corm density. Potassium fertilization increased the corm density, especially in the lowland. Protein content of the corms of upland and lowland taro which were fertilized with N increased by 53.5% over the control. In the pot experiments, the increase in protein content was 250%. The P and K contents of the corms also increased with P and K fertilization.

In the pot experiment, only N fertilization gave significant increases in the weights of the corms, roots and leaves of the plants. Nitrogen deficiency was observed in all plants which did not receive N fertilization. Analysis of the leaves showed that plants which received N had an average of 2.8% and 4.6% N in the petioles and blades, respectively, compared with 1.1% and 3.3% N in the petioles and blades of plants without N fertilization. No P and K deficiencies were observed.

The N, P, and K contents of the individual leaves showed a tendency to decrease from the youngest leaf to the oldest, except for P which increased from the youngest to the oldest when the P supply was not limiting.

Results of the experiments showed that soil and plant analysis can be used to evaluate the fertilizer requirements of taro. In soil analysis, however, other methods of extracting soil N should be used to give a reliable index for the N requirement of taro.

INTRODUCTION

Taro, *Colocasia esculenta* (L.) Schott, is a crop widely cultivated in most tropical and sub-tropical areas of the world. It is known as dasheen or eddoe in the West Indies (Gooding and Campbell, 1961), gabi or aba in most areas of the Philippines (Brown, 1951), arvi in India, kolkas or culcas in Egypt, tu chih, tsun chih or chiu in China and by a number of other names in many other places. Taxonomically, it belongs to the family Araceae which is composed of about 100 genera and 1500 species. There are about 100 varieties of taro in the Hawaiian Islands although Whitney, Bowers and Takahashi (1939) described only 74 in an effort to characterize and differentiate each of the important varieties. Brown (1951) listed about 80 varieties of taro in the Philippines, and an ancient Chinese book written about 400 B. C. listed 14 types of taro grown in China.

Records of taro cultivation date back to 400 B. C. It is used for food either as boiled, diced cubes or as "poi", a paste made from boiled, mashed corms allowed to ferment a day or more. It is also sliced and baked or made into taro chips. Dieticians have long recognized the unique properties of poi as baby food (Derstine and Rada, 1952; Miller, 1927, 1929; Miller, Bauer and Denning, 1952). Clinical studies conducted to determine the food properties of poi confirmed its value as food for normal, allergic, and potentially allergic babies (Glaser, Lawrence, Harrison and Ball, 1965).

Taro is of primary importance in the Pacific Basin because it is the staple food of most of the inhabitants (Goodale, 1966; Clay[1/], 1966; Massal and Barrau, 1955). In most of Asia and Africa, it is used as a vegetable similar to potato or sweet potato. In the Hawaiian Islands it is still an economically important crop despite the rapidly declining acreage devoted to its production (Akana, 1932; Bowers, 1965; MacCaughey, 1916, 1917a, 1917b; MacCaughey and Emerson, 1913, 1914; Rada, 1952).

Investigations conducted on the nutritional requirements of taro are few, however, available publications show that it responds readily to fertilization especially when it is grown in highly leached, tropical latosols (Wright, 1963; Wright and Van Westerndorp, 1965; Hodnett, 1958). Small plot experiments in Niue Island showed responses to N, P, and K fertilizers. Izawa and Okamoto (1961) also showed that yields increased with N applications but additions of K with N did not give significant yield increases. They also showed that total sugars in the corms and leaves of the plant are affected by fertilization. Percentages of total sugars and reducing sugars tended to decrease with N and K fertilization, but the total amount of both components increased in the tissues. The

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[1/] Horace Clay, Program Director, Institute of Technical Interchange, East-West Center, Honolulu, Hawaii. Personal communications.

decrease in percent sugars in the corms and leaves was probably due to dilution effect of increased growth and yield. Total nitrogen in the corms and leaves of both main and sucker plants also increased as nitrogen fertilizer was increased. In a recent paper on taro, Bowers, Plucknett and Younge (1964) showed that the quality of taro corms in terms of flour and poi yields increased with specific gravity. Percent poi in taro was also found to decrease with fertilization especially when the source of nitrogen was sodium nitrate (McGeorge, 1912).

The ability of the taro plant to thrive under conditions otherwise adverse for most crops makes it an ideal subsistence crop for areas where advanced agricultural technology is lacking. It can survive both in waterlogged and upland conditions. This ability to survive under waterlogged and highly reduced conditions is allegedly due to the ability of the plant to transport oxygen which is vital to normal root functioning from the leaves to the roots. This also accounts for the ability of the plant to withstand reduced soil conditions. Yamasaki (1952) showed that it can endure Eh values up to -0.29 volts. The movement of O_2 from the leaves of rice had been demonstrated with isotopes of oxygen but this phenomenon has yet to be shown in taro (Jensen, Stolzy and Letey, 1967).

The main objectives of this research were (1) to obtain information bearing on the nutritional requirements of the taro plant, (2) to determine the growth and nutrient uptake of taro as influenced by N, P, and K fertilization, (3) to determine the effects of fertilizers on corm quality, and (4) to study the relationships of pH, total N, soluble P and exchangeable cations of the soils and composition of taro leaves and corms.

LITERATURE REVIEW

Although man's attempts to evaluate and improve the fertility of the soil to increase the yields of his crops may have began earlier than recorded history, written records date back to hundreds of years B. C. which testify to the great efforts spent for this particular phase of agriculture. Even before man began to fully understand the factors involved in the nutrition and growth of plants, and before instrumentation advanced to enable agricultural scientists to measure soil properties with adequate precision, such practices as liming, fertilization or manuring, crop rotation and fallowing had been practiced.

As a result of the advances in science, the following methods were employed and modified for evaluating soil fertility and plant nutrition:

(a) Bio-assay method which often uses lower forms of plants like algae and fungi, although higher forms of plants are also used in some instances (Kitchen, 1948; Tisdale and Nelson, 1966). Bio-assay has been used mainly to determine micronutrient availability in soils. Although fairly sensitive, it is also tedious and subject to adverse or toxic effects of other elements in the soil extract, i.e. aluminum toxicity (Velasco, de la Fuente and de la Pena, 1960; Plucknett, Moomaw and Lamoureux, 1963).

(b) Visual deficiency symptoms is widely used in the field

(Sprague, 1964; Wallace, 1962; Malavolta, Haag, Mello and Brasil Sobro, 1962; Bonner and Galston, 1952; Meyer and Anderson, 1952), and is very useful when employed by well trained and experienced personnel. Symptoms exhibited vary with type of crop and different field and climatic conditions. Visual symptoms are important as an indicator for future requirements of the field, since it is often too late to correct deficiencies when symptoms become visible and distinct.

(c) Soil chemical analysis has the advantage of providing farmers and investigators a measure of the potential of the field under study. Soil analysis when correlated with yield or crop response is also very useful in forming a fertilization program for wide areas and a number of crops (Bray, 1948; Stanford, Ayres and Doi, 1965; Anderson, 1960; Forsee, 1951; Nelson, Reed and Munson, 1960; Kamprath and Fitts, 1960). Soil analysis has drawn criticism from some plant scientists because plants spend energy in the absorption of nutrients required for their growth from the soil, whereas soil analytical methods often employ dilute acids, bases and neutral salts for extracting the nutrients being studied from the soils (Clements, 1962, 1964; Bray, 1948).

Publications correlating soil chemical analyses to crop responses are numerous. For each of the essential elements, works had been published dealing with the levels of these nutrients in the soil and their relationship with crop absorption and yields. Bray

(1948) published a comprehensive paper covering the aims and concepts of soil testing. He also presented the requirements for a successful soil testing program for determining fertilizer requirements of crops. Earlier works on the nitrogen nutrition of plants and soil testing procedures for predicting nitrogen fertilization were not very successful. Some authors found soil analysis for nitrogen inconclusive (Allison, 1955; Pack and Gomez, 1956). Total soil nitrogen was found to be inaccurate as a means of predicting N requirements. Due to difficulties met in using total nitrogen data for fertilizer programs, a new method was devised whereby the amount of mineralizable nitrogen, either as ammonia or nitrate, or both, was used to predict the nitrogen fertilizer needs of soils (Fitts, Bartholomew and Heidel, 1955; Stanford and Hanway, 1955; Hanway and Dumemil, 1955; Stanford, Ayres and Doi, 1965). Boswell, Richer and Casida (1962) also found that microbiological methods using *Pseudomonas aeruginosa* and several other methods for determining the nitrifying capacity of soils gave significant correlations with soil nitrogen supply.

Phosphorus has received attention by many workers trying to find a reliable and precise method of predicting fertilizer needs of crops. Different methods of extracting soil phosphorus have been investigated, and values which may give responses to phosphorus fertilization had been presented for several crops and soils (Bingham, 1962, 1963; Bray and Kurtz, 1945; Breland and

Sierra, 1962; Chang and Jackson, 1957, 1958; Chang and Juo, 1963; van Diest, 1963, 1963a; Eik, Webb, Black, Smith and Pesek, 1961; Patel and Metha, 1961; Payne and Hanna, 1965; Susuki, Lawton and Doll, 1963; Vajragupta, Haley and Melsted, 1963). Bray and Kurtz (1945) were pioneers in fractionating the different forms of soil phosphorus and in devising methods of extracting and relating soil values found with plant needs and fertilizer programs. The modern use of radioactive isotopes has also gained attention in greenhouse and field studies (Bouldin and Black, 1960). Exchange resins were also employed in extracting soil phosphorus and results were used in predicting yields and crop response to phosphorus fertilization (Cooke and Hislop, 1965).

Different methods have been investigated for determining the availability of soil potassium to plants and predicting the fertilizer needs of soils (Benson and Toth, 1963; Ramamoorthy and Paliwal, 1965; Richards and MaClean, 1961; Schmitz and Pratt, 1953; White and Leaf, 1964, 1965).

Similarly, calcium, magnesium, sulfur and the micronutrients have been investigated and methods of extracting and predicting the soil supplying power for these elements have been reported (Fox, Olson and Rhoades, 1964; Mehlich and Reed, 1946; Nearpass and Drosdoff, 1952; Nearpass and Clark, 1960; Sanford and Lancaster, 1962).

(d) Plant tissue analysis has been found very important especially in programming fertilizer requirements of long maturing crops or perennials like oranges, apples, dates, sugarcane (Clements, 1957, 1958, 1959a, 1959b, 1961; Chapman, 1960; Heeny and Hill, 1961; de Villiers and Beyers, 1961; Willson, 1961; Malavolta and Gomes, 1961; Smith, 1962) and even short maturing crops like sugar beets, tobacco, potato, corn, rice, wheat, oats, barley, tomato, banana and other vegetables (Heeny and Hill, 1961; Ulrich, 1943, 1961; Lorenz, Tyler and Fullmer, 1964; Twyford and Coulter, 1964; Bould, 1964; Lorenz, 1965; Hanway and Dumemil, 1965; Tucker, 1965; Follet, 1965). This method has the advantage of being able to predict the immediate needs of a crop at any stage in the growth of the plant. Plant tissue analysis or foliar diagnosis as it is often known is based on the principle that the plant should be the best index for the complex system of soil-plant and climate, thus a plant not deficient in an element should have in its tissues an ample amount of that element for growth and a marked decrease in its tissues of any element which is lacking in the growth medium (Thomas, 1937; Clements, 1959b, 1961, 1964; Hoagland, 1948; Lundegardh, 1951).

In sugarcane "crop-logging", Clements (1957, 1958, 1962; Clements and Kubota, 1942; Clements and Moriguchi, 1942) used several tissues as indices for different elements. In corn, Tyler, Van Maren, Lorenz and Takatori (1964) found that yield and nitrogen content of leaves increased with increased rates of nitrogen fertilization. Zink and Yamaguchi (1962) did not find significant increases in total nitrogen content of head lettuce with varying rates of nitrogen application. They found, however, that fluctuations in the composition of the crop is related to age of the crop, that is, the nutrient composition decreased as the plants approached maturity.

Lowland rice when fertilized with nitrogen up to 30 kg/ha did not show increased nitrogen content of the leaves (Reyes, Davide, Orara and Calixihan, 1962). At the International Rice Research Institute (1965), the nitrogen content of the grain and straw at harvest was significantly correlated with yield.

Studies on phosphorus and potassium content of plant tissues and their effect on yield are numerous. Generally, increasing phosphorus fertilization brings about increased phosphorus in plant tissues, and the same holds true for K. Fertilizer experiments in rice showed that P content of both grain and straw was significantly correlated with extractable P (I.R.R.I., 1965). Potassium uptake by sugarcane was significantly correlated with fertilization and soil K extracted by 0.1 N HCl solution (Ricaud, 1965).

The taro plant: Neal (1965) describes the taro plant as " ... perennial herbs, consisting of a cluster of smooth, heart-shaped leaves, rising a foot or higher from underground tubers.

Leaf stems are a little longer than the blades and are attached to them slightly within the edge of the blade or to the edge. The top of the stem is bent, so the tip of the leaf points down. Some stems have variegated stripes or spots; some blades are white- or purple-mottled. The inflorescence consists of an open yellowish-white tube constricted below the middle and enclosing a large spike covered with flowers, sterile at the tip and middle, fertile male between, female below ... "

The variety Lehua is a commercially grown variety mainly under waterlogged conditions; however, it can also be grown under upland conditions. It is medium in height, well spreading, slender and matures within 8 to 12 months producing about 10 suckers. The petioles are yellowish-green reaching a length of 65 to 80 cm. The blades are sagittate, very smooth in outline and medium green. The corm flesh is light purple with dark purplish fibers and the skin is dark pinkish-lilac (Whitney, Bowers and Takahashi, 1939).

MATERIALS AND METHODS

Field Experiments

Nitrogen, phosphorus and potassium fertilization

Field experiments were conducted on the Island of Kauai. The lowland paddies were located in Hanalei Valley, the major taro producing area of the state. The site is about 3 m above sea level with an average annual rainfall of 230 cm. The soil used is classified as a Hauula Paddy. Chemical properties of the soil are shown in Table 1.

Soil descriptions from the Territory of Hawaii Soil Survey Manual (Cline *et al*., 1955) gives the following:

(a) Hauula Paddy

> The Hauula Paddy soils have developed hydromorphic characteristics and a distinct compact zone of clay accumulation because of flooding and continuous cropping to taro or rice.
>
> These soils are mapped on the islands of Kauai, Maui, Molokai and Oahu. They occur on alluvium and are generally at low elevations. On Kauai the rainfall for these soils is 100 to 370 cm (40 to 150 in) per year, on Maui, 50 to 100 cm (20 to 40 in), on Molokai, 25 to 75 cm (10 to 30 in), and on Oahu, 50 to 175 cm (20 to 70 in). Climate does not influence the location of these soils, for their characteristics have been induced by man.
>
> Modal profile of the Hauula Paddy soils:
>
> A_1 0 to 9 inches, gray or grayish-brown silt loam mottled with yellowish brown; in dry paddies this horizon is coarsely granular and friable, but in flooded paddies it is mucky; the material is somewhat sticky when wet but not highly plastic; pH values range from 5.5 to 7.0.

Table 1. Analysis of Soils Used in the Field Experiment[1/]

	Lowland	Upland
pH	5.7	4.6
C.E.C. (meq/100 g O.D.)	17.4	24.5
Exch. Ca (meq/100 g O.D.)	9.8	1.5
Exch. Mg (meq/100 g O.D.)	3.9	0.4
Exch. K (meq/100 g O.D.)	0.32	0.26
Total N (%)	0.22	0.23
Ext. P (ppm)	319	9

[1/] Average of determinations from 36 plots.

B 9 to 15 inches, strongly mottled gray, yellow, and brown silty clay; very compact in place; clods have the appearance of dryness even under flooded paddies; strong fine to medium blocky structure; firm when moist and slightly to moderately plastic when wet; pH 5.5 to 7.0.

C 15 inches +, brown or grayish-brown silt loam or silty clay loam with low-contrast pale yellow and gray mottling; not compact in place; friable when moist and slightly to moderately plastic when wet; this is alluvial material comparable in origin to that of Haualei or Kawaihapai soils; pH mainly above 6.0.

Development of the B horizon varies greatly according to the length of time the land has been used for paddies. Apparently, the B horizon is induced primarily by compaction and some sedimentation of fine material that takes place during cultivation of the flooded areas. The B horizon is effective in retaining water. In some of the lower lying and naturally poorly drained areas the B horizon may be almost entirely lacking. Some areas of these soils occur on older alluvium.

From available chemical data, it appears that these soils accumulate exchangeable magnesium as cultivation continues. Waters used for flooding generally carry a considerable amount of soluble magnesium salts, and some of the heavier textured soils of this group are now very high in exchangeable magnesium ...

(b) Hanamaulu series

Soils of the Hanamaulu series are deep, well-drained Humic Latosols developed in alluvium on nearly level to sloping terraces along streams in East Kauai. They are associated with the Kapaa series and with Gray Hydromorphic soils developed on alluvium. Hanamaulu soils are less red in color than Kapaa soils.

The Hanamaulu soils occur between sea level and 230 m (750 ft) elevation with mean annual rainfall from 125 to 250 cm (50 to 100 in). They are used principally for sugarcane and all areas are cultivated.

Description of surface soil sampled:

0 to 6 inches, very dark grayish-brown clay that feels like silty clay, brown when dry; moderate, coarse, medium and fine granular structure; friable, sticky, very plastic; abundant roots; few small pebbles, slight effervescence with H_2O_2.

The field experiments were laid out in an incomplete factorial arrangement of treatments in a randomized complete block design which had three replications.

Fertilizer rates were 0, 280, 560, and 1120 kilograms per hectare of elemental materials using urea as source of N, treble superphosphate as source of P, and potassium sulfate for K. The N-treated plots received basic applications of 280 kg/ha each of P and K. The P-treated plots received basic applications of 280 kg/ha each of N and K and the K-treated plots received 280 kg/ha each of N and P. The control plots which were used for all three experiments were not fertilized.

Just before planting, one-third of the N and K and all of the P fertilizers were applied by hand-broadcasting, followed by a plowing-under of the fertilizers to incorporate the materials with the soil. The remaining N and K were applied in equal amounts two and four months after planting. The plots used were 4.5 x 6 m and the plants were spaced 45 x 60 cm.

Periodic plant and soil samples were collected. Plant samples consisted of the petioles and blades of the physiologically most active leaves of three plants per plot at ages of 3, 6, 9, and 12 months after planting. The index tissue was the number 3 leaf of the plant starting with a numbering of 1 for the spindle or unopened leaf (Ulrich et al., 1959), or in some instances the third leaf from the youngest open leaf when the spindle leaf is still covered completely by the first leaf.

Petioles and blades were analyzed separately for N, P, K, Ca, and Mg.

Preparation of Samples

Plant samples

Plant samples were collected between 9 and 11 o'clock in the morning. The petiole was severed from the plant at about 5 cm from the point of connection with the main "stem" or corm. Plant samples were weighed after collection, washed with tap water and rinsed thoroughly with distilled water. The samples were then placed in paper bags and dried in a force-draft oven at 75°C for about 48 hours. After drying, the samples were weighed again and then ground in a Wiley mill using a #20 mesh sieve. The ground samples were put in 4-oz bottles where they were stored for future analysis.

The samples were re-dried at 75°C for at least two hours prior to weighing 0.5 g sample for the analysis of nitrogen using the macro-Kjeldahl method and another 0.5 g sample for ashing and analysis of P, K, Ca and Mg.

Soil sample

Soil samples were collected to a depth of six to 10 inches using a hand borer. Samples were collected before planting and just before the first fertilizers were applied in the fields. Later samples were taken with the plant samples.

Soil samples were stored in 8-oz jars after air-drying and grinding to pass a 20 mesh sieve. Moisture factors were always determined for each sample during the course of the analytical work. Soil reaction or pH measurements were performed immediately after collecting the samples using a Beckman Model G pH meter. A 1:1 paste was prepared from each of the samples and allowed to equilibrate overnight before the pH measurements were done.

Planting Materials

Seed pieces (or "hulis") consisting of cut suckers of the variety Lehua[2/] were obtained and prepared for planting. The

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[2/] Hulis or planting materials planted in the upland field were provided by Mr. Harold Kobayashi of Hanalei, Kauai.

hulis were cut from each sucker leaving about 2 cm of corm and 20 to 30 cm of leaves and planted at a depth of about 8 cm in the upland field using a pineapple planter. The hulis were treated with captan before planting to prevent fungus infections.

In the lowland paddies, hulis were planted by sticking them into the mud to a depth of about 8 cm[3/].

The plots were arranged systematically to prevent nutrient movement from plots receiving higher fertilization to the control plots and other plots receiving lower rates of fertilization. The phosphorus-treated plots were assigned nearest the irrigation water inlet, followed by the potassium-treated plots, then the nitrogen-treated plots. Within each block, the control and plots receiving low rates of fertilization were assigned near the water inlets and the plots receiving the highest rates of fertilization were placed beside the irrigation water outlet. Growth patterns of the lowland crop showed that there was very little or no movement of nutrients from the plots as shown by the uniformity in growth response to the fertilizer treatments. Nevertheless, the outermost rows from all sides of the plots were used as guard rows and never sampled for tissue analysis or yields.

[3/] Hulis provided by Mr. Paul Say Dock, Hanalei, Kauai, who owns the lowland paddies used in this study.

In the upland field, a black plastic mulch was used to help control weeds. Strips of the plastic mulch, approximately 45 cm wide, were laid between the rows. The last block was covered entirely with the plastic material and seed pieces were planted by making holes through the mulch. Weeds growing along the rows with the taro plants were eliminated periodically by hand weeding. Weed control in the lowland paddy was done entirely by hand weeding.

Harvesting Procedure

At the age of 12 months, 15 plants were pulled from each plot in the upland and lowland areas. The corms of the main plants were separated from the corms of the suckers and total weight was determined. The number of sucker corms harvested was also recorded for each plot. Specific gravity measurement was done by "displacement" method. A cylindrical metal container with a known cross-sectional area was filled half-way with water. The water level before the corms were put into the container was noted and then the final water level was recorded. The difference between the two readings was multiplied by the cross-sectional area of the container to give the volume of the corms.

The harvesting procedure was repeated in both field at ages 14 and 15 months and all measurements were obtained in the same manner.

Core Sampling

Three main corms and five sucker corms were randomly sampled from the yield samples obtained from each plot. Core samples were taken by thrusting a No 9 cork borer through the apical and basal portions of the main corms. Sucker corms were pierced through the center. Fresh weight of the samples was taken after which the volume of the disks or core samples was determined by displacement using 100 ml graduate cylinder. The samples were sliced thinly and dried at 70-75°C in the oven.

After drying, the samples were weighed, ground and prepared for analysis of N, P, K, Ca and Mg.

Pot Experiment

N x P x K interaction

Twenty-four five-gallon cans were filled with about 15 kg of air dried soils taken from the Waimanalo Experiment Station of the University of Hawaii. The soil used is classified under the Waimanalo series of the Low Humic Latosol Great Soil Group (Cline *et al.*, 1955). A completely randomized 2 x 2 x 2 N-P-K interaction was set up with three replications. Rates of fertilizers used were uniform for N, P, and K being 0 and 15 grams of each element per pot (approximately equivalent to the 560 kg/ha rate in the field experiments). Just before planting, one-third of the N (urea) and K (potassium sulfate) and all of the P (treble superphosphate) were incorporated with the soil. The remaining N and K were applied in equal amounts two and four months after planting.

Hulis which were previously dipped in a dilute solution of PMA (phenylmercuric acetate) were planted at one plant per pot.

Plant samples were collected at two and four months. The same "index tissue" used in the field experiments was taken for chemical analysis. At the age of six months, the plants were harvested for analysis. The corms, roots, petioles and blades were separated and analyzed for N, P and K. The individual leaves were also separately analyzed to determine variations in contents of the elements under study within each plant. Harvesting was done by pulling out the individual plants and washing them with water to remove the soil from the roots.

All plant samples were prepared in the same manner as those from the field experiments. Periodic observations of both field and pot experiments were made and visual symptoms of deficiency and growth patterns were noted.

Nitrogen was analyzed by the Kjeldahl method modified to include nitrates. Phosphorus was determined colorimetrically while K was analyzed using a flame photometer (Beckman Model DU). Calcium and Mg were analyzed by a complexometric method using EDTA. Complete methods of analysis for both plant and soil samples are given in Appendix pages 114 to 131.

Appropriate statistical analysis of the data was performed. Analysis of variance was used for determining the response of the crops to fertilization. The influences of fertilization on the composition of the tissues and on the chemical analysis of the soils were determined by correlation and regression analyses (Fisher, 1958; Snedecor, 1956). The correlation and regression analyses were calculated by using the computer at the Statistical and Computing Center of the University. Correlation coefficients, regression coefficients and other statistical data were tabulated and are shown in Appendix Tables 1 to 15.

RESULTS AND DISCUSSION

Nitrogen Fertilization

Effects of N fertilization on soil pH, total N, soluble P and exchangeable cations and on plant composition

Tables 2 and 3 show the effects of increasing rates of N fertilization on the pH, total N, soluble P and exchangeable K, Ca and Mg of upland and lowland soils. The total N content of the upland soils tended to increase with increasing N fertilization and time, however, the increases were not statistically significant. The pH and exchangeable Ca decreased significantly when N was applied, whereas the decrease in exchangeable Mg was not significant. Exchangeable K and soluble P decreased, but the decreases were not due to fertilization but to age, that is, the amounts of exchangeable K and soluble P in the soil decreased with time (Table 2 and Appendix Table 12).

In the lowland soils, there was a significant increase in total N content due to increasing N fertilization up to 580 kg/ha, but at 1120 kg/ha, the total N content decreased. The decrease in exchangeable K and soluble P were highly significant, the exchangeable K decreases being due to both N applications and age while that of soluble P due to age alone (Table 3 and Appendix Table 12). Changes in soil pH, exchangeable Ca and Mg were not significant and the tendencies were to decrease with fertilization

Table 2. Effects of N Fertilization on the Upland Soils

Treatments kg/ha N	Months After Planting 0	3	6	9	12
			Total N (%)		
0 (control)	0.24	0.22	0.22	0.22	0.22
0	0.23	0.22	0.22	0.22	0.21
280	0.23	0.22	0.22	0.23	0.22
560	0.23	0.22	0.23	0.22	0.23
1120	0.23	0.22	0.24	0.24	0.22
			Extractable P (ppm)		
0 (control)	8.6	8.3	5.3	3.9	4.9
0	9.6	19.4	29.7	23.8	23.4
280	9.1	50.1	36.0	24.7	26.4
560	9.6	34.1	30.0	31.1	24.6
1120	7.6	36.6	33.0	28.8	23.1
			Exchangeable Ca (meq/100 g)		
0 (control)	1.92	1.87	1.61	1.39	1.73
0	1.73	2.38	2.01	1.90	1.88
280	1.40	2.26	1.52	1.46	1.44
560	1.48	1.88	1.35	1.29	1.16
1120	1.37	1.56	1.03	0.82	0.91
			Exchangeable Mg (meq/100 g)		
0 (control)	0.42	0.57	0.35	0.47	0.44
0	0.45	0.47	0.39	0.46	0.42
280	0.49	0.57	0.36	0.40	0.44
560	0.39	0.45	0.46	0.48	0.44
1120	0.40	0.47	0.36	0.29	0.33
			Exchangeable K (meq/100 g)		
0 (control)	0.26	0.21	0.23	0.18	0.15
0	0.26	0.55	0.66	0.29	0.31
280	0.26	0.62	0.75	0.30	0.35
560	0.24	0.43	0.81	0.30	0.24
1120	0.24	0.44	0.75	0.25	0.24
			pH (1:1 paste)		
0 (control)	4.67	4.58	4.69	4.47	4.54
0	4.69	4.70	4.79	4.58	4.55
280	4.59	4.41	4.54	4.43	4.41
560	4.60	4.40	4.41	4.31	4.30
1120	4.62	4.13	4.20	4.18	4.15

Table 3. Effects of N Fertilization on the Lowland Soils

Treatments kg/ha N	Months After Planting				
	0	3	6	9	12
			Total N (%)		
0 (control)	0.21	0.20	0.19	0.22	0.21
0	0.22	0.20	0.22	0.20	0.20
280	0.20	0.21	0.22	0.23	0.22
560	0.23	0.20	0.22	0.22	0.23
1120	0.19	0.19	0.18	0.19	0.19
			Extractable P (ppm)		
0 (control)	328	365	345	279	314
0	328	404	376	332	317
280	326	410	384	330	318
560	302	385	348	318	318
1120	303	372	354	329	309
			Exchangeable Ca (meq/100 g)		
0 (control)	9.34	8.85	8.70	8.72	8.12
0	9.81	8.99	7.97	8.23	6.97
280	8.72	8.44	6.76	8.13	7.10
560	9.71	9.21	7.35	6.98	8.48
1120	8.50	8.26	7.81	7.72	6.79
			Exchangeable Mg (meq/100 g)		
0 (control)	4.00	5.13	8.22	7.33	7.68
0	3.79	5.19	8.69	5.88	7.36
280	4.33	5.46	8.58	7.76	7.64
560	4.11	6.02	8.24	7.83	8.69
1120	3.52	6.91	7.78	5.33	6.60
			Exchangeable K (meq/100 g)		
0 (control)	0.29	0.28	0.18	0.15	0.12
0	0.29	0.34	0.40	0.24	0.13
280	0.39	0.33	0.25	0.20	0.13
560	0.25	0.30	0.23	0.18	0.14
1120	0.32	0.33	0.20	0.15	0.10
			pH (1:1 paste)		
0 (control)	5.27	6.75	6.75	6.55	6.46
0	5.65	6.54	6.42	6.32	6.32
280	5.51	6.55	6.37	6.25	6.54
560	5.47	6.52	6.49	6.24	6.41
1120	5.60	6.58	6.53	6.54	6.43

and age except for pH which tended to increase with N applications.

The composition of leaves of both upland and lowland taro was affected significantly by fertilization and age (Tables 4 and 5). In upland taro (Table 4 and Figure 1), only percent N in the petioles was increased significantly by fertilization. Percent P, K and Ca decreased with increasing N fertilization, while percent Mg tended to increase but the increase was not significant. In the blades, percent N and Mg also increased significantly when N fertilization was increased but decreased as the plants grew older. Nitrogen fertilization and maturity decreased the percentages of P, K, and Ca in the blades significantly (Appendix Table 12a).

Percent N and Mg in the petioles of lowland taro leaves showed significant increases due to N fertilizer and decreases due to maturation (Table 5). The effect of N applications on percent P and K of lowland taro leaves is similar to those obtained from the upland crop. Percent P and K decreased with increased fertilization and Ca decreased with age. Phosphorus content of the petioles increased also as the crop matured. The trends in the composition of the blades followed the same effects that fertilizer and age had on the composition of the petioles (Figure 2).

The effects of N fertilization on the growth of upland and lowland taro is shown in Table 6. Growth of the taro plants is characterized by a rapid increase in vegetative growth in the first

Table 4. Effects of N Fertilization on the Composition of Upland Taro Leaves

Treatments kg/ha N	Petioles				Blades			
	Age in Months				Age in Months			
	3	6	9	12	3	6	9	12
				Percent N				
0 (control)	1.25	1.12	0.80	1.29	3.75	3.27	3.09	3.43
0	1.00	1.04	0.77	1.11	3.64	3.30	3.02	3.32
280	1.63	1.20	0.73	1.11	4.09	3.80	3.33	3.20
560	2.28	1.72	0.82	1.18	4.45	4.14	3.69	3.46
1120	2.70	1.82	0.87	1.32	4.88	4.33	3.64	3.51
				Percent P				
0 (control)	0.11	0.16	0.16	0.20	0.23	0.26	0.25	0.27
0	0.31	0.41	0.43	0.38	0.36	0.34	0.31	0.34
280	0.16	0.16	0.28	0.28	0.34	0.28	0.29	0.30
560	0.16	0.14	0.18	0.28	0.32	0.28	0.29	0.31
1120	0.16	0.14	0.18	0.23	0.32	0.29	0.30	0.29
				Percent K				
0 (control)	8.40	7.30	3.32	4.76	4.73	5.27	3.91	4.03
0	10.70	7.99	6.53	6.85	5.52	5.30	4.90	4.40
280	10.13	7.85	5.77	5.33	5.70	5.79	4.77	4.05
560	9.15	7.10	4.19	4.50	5.07	5.46	3.92	3.72
1120	7.90	6.27	3.65	4.80	4.63	5.00	4.12	3.98
				Percent Ca				
0 (control)	1.19	0.87	0.72	1.08	1.39	1.24	1.16	1.63
0	1.06	0.71	0.57	0.88	1.29	1.03	1.21	1.44
280	0.87	0.66	0.57	0.76	1.17	0.92	0.92	1.25
560	0.95	0.83	0.57	0.81	1.20	0.95	0.89	1.32
1120	0.97	0.75	0.54	0.74	1.19	0.75	0.75	1.10
				Percent Mg				
0 (control)	0.10	0.15	0.13	0.14	0.18	0.13	0.22	0.24
0	0.10	0.12	0.10	0.12	0.15	0.11	0.19	0.21
280	0.11	0.13	0.12	0.14	0.18	0.15	0.19	0.23
560	0.12	0.18	0.12	0.15	0.19	0.17	0.20	0.23
1120	0.13	0.14	0.11	0.12	0.20	0.15	0.17	0.22

Table 5. Effects of N Fertilization on the Composition of Lowland Taro Leaves

Treatments kg/ha N	Petioles Age in Months				Blades Age in Months			
	3	6	9	12	3	6	9	12
				Percent N				
0 (control)	1.00	0.97	0.81	0.65	4.02	4.09	3.13	2.78
0	0.99	0.98	0.73	0.63	4.11	4.10	3.18	2.77
280	1.06	1.05	0.71	0.64	4.32	4.23	3.23	2.99
560	1.22	1.39	0.76	0.68	4.37	4.61	3.47	3.09
1120	1.38	1.81	0.87	0.61	4.77	4.96	3.69	2.98
				Percent P				
0 (control)	0.27	0.57	0.52	0.31	0.40	0.48	0.38	0.32
0	0.35	0.65	0.52	0.36	0.44	0.50	0.36	0.32
280	0.38	0.64	0.48	0.34	0.46	0.52	0.38	0.32
560	0.36	0.63	0.44	0.25	0.46	0.57	0.38	0.32
1120	0.25	0.58	0.44	0.24	0.44	0.56	0.34	0.31
				Percent K				
0 (control)	2.05	3.60	1.93	1.02	2.83	4.30	2.85	2.60
0	4.61	6.40	3.94	1.76	4.44	5.23	4.27	3.45
280	4.03	5.69	3.49	1.64	4.06	4.97	4.14	3.37
560	3.05	4.77	2.33	0.97	3.37	4.80	3.34	2.71
1120	2.30	3.90	1.44	0.85	2.99	4.53	2.70	2.46
				Percent Ca				
0 (control)	0.77	0.74	0.88	0.69	1.59	1.55	1.55	1.76
0	0.64	0.62	0.72	0.70	1.22	1.22	1.25	1.66
280	0.67	0.71	0.71	0.51	1.11	1.29	1.28	1.43
560	0.74	0.80	0.77	0.45	1.31	1.29	1.32	1.01
1120	0.85	0.74	0.64	0.42	1.43	1.22	1.27	1.02
				Percent Mg				
0 (control)	0.58	0.44	0.48	0.33	0.71	0.35	0.35	0.33
0	0.46	0.33	0.31	0.32	0.62	0.32	0.24	0.27
280	0.52	0.41	0.34	0.32	0.51	0.35	0.24	0.32
560	0.61	0.49	0.45	0.29	0.64	0.35	0.33	0.27
1120	0.56	0.49	0.45	0.32	0.62	0.33	0.38	0.29

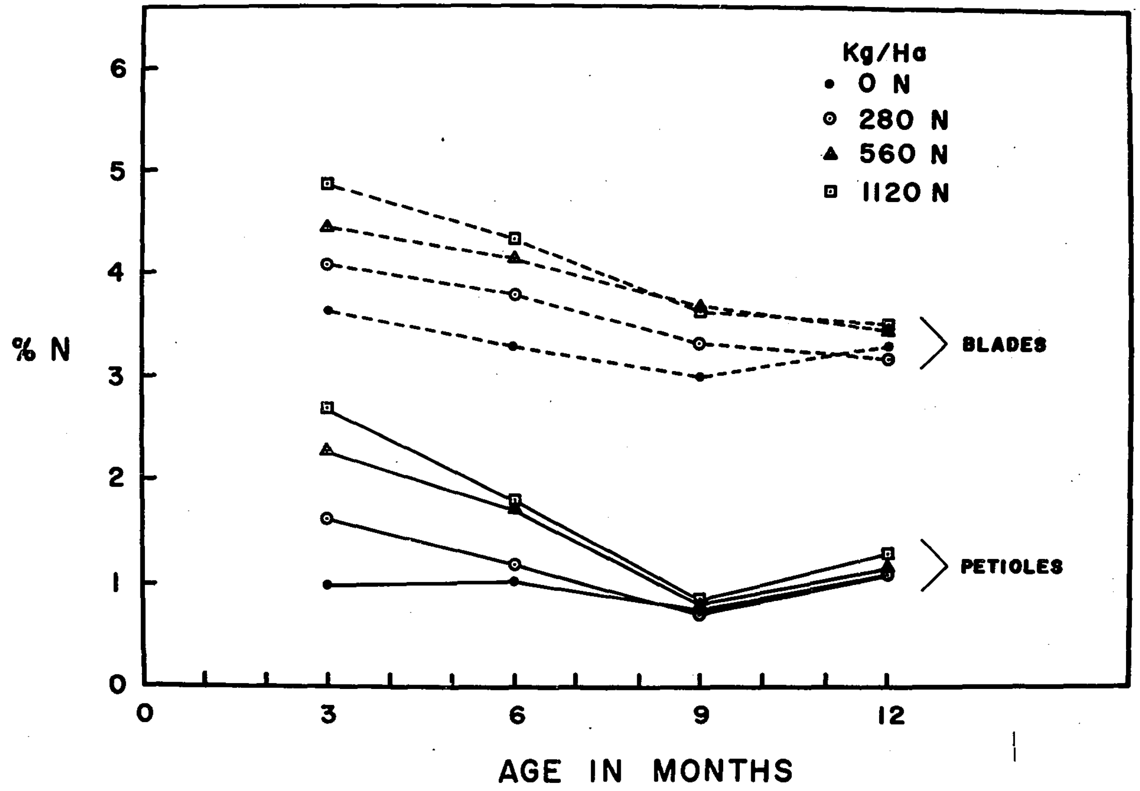

Figure 1. Percent N in Upland Taro Leaves as Influenced by Age and N Fertilization

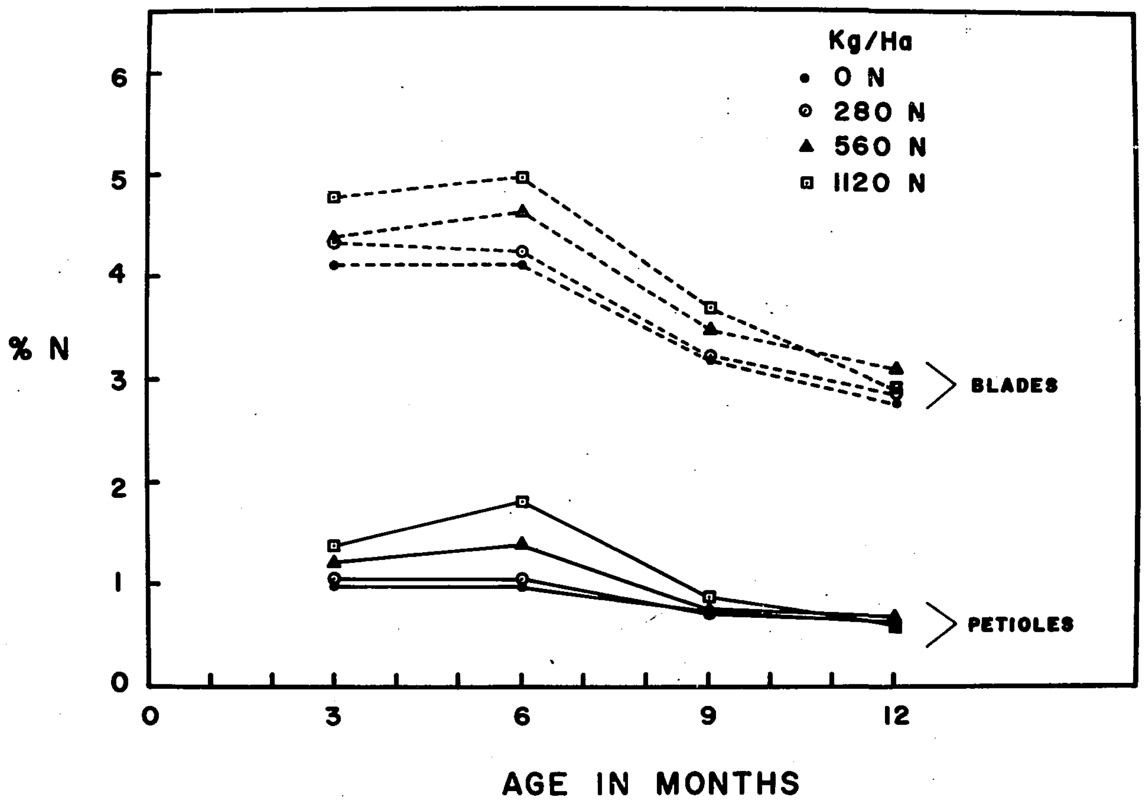

Figure 2. Percent N in Lowland Taro Leaves as Influenced by Age and N Fertilization

Table 6. Total Dry Weight Per Plant of the Blades, Petioles and Corms of Upland and Lowland Taro Fertilized With N

Treatments kg/ha N	Blades g/plant			Petioles g/plant			Corms g/plant		
	3 mos.	6 mos.	9 mos.	3 mos.	6 mos.	9 mos.	3 mos.	6 mos.	9 mos.
				Upland					
Control	2.1	1.4	3.5	2.2	1.6	5.4	8.4	20.3	16.6
0N	1.9	1.5	6.2	2.0	2.0	8.1	5.0	15.3	24.4
280N	9.2	7.9	6.6	7.0	11.0	11.4	11.2	80.9	156.5
560N	29.1	10.0	12.7	24.0	12.1	18.2	24.6	120.4	202.5
1120N	28.0	10.1	12.2	27.1	13.0	19.7	31.3	173.2	308.5
$\overline{x}$	14.1	6.2	8.2	12.5	7.9	12.6	16.1	82.0	141.7
				Lowland					
Control	10.7	7.2	10.0	14.8	11.1	13.8	11.1	75.4	120.8
0N	12.7	9.3	18.1	18.4	17.4	28.4	11.8	70.6	189.0
280N	29.4	13.3	21.3	43.2	30.4	30.4	21.1	80.4	205.0
560N	36.8	18.6	32.3	68.4	40.5	50.5	52.8	75.1	224.6
1120N	33.4	37.0	30.6	54.4	64.2	47.6	54.7	92.5	196.4
$\overline{x}$	24.6	17.1	22.5	39.8	32.7	34.1	30.3	78.8	187.2

3 to 5 months with the highest amount of dry matter produced per plant at the age of three months, followed by a decline in vegetative growth after five or six months. Corm production, however, increased from three months until maturity. Nitrogen fertilization increased not only the weight of corms produced by both upland and lowland taro but also the weight of petioles and blades produced per plant.

Results of the experiment show that total N is not a reliable index for determining the availability of soil N to the crop (Appendix Table 12). The results of plant tissue analysis, on the other hand, showed a highly significant correlation between nitrogen content of the tissues and yields (Appendix Table 12a). Stanford, Ayres and Doi (1965) used mineralizable N from incubated soil samples as an index in determining the N requirements of sugarcane. Pack and Gomez (1956) also found that total soil N was negatively correlated to the N content of alfalfa and cotton and suggested other means of extracting or measuring soil N for use as an index in N fertilization programs. The use of microbiological methods and analysis of mineralizable N both as NO_3 or NH_4 were successfully employed by several investigators (Fitts, Bartholomew and Heidel, 1955; Stanford and Hanway, 1955; Hanway and Dumemil, 1955; Hunter and Carter, 1965; Boswell, Richer and Casida, 1962).

The difficulties involved in the determination of N indices for use in fertilizer programs are due to the relative ease by which N is lost from the soil. Losses of soil N through leaching has been reported as high as 5 to 20% of applied fertilizer N and denitrification losses as high as 33% in a period of two years (Owens, 1960). Immobilization of soil N by soil microorganisms makes the situation more complicated since immobilized N is included in the analysis for total N.

Under paddy or waterlogged conditions, the loss of N through denitrification is not as high as the losses from the upland or well-drained soils; however, leaching would be the main factor in N losses.

The depressing effects of N fertilization on P, K and Ca content of petioles of both upland and lowland taro were probably due to a dilution effect brought about by increased growth of the plants with N fertilization. In rice, fertilization with relatively low rates of N showed that N contents of the leaves do not increase significantly (Reyes, Davide, Orara and Calixihan, 1962) and N content of control plants were higher than in fertilized plants (Steenbjerg effect). They also found that N, P, and K in leaves of rice decrease with age. The consistently lower concentration of nitrogen in the petioles of taro parallels the findings of Bould (1964) wherein the petioles of raspberry contained lower N than the blades. Rumberg, Wallace and Raleigh (1964) found that N of a meadow vegetation increased with N fertilization at early stages of growth, and at later stages of growth N fertilized plants contained less N, as percent, than control plants. Increased rate of growth of plants at later stages resulted in a dilution of nutrient content of the tissues.

Working with corn, Nielsen, Carson and Hoffman (1963) found that N fertilization increased not only the N but also the P content of the tissues. Potassium in corn tissues decreased with N applications. In oats, N fertilization also increased P and K uptake (Grunes and Krantz, 1958). McLean, Adams and Franklin (1956) concluded that increased P and K uptake with addition of N is brought about by the increase in the cation exchange capacity of the plant roots.

Effects of N fertilization on yields of upland and lowland taro

The total yields in tons per hectare of upland and lowland taro as affected by increasing rates of N applications are shown in Table 7 and Figure 3. Statistical analysis of the yield data shows significant differences among means of different treatments both in the upland and lowland fields. In the upland crop, however, only increasing N fertilization increased the yields significantly whereas in the lowland, both fertilization and date of harvesting gave significant increases in the yields which seems to indicate that upland taro matures earlier than lowland taro. Harvesting upland taro at 12, 14 or 15 months gave no significant differences in total yields, while yields of lowland taro

Table 7. Yields in Tons Per Hectare of Upland and Lowland Taro as Influenced by N Fertilization[1/]

Treatments kg/ha N	Age at Harvest								
	12 Months			14 Months			15 Months		
	Main Plants	Suckers	Total	Main Plants	Suckers	Total	Main Plants	Suckers	Total
				Upland Taro					
0 (control)	6.12	0.57	6.69	5.68	0.50	6.18	5.82	1.50	7.32
0	8.39	1.28	9.67^{c}	10.27	0.36	12.63^{bc}	8.78	0.98	9.77^{c}
280	12.76	5.82	18.58^{ab}	14.72	6.55	21.27^{ab}	13.97	0.66	20.63^{ab}
560	13.21	9.35	22.56^{a}	14.09	8.31	22.40^{a}	15.63	9.91	25.54^{a}
1120	10.76	8.80	19.56^{ab}	8.76	8.47	17.23^{abc}	10.38	6.29	16.67^{abc}
				Lowland Taro					
0 (control)	8.23	15.83	24.06	9.93	19.04	28.97	11.29	21.20	32.49
0	8.00	16.73	24.73^{p}	11.45	25.40	36.85^{no}	11.06	22.08	33.14^{o}
280	9.89	22.92	32.81^{o}	11.90	29.38	41.29^{mn}	13.02	31.00	44.02^{m}
560	9.49	23.97	33.45^{o}	12.80	38.74	51.54^{kl}	12.75	37.66	50.41^{l}
1120	10.29	27.65	37.95^{mno}	11.78	43.23	55.01^{kl}	12.43	45.19	57.62^{k}

[1/] Differences among values (total yields) with the same letter in the superscript are not significant. Control data not included in statistical analysis.

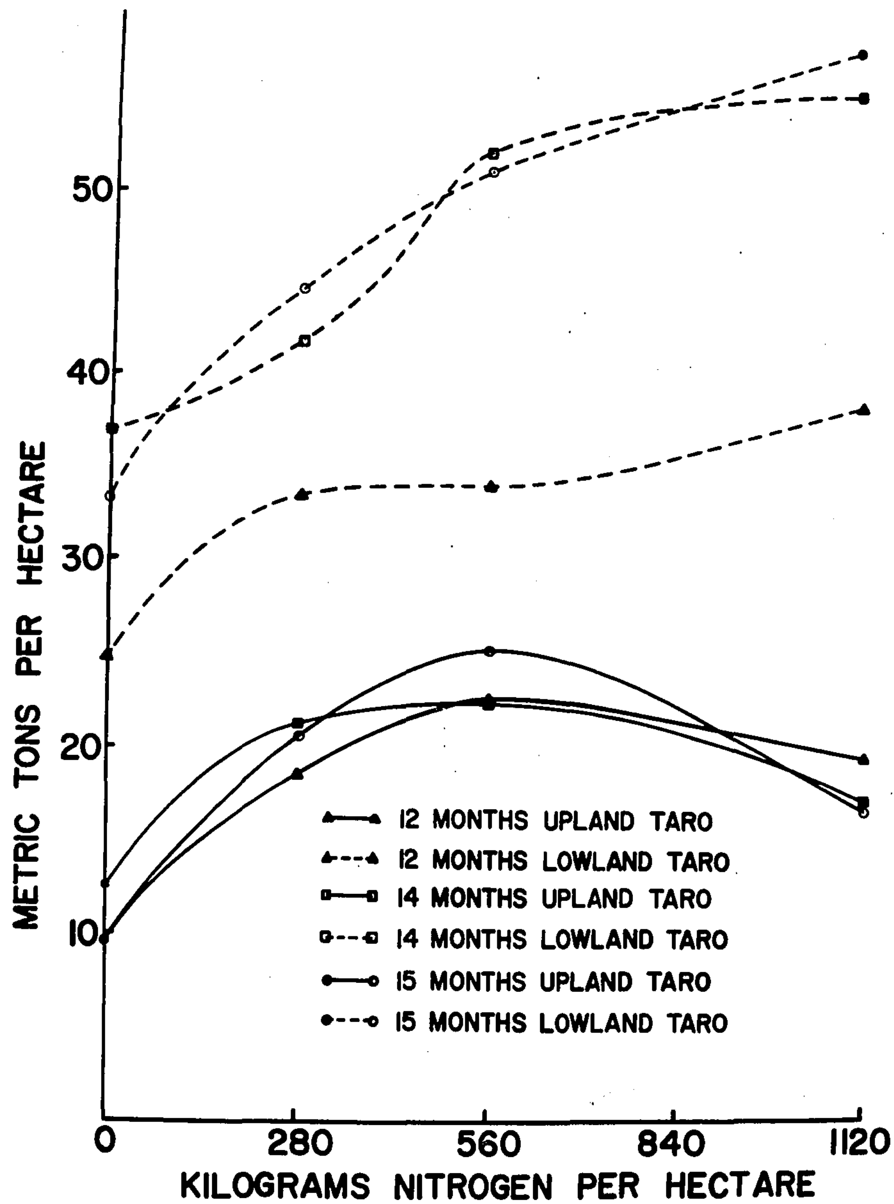

Figure 3. Effects of N Fertilization and Age on Total Yields of Upland and Lowland Taro

increased with time up to 14 months. In an irrigation experiment at the Kauai Experiment Station[4/], upland taro when given adequate supply of moisture by periodic irrigation matured later than when moisture supply is limiting.

The highest yields in upland taro were obtained from plots which received 560 kg/ha N. The yields at 280 kg/ha and 1120 kg/ha N were also higher than those from the control; the decrease in yields at the highest level of N was probably due to inadequate supply of other nutrients or an imbalance brought about by the excessive supply of N.

Highest of lowland taro yields were obtained from the plots given 1120 kg/ha N. Although the trends in yield increase for both crops were curvilinear, the highest rate of N application did not seem to upset the balance of nutrients in the lowland field since soil analysis of both fields showed that the lowland fields had higher exchangeable Ca and Mg, soluble P, and about the same level of exchangeable K. The cation exchange capacity of the lowland soil was lower, thus the percent base saturation of the lowland soil was much higher than that of the upland soil.

Effects of N fertilization on the quality of upland and lowland taro corms

Bowers, Plucknett and Younge (1964) found that quality of

[4/] Plucknett, D. L. and R. S. de la Pena. 1966. University of Hawaii. Unpublished data.

taro corms in terms of poi recovery is directly correlated to the specific gravity of the corms. Specific gravity of corms taken from both upland and lowland fields are shown in Table 8. Core samples were also taken from the same yields by means of a #9 cork borer, and specific gravity was measured. These data are presented in Table 8. Included in Table 9 are measurements of the percent dry matter content of the core samples.

Regression analysis of the effects of N fertilization and age at harvest for both lowland and upland crops shows that increasing rates of N fertilization tended to decrease the density of the main corms and sucker corms of both crops (Appendix Table 15). The corms of the lowland crop increased in density as harvesting was delayed which seems to account for part of the increase in yields of the lowland crop with delayed harvesting. Increases due to delayed harvesting were also significant for main corms of upland taro. Increases in density of both main and sucker corms of lowland taro were significant at the 1% level. The tendency of corms to decrease in density with N application was not statistically significant for either crop.

Measurements from core samples showed the same trends as those from the gross yields. The core samples from the apical portion of the main corms were denser than samples taken from the basal portion, especially from the lowland taro corms. Sucker corms gave higher specific gravity readings than main

Table 8. Effects of Age and N Fertilization on the Specific Gravity of Upland and Lowland Taro Corms

Treatments kg/ha N	Age at Harvest					
	12 Months		14 Months		15 Months	
	Main Corms	Sucker Corms	Main Corms	Sucker Corms	Main Corms	Sucker Corms
			Upland Taro			
0 (control)	1.074	1.105	1.090	1.148	1.105	1.125
0	1.090	1.095	1.100	1.150	1.098	1.186
280	1.075	1.113	1.097	1.123	1.100	1.107
560	1.079	1.084	1.087	1.126	1.104	1.084
1120	1.063	1.095	1.074	1.096	1.084	1.086
			Lowland Taro			
0 (control)	0.994	1.064	1.071	1.137	1.105	1.157
0	0.994	1.066	1.096	1.153	1.128	1.128
280	1.003	1.065	1.094	1.142	1.096	1.142
560	0.996	1.059	1.090	1.151	1.096	1.168
1120	0.970	1.046	1.079	1.143	1.107	1.147

Table 9. Specific Gravity and Percent Dry Matter of Core Samples from Upland and Lowland Taro Corms

Treatments kg/ha N	Upland Taro						Lowland Taro					
	Apex		Base		Sucker Corms		Apex		Base		Sucker Corms	
	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.
						12 Months						
0 (control)	1.202	39.6	1.158	35.8	1.153	34.8	1.116	45.1	0.954	43.0	1.114	43.0
0	1.115	37.9	1.125	36.5	1.132	37.5	1.116	43.0	0.929	40.4	1.074	41.3
280	1.115	36.7	1.142	35.4	1.133	36.3	1.133	44.9	0.860	37.2	1.070	43.3
560	1.147	37.1	1.146	35.1	1.151	35.5	1.132	44.5	0.843	35.1	1.086	42.9
1120	1.128	37.1	1.113	33.6	1.140	36.1	1.115	43.2	0.872	32.1	1.111	42.7
						14 Months						
0 (control)	1.104	31.4	1.089	29.6	1.098	27.2	1.167	42.6	1.007	38.9	1.196	42.0
0	1.090	30.2	1.104	31.4	1.111	32.0	1.169	42.7	1.002	39.1	1.166	41.5
280	1.103	32.6	1.093	29.4	1.084	30.9	1.183	41.3	1.001	36.5	1.177	41.8
560	1.106	32.6	1.076	28.1	1.113	32.4	1.175	43.7	0.985	32.7	1.161	43.4
1120	1.089	30.7	1.104	30.3	1.093	30.8	1.159	44.3	0.956	25.9	1.163	42.8
						15 Months						
0 (control)	1.139	31.0	1.129	30.6	1.129	32.7	1.133	43.7	0.964	37.0	1.108	42.3
0	1.135	28.7	1.103	26.5	1.147	36.0	1.123	40.8	0.979	35.8	1.108	39.8
280	1.132	30.9	1.107	27.0	1.111	28.6	1.134	41.9	0.976	34.9	1.122	40.6
560	1.093	28.0	1.098	26.2	1.124	31.7	1.132	43.8	0.912	28.8	1.143	44.4
1120	1.118	30.3	1.108	26.3	1.137	30.6	1.138	44.7	0.975	29.2	1.137	44.8

corms.

It is interesting to note that correlation studies on the relationship between specific gravity and percent dry matter content of the core samples showed that specific gravity and percent dry matter of upland taro corms are highly correlated with correlation coefficients of 0.626** and 0.681** for the apical and basal portions of the main corms, respectively, and 0.761** for the sucker corms (Appendix Table 10).

In the lowland corms, however, correlation coefficients for the apical and basal portions of the main corms are 0.069 and 0.085, respectively, and 0.110 for sucker corms, none of which is significant.

Phosphorus Fertilization

Effects of P fertilization on soil pH, total N, soluble P and exchangeable cations and on plant composition

Applications of P up to 1120 kg/ha increased the pH of the upland soils significantly. Exchangeable Ca and soluble P were also increased significantly (1% level) by P fertilization. Exchangeable Ca decreased with time whereas soluble P tended to increase, but the increase was not statistically significant. Exchangeable K and Mg and total N in the soil tended to decrease with P fertilization and time, with the decreases due to time being significant for both exchangeable K and Mg and not significant for total N (Table 10).

In the lowland soil (Table 11), exchangeable K, total N and soluble P all increased significantly. Increases in exchangeable Ca were not statistically significant. There was a tendency for both pH and exchangeable Mg to decrease with increased P fertilization, however, statistical analysis also showed that the decreases were not significant (Appendix Table 13).

Leaf composition of upland and lowland taro fertilized with increasing rates of P are shown in Tables 12 and 13 and Figures 4 and 5. The percent P in petioles of upland taro was directly related to P fertilization while other elements studied were negatively affected by P applications. Both percent K and Ca decreased significantly as the rate of P fertilizer increased. Decreases in percent N and Mg due to fertilizer P were not significant.

Age of plants when samples were collected also affected the composition of petioles. Percent N, P, K, and Ca decreased in the petiole with age, while percent Mg increased but not significantly. In leaf blades, N, P and Ca increased with P fertilization but only the increase in percent P was significant. Decreases in percent K and Mg due to fertilizer P were not significant.

Similarly, the composition of the petioles of the lowland crop was influenced by P fertilization and age. The decrease in

Table 10. Effects of P Fertilization on the Upland Soils

Treatments kg/ha P	Months After Planting				
	0	3	6	9	12
			Total N (%)		
0 (control)	0.24	0.22	0.22	0.22	0.22
0	0.24	0.22	0.23	0.23	0.22
280	0.23	0.22	0.22	0.23	0.22
560	0.23	0.22	0.22	0.22	0.22
1120	0.23	0.21	0.22	0.22	0.22
			Extractable P (ppm)		
0 (control)	8.6	8.3	5.3	3.9	4.9
0	8.8	9.3	5.0	5.3	5.3
280	9.8	50.3	36.0	24.7	26.0
560	9.4	54.0	88.0	40.7	95.3
1120	9.7	129.0	122.7	117.0	158.7
			Exchangeable Ca (meq/100 g O.D.)		
0 (control)	1.92	1.87	1.61	1.39	1.73
0	1.84	1.86	1.31	1.36	1.37
280	1.40	2.26	1.52	1.46	1.44
560	1.46	2.33	2.01	1.80	2.78
1120	1.42	3.42	2.89	2.96	3.08
			Exchangeable Mg (meq/100 g O.D.)		
0 (control)	0.42	0.57	0.35	0.47	0.44
0	0.46	0.44	0.36	0.49	0.46
280	0.49	0.57	0.36	0.40	0.44
560	0.51	0.51	0.39	0.38	0.44
1120	0.50	0.47	0.40	0.41	0.41
			Exchangeable K (meq/100 g O.D.)		
0 (control)	0.26	0.21	0.23	0.18	0.15
0	0.26	0.85	0.58	0.41	0.28
280	0.26	0.62	0.75	0.30	0.35
560	0.30	0.88	0.75	0.35	0.34
1120	0.28	0.52	0.64	0.36	0.31
			pH (1:1 paste)		
0 (control)	4.67	4.58	4.69	4.47	4.54
0	4.58	4.53	4.47	4.42	4.40
280	4.58	4.41	4.54	4.43	4.41
560	4.51	4.37	4.59	4.41	4.57
1120	4.53	4.61	4.69	4.54	4.58

Table 11. Effects of P Fertilization on the Lowland Soils

Treatments kg/ha P	Months After Planting 0	3	6	9	12
			Total N (%)		
0 (control)	0.21	0.20	0.20	0.22	0.21
0	0.22	0.19	0.17	0.20	0.21
280	0.20	0.21	0.22	0.23	0.22
560	0.23	0.24	0.24	0.23	0.23
1120	0.22	0.21	0.22	0.19	0.22
			Extractable P (ppm)		
0 (control)	328	365	345	279	314
0	339	415	317	305	301
280	326	410	384	330	318
560	317	441	392	305	340
1120	327	468	427	350	372
			Exchangeable Ca (meq/100 g O.D.)		
0 (control)	9.34	8.85	8.70	8.72	8.12
0	9.94	8.96	7.91	8.62	7.54
280	8.72	8.44	6.76	8.13	7.10
560	10.17	10.63	10.10	9.47	8.78
1120	10.59	9.31	8.58	7.18	7.24
			Exchangeable Mg (meq/100 g O.D.)		
0 (control)	4.00	5.13	8.22	7.33	7.68
0	3.93	6.10	6.47	6.39	6.89
280	4.33	5.46	8.58	7.76	7.64
560	3.90	5.71	7.36	7.17	6.64
1120	3.74	6.70	6.32	5.95	7.55
			Exchangeable K (meq/100 g O.D.)		
0 (control)	0.29	0.28	0.18	0.15	0.12
0	0.36	0.34	0.19	0.18	0.10
280	0.39	0.33	0.25	0.20	0.13
560	0.33	0.39	0.33	0.21	0.13
1120	0.40	0.37	0.31	0.19	0.12
			pH (1:1 paste)		
0 (control)	5.77	6.75	6.75	6.55	6.46
0	5.72	6.62	6.64	6.53	6.56
280	5.51	6.55	6.37	6.25	6.54
560	5.61	6.70	6.46	6.63	6.65
1120	5.85	6.58	6.37	6.25	6.31

Table 12. Effects of P Fertilization on the Composition of Upland Taro Leaves

Treatments kg/ha P	Petioles				Blades			
	Age in Months							
	3	6	9	12	3	6	9	12
	Percent N							
0 (control)	1.25	1.12	0.80	1.29	3.75	3.27	3.09	3.43
0	2.48	1.70	0.84	1.25	4.38	3.99	3.53	3.53
280	1.63	1.20	0.73	1.11	4.09	3.80	3.33	3.20
560	2.12	1.48	0.83	1.32	4.23	3.99	3.68	3.74
1120	2.00	1.21	0.77	1.22	4.28	3.72	3.16	3.66
	Percent P							
0 (control)	0.11	0.16	0.16	0.20	0.23	0.26	0.25	0.27
0	0.12	0.13	0.12	0.16	0.23	0.25	0.24	0.27
280	0.16	0.16	0.28	0.28	0.34	0.28	0.29	0.30
560	0.24	0.14	0.23	0.31	0.34	0.29	0.31	0.32
1120	0.31	0.15	0.24	0.46	0.41	0.28	0.32	0.38
	Percent K							
0 (control)	8.40	7.30	3.32	4.76	4.73	5.27	3.91	4.03
0	10.90	8.68	5.67	6.20	5.39	5.38	4.65	4.15
280	10.13	7.85	5.77	5.33	5.70	5.79	4.77	4.05
560	9.67	7.26	5.12	5.51	5.70	5.23	4.59	3.93
1120	8.77	7.08	4.60	5.27	5.50	5.13	4.50	4.11
	Percent Ca							
0 (control)	1.19	0.87	0.72	1.08	1.39	1.24	1.16	1.63
0	0.99	0.77	0.68	0.81	1.13	0.89	1.04	1.27
280	0.87	0.66	0.57	0.76	1.17	0.92	0.92	1.25
560	0.87	0.71	0.56	0.78	1.16	0.95	0.95	1.23
1120	0.94	0.82	0.53	0.90	1.27	0.96	1.11	1.35
	Percent Mg							
0 (control)	0.10	0.15	0.13	0.14	0.18	0.13	0.22	0.24
0	0.09	0.13	0.10	0.16	0.16	0.14	0.20	0.26
280	0.11	0.13	0.12	0.14	0.18	0.15	0.19	0.23
560	0.13	0.12	0.13	0.15	0.18	0.14	0.20	0.25
1120	0.13	0.12	0.10	0.12	0.19	0.14	0.17	0.20

Table 13. Effects of P Fertilization on the Composition of Lowland Taro Leaves

Treatments kg/ha P	Petioles				Blades			
	Age in Months							
	3	6	9	12	3	6	9	12
				Percent N				
0 (control)	1.00	0.97	0.81	0.65	4.02	4.09	3.13	2.78
0	1.31	1.17	0.74	0.62	4.74	4.44	3.30	3.07
280	1.06	1.05	0.71	0.64	4.32	4.23	3.23	2.90
560	1.16	1.19	0.73	0.66	4.61	4.46	3.50	2.99
1120	1.10	1.27	0.74	0.70	4.28	4.42	3.43	3.06
				Percent P				
0 (control)	0.27	0.57	0.52	0.31	0.40	0.48	0.38	0.32
0	0.33	0.67	0.42	0.29	0.49	0.53	0.36	0.34
280	0.38	0.64	0.48	0.34	0.46	0.52	0.38	0.32
560	0.37	0.67	0.47	0.30	0.48	0.56	0.39	0.33
1120	0.37	0.64	0.43	0.29	0.46	0.57	0.37	0.34
				Percent K				
0 (control)	2.05	3.60	1.93	1.02	2.83	4.30	2.85	2.60
0	5.02	6.00	2.33	1.33	4.45	4.70	3.32	3.08
280	4.03	5.69	3.49	1.64	4.06	4.97	4.14	3.37
560	3.85	5.63	2.52	1.26	4.10	4.83	3.45	2.76
1120	3.75	5.00	1.93	1.00	3.94	4.83	3.12	2.56
				Percent Ca				
0 (control)	0.77	0.74	0.88	0.69	1.59	1.55	1.55	1.76
0	0.61	0.69	0.74	0.56	1.09	1.24	1.21	1.42
280	0.67	0.71	0.71	0.51	1.11	1.29	1.28	1.43
560	0.66	0.79	0.71	0.49	1.10	1.37	1.23	1.37
1120	0.66	0.67	0.71	0.53	1.13	1.27	1.32	1.28
				Percent Mg				
0 (control)	0.58	0.44	0.48	0.33	0.71	0.35	0.35	0.33
0	0.60	0.44	0.37	0.31	0.64	0.37	0.30	0.29
280	0.52	0.41	0.34	0.32	0.51	0.35	0.24	0.32
560	0.45	0.45	0.39	0.31	0.52	0.35	0.28	0.35
1120	0.53	0.46	0.39	0.31	0.55	0.35	0.31	0.30

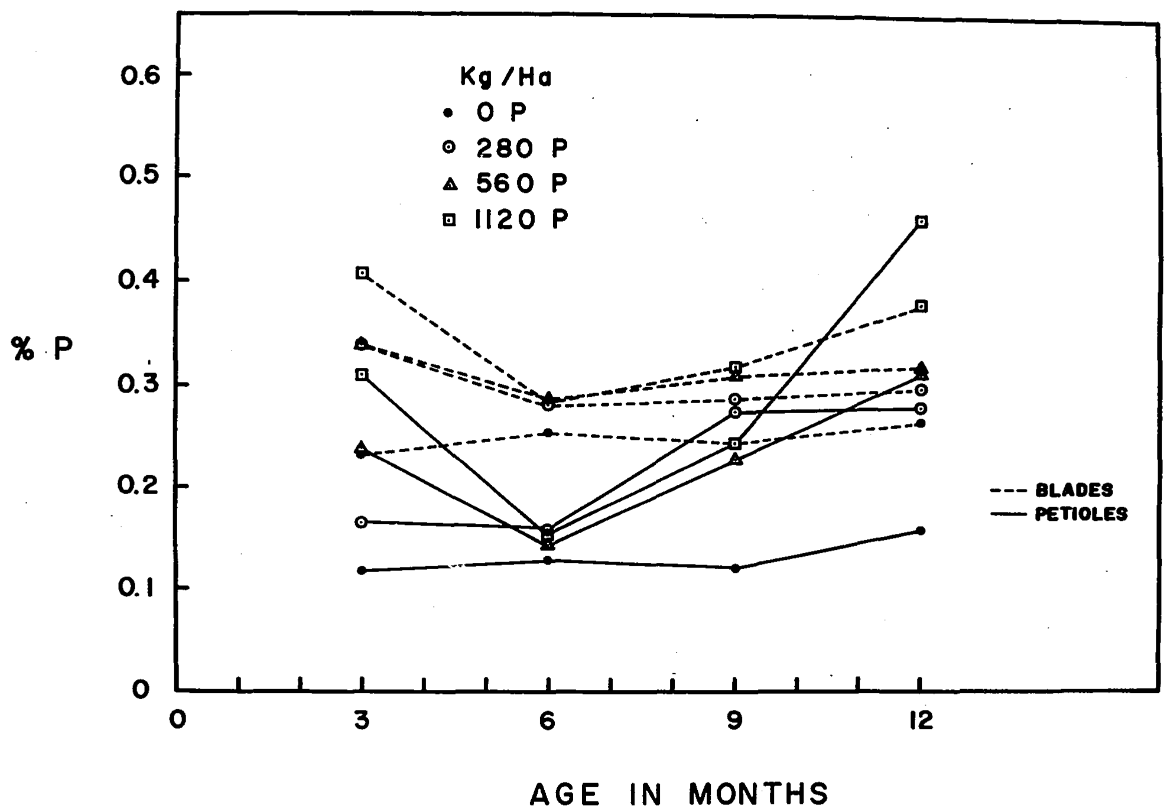

Figure 4. Percent P in Upland Taro Leaves as Influenced by Age and P Fertilization

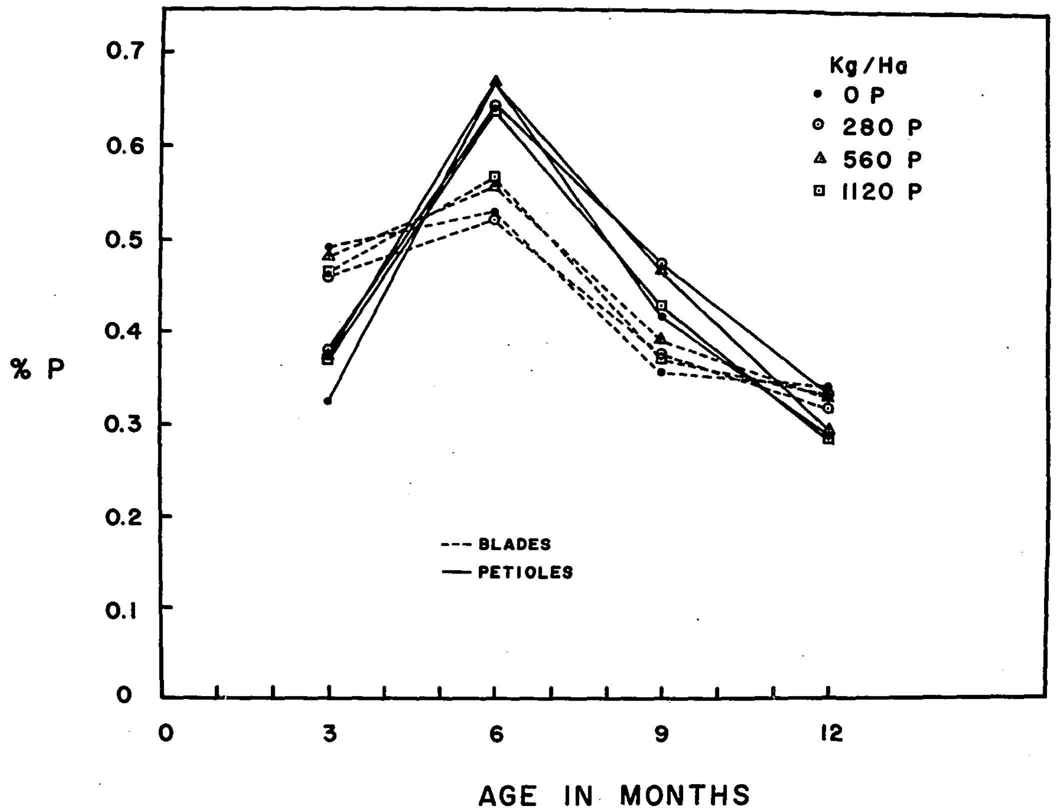

Figure 5. Percent P in Lowland Taro Leaves as Influenced by Age and P Fertilization

Table 14. Total Dry Weight Per Plant of the Blades, Petioles and Corms of Upland and Lowland Taro Fertilized With P

Treatment kg/ha P	Blades (g/plant)			Petioles (g/plant)			Corms (g/plant)		
	Age in Months								
	3	6	9	3	6	9	3	6	9
				Upland					
Control	2.1	1.4	3.5	2.2	1.6	5.4	8.4	20.3	16.6
0P	3.3	2.9	8.3	3.0	3.8	14.5	7.7	42.5	77.6
280P	9.2	7.9	6.6	7.0	11.0	11.4	11.2	80.9	156.5
560P	15.4	4.6	14.5	13.2	7.7	27.4	13.1	80.2	394.6
1120P	19.2	6.9	14.0	18.8	10.7	22.5	27.1	197.1	203.2
				Lowland					
Control	10.7	7.2	10.0	14.8	11.1	13.8	11.1	75.4	120.8
0P	24.8	13.9	14.5	36.3	25.6	22.0	28.4	70.7	147.2
280P	29.4	13.3	21.3	43.2	30.4	30.4	21.1	80.4	205.0
560P	28.2	15.2	23.6	46.0	30.2	35.2	39.1	57.1	225.4
1120P	34.8	14.2	20.9	51.2	28.3	31.5	41.6	90.0	187.0

percent K was the only significant change, although percent P, Ca and Mg tended to decrease. All elements studied decreased significantly as plants reached maturity. Percentages of N, P, K, Ca and Mg in the blades were significantly affected only by age of the plants when the samples were collected. N, K, Ca and Mg tended to decrease and P increased due to P applications. The influence of age on leaf blade composition was highly significant. Percent N and Mg decreased and percent P, K and Ca increased with age. Significant curvilinear tendencies in percent P, K and Mg were observed as crop maturity increased.

Analysis of soils fertilized with increasing rates of P showed that soluble P extracted with modified Truog's extractant (0.02 N H_2SO_4 containing 3 g $(NH_4)_2SO_4$ per liter) increased with added P. Regression analysis gave highly significant regression coefficients for both upland and lowland soils. The increase in soluble P in the soil is clearly illustrated in Tables 10 and 11 which also showed that residual effects of P fertilization in both soils used was good.

Plant tissue analysis also proved to be a good index in determining the P nutrition of taro. This was especially true in the upland crop where percent P in both petioles and blades was significantly related to the fertilizer applications. The lack of significant effects of P fertilization on the contents of petioles and blades of lowland taro seems to be due to the relatively high concentration of soluble P in the lowland soil. Luxury consumption is quite evident despite the presence of a significant response to P fertilization. The P content of control plants and P-fertilized plants did not differ significantly.

The total dry weight of petioles, blades and corms of upland and lowland taro fertilized with P is shown in Table 14. A very interesting observation on the relationship between the total weight of petioles and blades produced per plant and the concentration of P in the tissues of both upland and lowland taro is that in upland taro, the concentration of P in the tissues was high when the total amount of dry matter per plant was high, i.e. at three and nine months, whereas, in lowland taro, the concentration of P in the tissues was higher at the age of six months than at three or nine months. Phosphorus fertilization increased the growth of both upland and lowland taro. Total weight of corms produced per plant also increased with age and P fertilization.

Literature is replete with investigations conducted on the use of chemical analysis of soils and plant tissues as means of determining the P requirements of crops. Chang and Juo (1963) used eight methods of extracting soil P in an attempt to find the most suitable extractant for estimating soil P requirements. Breland and Sierra (1962) also used eight methods for extracting soil P and found that solutions of HCl and NH_4F or HCl and H_2SO_4 extracted more P from the soil than the other methods they used.

Patel and Metha (1961), Payne and Hanna (1965), Bingham (1962), van Diest (1963, 1963a), Blanchar and Caldwell (1964), Susuki, Lawton and Doll (1963) and Vajragupta, Haley and Melsted (1963) all worked on several methods of extracting soil P and found that most acid extractants gave results which correlated significantly with yields of crops used. Use of plant tissue analysis, on the other hand, did not show as much significance due to the relatively low P requirements of most crops. Most work on soil extraction was also correlated with plant P content. Use of radioactive P as a method for evaluating P fertilizers has been used (Bouldin and Black, 1960). Cooke and Hislop (1963) used anion-exchange resin for the assessment of available soil P. Occasionally, fractionation of soil P into the different forms of soil P proved to be useful in determining the P status of soils (Patel and Metha, 1961; Awan and Richer, 1964; Payne and Hanna, 1965; Susuki, Lawton and Doll, 1963; Bray and Kurtz, 1945; Chang and Jackson, 1957, 1958).

Effects of P fertilization on yields of upland and lowland taro

Corm yields of both upland and lowland taro in tons per hectare are shown in Table 15 and Figure 6. Yields of both upland and lowland taro were increased significantly as P fertilization increased. In the upland crop, the effect of P is curvilinear (Appendix Table 15) and highest yields were obtained from plots fertilized with 560 kg/ha of P. Delayed harvesting did not give

Table 15. Yields in Tons Per Hectare of Upland and Lowland Taro as Influenced by P Fertilization

Treatments kg/ha P	Age at Harvest								
	12 Months			14 Months			15 Months		
	Main Plants	Suckers	Total	Main Plants	Suckers	Total	Main Plants	Suckers	Total
				Upland Taro					
0 (control)	6.12	0.57	6.69	5.68	0.50	6.18	5.82	1.50	7.32
0	11.92	2.09	14.01^{g}	14.15	2.65	16.80^{fg}	11.00	3.91	14.91^{fg}
280	12.76	5.82	18.58^{efg}	14.72	6.55	21.27^{cdefg}	13.97	6.66	20.63^{defg}
560	16.48	13.18	29.66^{bcd}	15.27	11.66	26.94^{bcde}	21.85	18.33	40.18^{a}
1120	17.18	14.92	32.10^{a}	13.87	9.97	23.84^{bcdef}	15.54	14.55	30.09^{bc}
				Lowland Taro					
0 (control)	8.23	15.83	24.06	9.93	19.04	28.97	11.29	21.20	32.49
0	9.65	19.60	29.26^{op}	12.75	25.92	38.67^{lmn}	12.81	29.46	39.27^{lmn}
280	9.89	22.92	32.81^{mnop}	11.90	29.38	41.29^{klm}	13.02	31.00	44.02^{kl}
560	8.54	15.94	24.47^{p}	11.46	26.23	37.69^{lmno}	12.96	25.22	38.18^{lmno}
1120	9.94	21.48	31.42^{nop}	13.45	33.36	46.80^{kl}	14.14	34.52	48.66^{k}

1/ Differences among values (total yields) with the same letter in the superscript are not significant. Control data not included in statistical analysis.

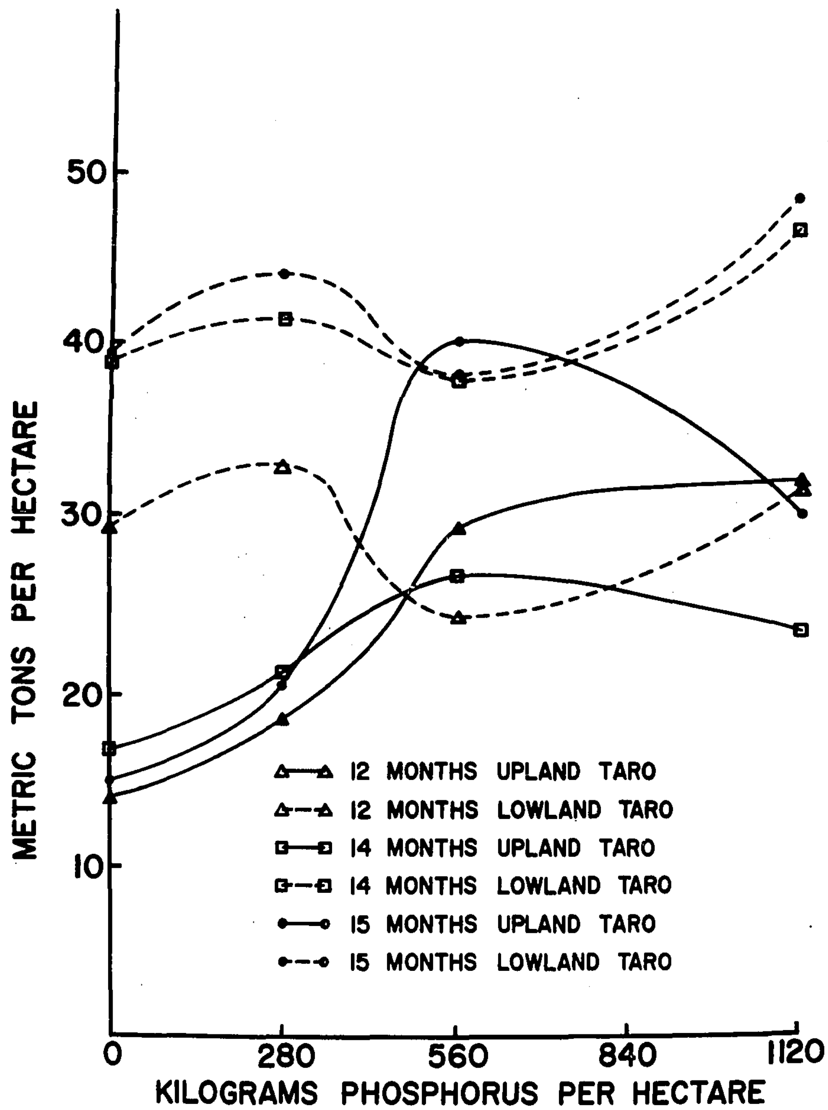

Figure 6. Effects of P Fertilization and Age on the Yields of Upland and Lowland Taro

any significant effects on yields of upland taro, again showing that upland taro matures earlier than lowland taro.

Yields of lowland taro were significantly influenced by increasing rates of P fertilization and delayed harvesting. Increases due to delayed harvesting were more significant than the increases due to P fertilization, which is contrary to that found in the upland crop. This is perhaps due to the relatively more fertile conditions of the lowland field, especially in terms of soluble P which was about 40 times higher than in the upland soil at the start of the experiments. The highest yields obtained from P-fertilized plots in lowland fields were from plots which received 1120 kg/ha of P and which were harvested at the age of 15 months.

Effects of P fertilization on quality of upland and lowland taro corms

Specific gravity measurements of corms from upland and lowland crops (Table 16) show that P has a tendency to increase specific gravity of the corms. Delayed harvesting, on the other hand, had different effects on corm quality. In upland taro, delayed harvesting decreased the specific gravity of the corms. Aside from the effect of P on hastening maturity of the crop, the limited supply of moisture also accounted for earlier maturity of upland taro than lowland taro. It was observed that basal portions of taro corms became spongy and light when left too long in the field. Decreases in density due to delayed harvesting in up-

Table 16. Effects of Age and P Fertilization on the Specific Gravity of Upland and Lowland Taro Corms

Treatments kg/ha P	Age at Harvest					
	12 Months		14 Months		15 Months	
	Main Corms	Sucker Corms	Main Corms	Sucker Corms	Main Corms	Sucker Corms
			Upland Taro			
0 (control)	1.074	1.105	1.090	1.148	1.105	1.125
0	1.108	1.107	1.103	1.092	1.032	1.064
280	1.075	1.113	1.097	1.123	1.100	1.107
560	1.088	1.111	1.081	1.089	1.092	1.110
1120	1.080	1.105	1.093	1.112	1.036	1.113
			Lowland Taro			
0 (control)	0.994	1.064	1.071	1.137	1.105	1.157
0	0.997	1.055	1.076	1.142	1.097	1.145
280	1.003	1.065	1.094	1.142	1.096	1.142
560	0.985	1.061	1.076	1.141	1.093	1.146
1120	0.999	1.062	1.101	1.152	1.096	1.145

land taro corms, however, were not significant. In the lowland taro, delayed harvesting significantly increased specific gravity. Increasing rates of P tended to increase the specific gravity of lowland taro corms, but not significantly, whereas delayed maturity increased the density of the taro corms significantly following a curvilinear pattern (Appendix Table 15).

Correlation analysis of specific gravity and percent dry matter of upland and lowland taro corms from P-treated plots showed that specific gravity and percent dry matter content of upland taro (Table 17) were highly correlated, while in lowland taro corms there were no correlations (Appendix Table 10). Correlation coefficients for upland taro corms were 0.439^{**} and 0.605^{**} for the apical and basal portions of the main corms and 0.455^{**} for the sucker corms. In the lowland, the "r" values for the apex and base of main corms were -0.166 and -0.119 and for the sucker corms, 0.094, none of which is significant.

Potassium Fertilization

Effects of K fertilization on soil pH, total N, soluble P and exchangeable cations and on plant composition

Results of soil analysis for pH, total N, soluble P and exchangeable K, Ca and Mg in upland and lowland soils fertilized with increasing rates of K are shown in Tables 18 and 19. Regression analysis (Appendix Table 14) of K treatment effects

Table 17. Specific Gravity and Percent Dry Matter of Core Samples from Upland and Lowland Taro Corms

Treatments kg/ha P	Upland Taro						Lowland Taro					
	Apex		Base		Suckers		Apex		Base		Suckers	
	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.
						12 Months						
0 (control)	1.202	39.6	1.158	35.8	1.153	34.8	1.116	45.1	0.954	43.0	1.114	43.0
0	1.102	34.2	1.133	33.8	1.108	32.1	1.144	44.4	0.909	36.4	1.174	42.2
280	1.115	36.7	1.142	35.4	1.133	36.3	1.133	44.9	0.860	37.2	1.070	43.3
560	1.110	33.1	1.125	33.1	1.136	34.6	1.133	43.4	0.863	38.9	1.103	43.2
1120	1.105	33.0	1.107	33.5	1.128	34.3	1.122	43.8	0.905	38.7	1.103	43.0
						14 Months						
0 (control)	1.104	31.6	1.089	29.6	1.098	27.2	1.167	42.6	1.007	38.9	1.196	42.0
0	1.072	27.8	1.088	27.7	1.114	31.8	1.193	43.6	0.961	37.8	1.170	43.3
280	1.103	32.6	1.093	29.4	1.084	30.9	1.183	41.3	1.001	36.5	1.177	41.8
560	1.066	28.4	1.076	26.3	1.093	29.3	1.171	42.6	0.954	35.8	1.169	42.5
1120	1.095	32.2	1.079	28.4	1.118	32.6	1.180	44.0	1.041	36.6	1.155	43.6
						15 Months						
0 (control)	1.139	31.0	1.129	30.6	1.129	32.7	1.133	43.7	0.964	37.0	1.108	42.3
0	1.119	26.9	1.099	24.2	1.153	25.1	1.132	44.7	0.982	36.4	1.121	41.7
280	1.132	30.9	1.107	27.0	1.111	28.6	1.134	41.9	0.976	34.9	1.122	40.6
560	1.106	29.0	1.087	25.3	1.131	32.7	1.124	42.6	0.999	36.5	1.142	42.9
1120	1.130	28.6	1.109	25.1	1.139	31.4	1.123	44.5	0.975	43.1	1.131	43.7

Table 18. Effects of K Fertilization on the Upland Soils

Treatments kg/ha K	Months After Planting 0	3	6	9	12
			Total N (%)		
0 (control)	0.24	0.22	0.22	0.22	0.22
0	0.23	0.21	0.22	0.22	0.23
280	0.23	0.22	0.22	0.23	0.22
560	0.23	0.22	0.22	0.23	0.22
1120	0.23	0.22	0.22	0.22	0.22
			Extractable P (ppm)		
0 (control)	8.6	8.3	5.3	3.9	4.9
0	8.0	42.0	31.0	20.5	29.0
280	9.8	50.1	36.0	24.7	26.4
560	9.1	42.5	34.3	35.9	25.3
1120	12.9	24.6	34.7	46.9	30.0
			Exchangeable Ca (meq/100 g O.D.)		
0 (control)	1.92	1.87	1.61	1.39	1.73
0	1.45	2.34	1.40	1.23	1.39
280	1.40	2.26	1.52	1.46	1.44
560	1.56	2.15	1.61	1.53	1.53
1120	1.45	2.00	1.41	1.34	1.59
			Exchangeable Mg (meq/100 g O.D.)		
0 (control)	0.42	0.57	0.35	0.47	0.44
0	0.37	0.45	0.40	0.55	0.51
280	0.49	0.57	0.36	0.40	0.44
560	0.50	0.48	0.35	0.41	0.43
1120	0.44	0.49	0.41	0.43	0.43
			Exchangeable K (meq/100 g O.D.)		
0 (control)	0.26	0.21	0.23	0.18	0.15
0	0.26	0.21	0.29	0.18	0.17
280	0.26	0.62	0.75	0.30	0.35
560	0.26	0.73	0.95	0.44	0.44
1120	0.25	1.02	1.62	0.66	0.63
			pH (1:1 paste)		
0 (control)	4.67	4.58	4.69	4.47	4.54
0	4.56	4.48	4.47	4.33	4.33
280	4.58	4.41	4.54	4.43	4.41
560	4.58	4.52	4.57	4.36	4.39
1120	4.55	4.52	4.67	4.39	4.44

Table 19. Effects of K Fertilization on the Lowland Soils

Treatments kg/ha K	Months After Planting 0	3	6	9	12
			Total N (%)		
0 (control)	0.21	0.20	0.20	0.22	0.21
0	0.23	0.22	0.22	0.24	0.21
280	0.20	0.21	0.22	0.23	0.22
560	0.22	0.22	0.22	0.22	0.21
1120	0.22	0.20	0.20	0.19	0.19
			Extractable P (ppm)		
0 (control)	328	365	345	279	314
0	294	366	333	322	314
280	326	410	384	330	318
560	314	416	365	289	304
1120	319	450	376	308	348
			Exchangeable Ca (meq/100 g O.D.)		
0 (control)	9.34	8.85	8.70	8.72	8.12
0	9.97	8.20	8.40	7.84	6.93
280	8.82	8.44	6.76	8.13	7.10
560	11.05	10.06	9.18	8.61	7.83
1120	9.44	9.25	6.67	7.92	7.03
			Exchangeable Mg (meq/100 g O.D.)		
0 (control)	4.00	5.13	8.22	7.33	7.68
0	3.97	5.20	7.81	7.74	7.32
280	4.33	5.46	8.58	7.76	7.64
560	3.78	6.98	5.87	7.74	7.83
1120	3.94	6.68	9.26	6.08	6.50
			Exchangeable K (meq/100 g O.D.)		
0 (control)	0.29	0.28	0.18	0.15	0.12
0	0.34	0.26	0.20	0.15	0.11
280	0.39	0.33	0.25	0.20	0.13
560	0.32	0.35	0.39	0.25	0.17
1120	0.28	0.66	0.64	0.39	0.18
			pH (1:1 paste)		
0 (control)	5.77	6.75	6.75	6.55	6.46
0	5.82	6.72	6.55	6.43	6.56
280	5.51	6.55	6.37	6.25	6.54
560	5.78	6.50	6.54	6.57	6.56
1120	5.52	6.47	6.38	6.34	6.52

on the properties analyzed shows that increasing K applications in the upland field increased the amounts of exchangeable K, soluble P, and pH of the soil. The increase in exchangeable K was highly significant, the increase in the pH was significant at 5%, while the increase in soluble P was not significant. There were tendencies for exchangeable Ca and Mg and total N to decrease with increasing K applications, but they were not statistically significant. The pH, soluble P, exchangeable K, Ca and Mg decreased as the crop matured, total N tended to increase, but the increase was not significant.

Potassium fertilization did not have significant effect on pH, exchangeable Ca and Mg and soluble P of the lowland soil. As expected, there was a highly significant increase in exchangeable K in the soil. The total N content of the soil decreased significantly with K fertilization. Only exchangeable K and soluble P significantly decreased with age in the lowland soil.

Effects of K fertilization on the composition of petioles and blades of upland and lowland taro are shown in Tables 20 and 21. Percent N, P and K in petioles of upland taro increased with K fertilization. The increases in percent N and K (Figure 7) were highly significant while the increase in percent P was not significant. Potassium application significantly decreased Ca and Mg content of the petioles. Age also affected the composition of the petioles; percent N, K and Ca decreased significantly as

Table 20. Effects of K Fertilization on the Composition of Upland Taro Leaves

Treatments kg/ha K	Petioles				Blades			
	Age in Months							
	3	6	9	12	3	6	9	12
				Percent N				
0 (control)	1.25	1.12	0.80	1.29	3.75	3.27	3.09	3.43
0	1.62	1.19	0.73	1.33	4.20	3.86	3.16	3.47
280	1.63	1.20	0.73	1.11	4.09	3.80	3.33	3.20
560	1.69	1.83	0.92	1.21	4.18	3.87	3.50	3.23
1120	1.92	2.27	0.88	1.30	4.12	3.95	3.59	3.68
				Percent P				
0 (control)	0.11	0.16	0.16	0.20	0.23	0.26	0.25	0.27
0	0.15	0.14	0.25	0.31	0.29	0.30	0.31	0.32
280	0.16	0.16	0.28	0.28	0.34	0.28	0.29	0.30
560	0.20	0.14	0.27	0.35	0.34	0.26	0.30	0.30
1120	0.17	0.15	0.23	0.36	0.33	0.27	0.30	0.32
				Percent K				
0 (control)	8.40	7.30	3.32	4.76	4.73	5.27	3.91	4.03
0	3.10	2.71	3.13	3.53	3.20	3.30	3.31	3.24
280	10.13	7.85	5.77	5.33	5.70	5.79	4.77	4.05
560	10.27	9.61	5.70	5.86	6.10	6.28	4.67	4.20
1120	11.15	11.27	5.90	7.11	6.17	6.35	4.69	4.53
				Percent Ca				
0 (control)	1.19	0.87	0.72	1.08	1.39	1.24	1.16	1.63
0	1.17	1.04	0.63	0.95	1.87	1.78	1.30	1.44
280	0.87	0.66	0.57	0.76	1.17	0.92	0.92	1.25
560	0.84	0.68	0.60	0.84	1.16	0.88	0.77	1.27
1120	0.87	0.63	0.55	0.67	1.22	0.92	0.65	0.97
				Percent Mg				
0 (control)	0.10	0.15	0.13	0.14	0.18	0.13	0.22	0.24
0	0.19	0.26	0.18	0.22	0.31	0.27	0.24	0.33
280	0.11	0.13	0.12	0.14	0.18	0.15	0.19	0.23
560	0.11	0.13	0.13	0.12	0.16	0.14	0.22	0.21
1120	0.10	0.12	0.10	0.09	0.15	0.11	0.19	0.20

Table 21. Effects of K Fertilization on the Composition of Lowland Taro Leaves

Treatments kg/ha K	Petioles				Blades			
	Age in Months							
	3	6	9	12	3	6	9	12
				Percent N				
0 (control)	1.00	0.97	0.81	0.65	4.02	4.09	3.13	2.78
0	1.21	1.18	0.78	0.74	4.62	4.42	3.31	3.11
280	1.06	1.05	0.71	0.64	4.32	4.23	3.23	2.90
560	1.11	1.17	0.69	0.66	4.51	4.29	3.24	2.81
1120	1.12	1.22	0.71	0.71	4.30	4.22	3.25	2.85
				Percent P				
0 (control)	0.27	0.57	0.52	0.31	0.40	0.48	0.38	0.32
0	0.33	0.63	0.46	0.31	0.44	0.54	0.38	0.33
280	0.38	0.64	0.48	0.34	0.46	0.52	0.38	0.32
560	0.36	0.68	0.47	0.32	0.46	0.55	0.36	0.32
1120	0.36	0.68	0.40	0.32	0.44	0.53	0.34	0.31
				Percent K				
0 (control)	2.05	3.60	1.93	1.02	2.83	4.30	2.85	2.60
0	1.84	2.87	1.36	0.92	2.51	3.56	2.30	2.28
280	4.03	5.69	3.49	1.64	4.06	4.97	4.14	3.37
560	5.50	6.93	3.24	1.49	4.83	5.27	3.90	3.32
1120	7.23	8.51	4.15	2.24	5.42	5.87	4.30	3.62
				Percent Ca				
0 (control)	0.77	0.74	0.88	0.69	1.59	1.55	1.55	1.76
0	0.81	0.84	0.77	0.58	1.47	1.65	1.44	1.33
280	0.67	0.71	0.71	0.51	1.11	1.29	1.28	1.43
560	0.56	0.71	0.60	0.58	0.91	1.19	1.14	1.39
1120	0.50	0.62	0.45	0.52	0.86	1.13	1.02	1.09
				Percent Mg				
0 (control)	0.58	0.44	0.48	0.33	0.71	0.35	0.35	0.33
0	0.57	0.58	0.46	0.33	0.68	0.43	0.45	0.37
280	0.52	0.41	0.34	0.32	0.51	0.35	0.24	0.32
560	0.42	0.40	0.33	0.33	0.52	0.36	0.25	0.27
1120	0.40	0.38	0.25	0.27	0.56	0.40	0.26	0.28

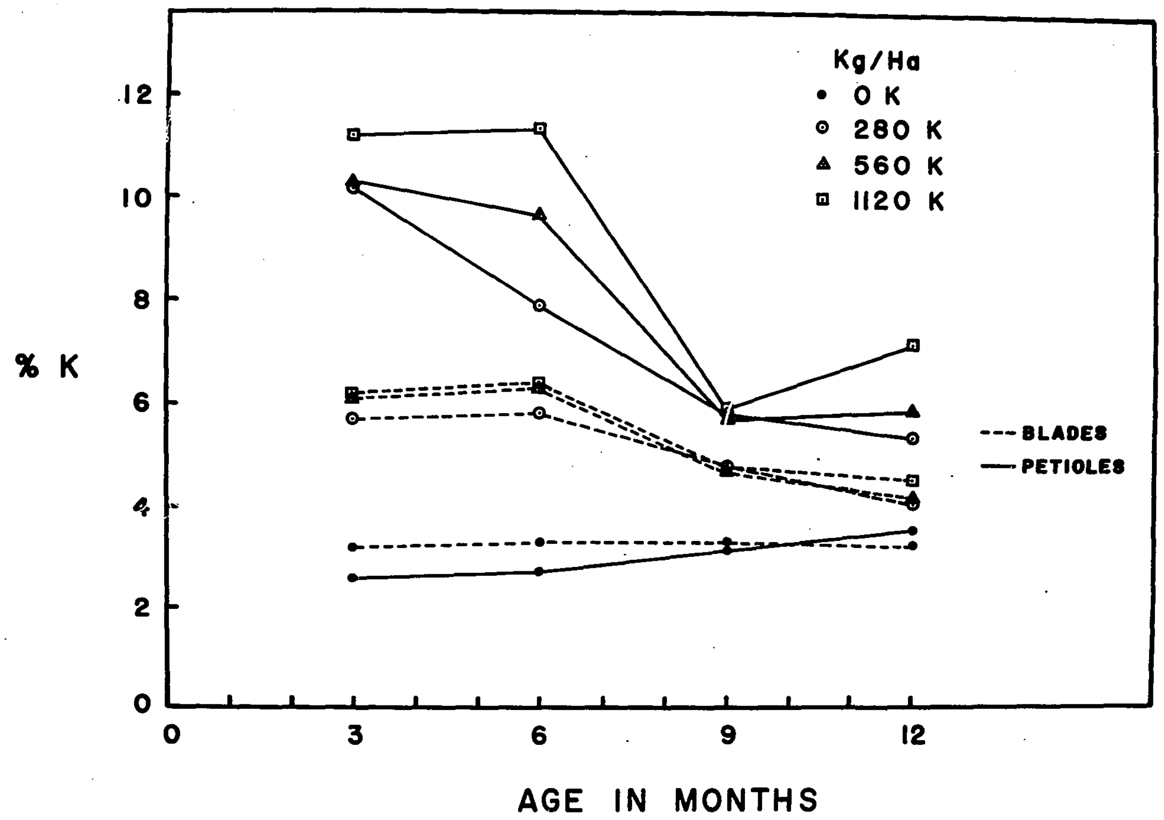

Figure 7. Percent K in Upland Taro Leaves as Influenced by Age and K Fertilization

the plants matured. Percent P increased significantly, while increase in percent Mg was not significant. The composition of leaf blades of upland taro showed the same trends as those found in the petioles, however, increase in percent N and P were not significant while increase in percent K and decreases in percent Ca and Mg were highly significant. The only element analyzed in the blade which increased as the plants matured was Mg; all other constituents decreased significantly (1% level of significance).

Increasing rates of K fertilization increased K in petioles of lowland taro significantly (Figure 8). Percent P tended to increase, but the increase was not significant. Calcium and Mg in petioles decreased significantly with K fertilization while the decrease in N in the petiole was not significant. Plant age at sampling affected the composition of petioles significantly. Percent N and Mg decreased significantly while P, K and Ca increased. In the blades, only the K content increased significantly with increasing K fertilizers. Potassium fertilization had negative effects on N, P, Ca and Mg contents of the blades. Decreases in percent Ca and Mg were highly significant while decreases in percent N and P were not. Age also affected the composition of blades of lowland taro, with percent N and Mg decreasing significantly while P, K, and Ca increased significantly.

Tables 20 and 21 and Figures 7 and 8 show that the concentration of K in the petioles of upland and lowland taro was

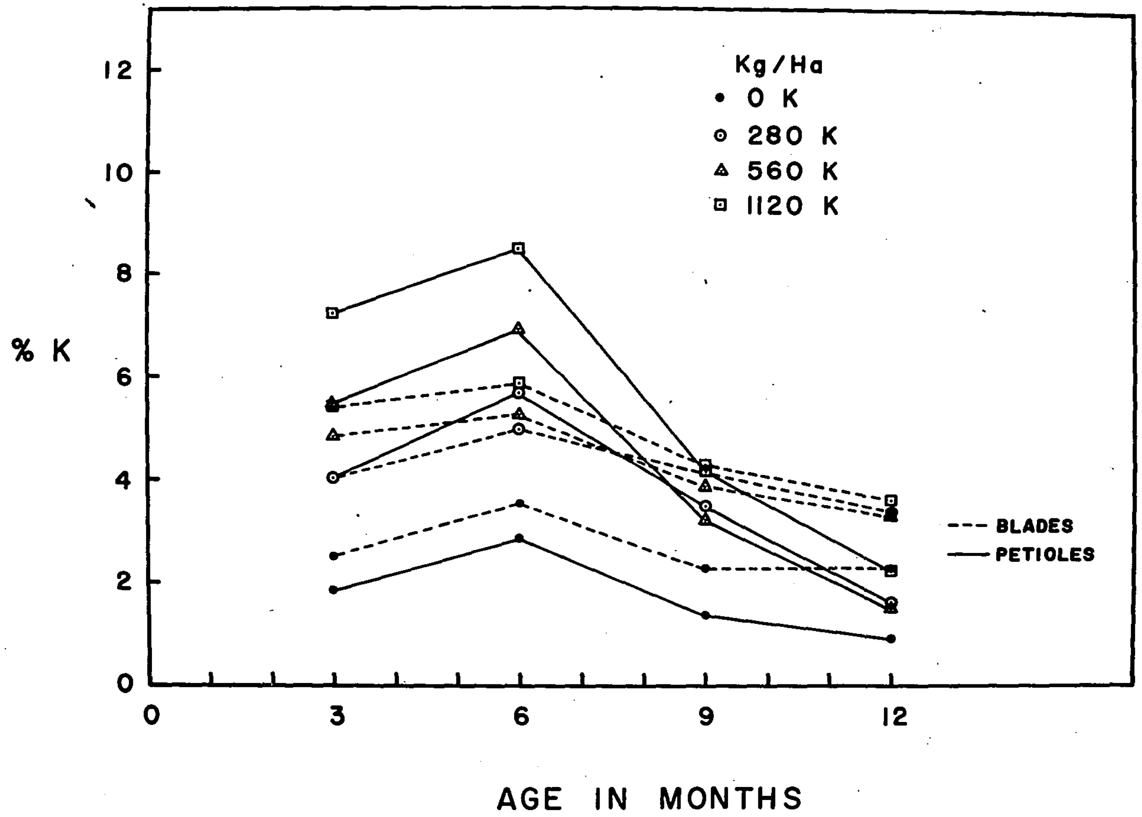

Figure 8. Percent K in Lowland Taro Leaves as Influenced by Age and K Fertilization

higher than the concentration of K in the blades. When K concentration were expressed on a tissue moisture basis (not moist tissue), however, the concentration of K in the blades was higher (Table 22). This method of expressing the K content of plant tissues is based on the assumption that K appears to be entirely soluble in the cell sap (Clements, 1959a). Values obtained from the petioles of upland and lowland taro are comparable to values obtained by Clements (1959a) in sugarcane, but values obtained from the blades of taro are about three or four times greater. This reversal was due to the higher moisture content of the petioles than the blades of taro.

Calculation of the ratio of K content of the petiole to the K content of the blade is shown in Table 23. The ratios obtained for upland taro were generally higher than those obtained for lowland taro. Potassium fertilization increased the values obtained from both upland and lowland taro but the values in the upland were higher than in the lowland taro.

Potassium fertilization had similar effects on the growth of taro as those of N and P. Total dry weight of petioles and blades per plant increased with K fertilization and again, the highest values were obtained when the plants were three months old. Weights of the corms produced per plant increased with age and K fertilization (Table 24).

Exchangeable K from soils fertilized with K was directly

Table 22. Percent K on a Tissue Moisture Basis (K-H_2O) of Petioles and Blades of Upland and Lowland Taro

Treatments kg/ha K	Petioles				Blades			
	Age in Months							
	3	6	9	12	3	6	9	12
				Upland Taro				
0	0.25	0.26	0.22	0.38	0.65	0.82	0.70	0.83
280	0.69	0.69	0.53	0.53	1.03	1.24	1.03	0.96
560	0.69	0.74	0.52	0.57	1.04	1.31	1.00	1.05
1120	0.75	0.82	0.52	0.67	1.06	1.29	0.97	1.11
Mean	0.60	0.63	0.45	0.54	0.94	1.17	0.92	0.99
				Lowland Taro				
0	0.14	0.24	0.14	0.11	0.45	1.01	1.15	0.61
280	0.29	0.41	0.36	0.19	0.69	1.30	1.65	0.82
560	0.39	0.48	0.35	0.17	0.79	1.37	2.16	0.81
1120	0.50	0.57	0.45	0.25	0.91	1.52	1.73	0.91
Mean	0.33	0.42	0.32	0.18	0.71	1.30	1.67	0.79

Table 23. Ratio of % K in Petiole to % K in Blade of Upland and Lowland Taro Fertilized With K

Treatments kg/ha K	Age in Months 3	6	9	12
		Upland Taro		
0	1.27	0.79	0.62	1.09
280	1.79	1.36	1.22	1.29
560	1.69	1.53	1.22	1.40
1120	1.81	1.78	1.26	1.57
		Lowland Taro		
0	0.74	0.81	0.55	0.40
280	1.00	1.14	0.83	0.48
560	1.14	1.30	0.81	0.44
1120	1.33	1.45	0.96	0.61

Table 24. Total Dry Weight Per Plant of the Blades, Petioles and Corms of Upland and Lowland Taro Fertilized With K

Treatments	Blades			Petioles			Corms		
kg/ha K	3 mos.	6 mos.	9 mos.	3 mos.	6 mos.	9 mos.	3 mos.	6 mos.	9 mos.
					Upland				
0 (control)	2.1	1.4	3.5	2.2	1.6	5.4	8.4	20.3	16.6
0	3.8	2.2	4.7	3.8	3.3	8.5	8.5	46.8	98.8
280	9.2	7.9	6.6	7.0	11.0	11.4	11.2	80.9	156.5
560	14.1	9.2	9.8	12.8	9.4	15.3	15.0	60.4	202.2
1120	23.2	8.4	11.0	22.2	9.6	14.5	27.2	99.7	136.8
					Lowland				
0 (control)	10.7	7.2	10.0	14.8	11.1	13.8	11.1	75.4	120.8
0	34.2	14.3	14.6	51.6	25.4	19.8	41.5	105.4	170.2
280	29.4	13.3	21.3	43.2	30.4	30.4	21.1	80.4	205.0
560	34.2	16.9	21.4	59.9	32.2	36.1	46.9	66.5	250.8
1120	31.0	20.1	16.7	48.4	37.3	28.0	29.8	82.1	265.8

related to the rate of fertilization in both upland and lowland soils. Analysis of plant tissues also showed that K content of petioles and blades of upland and lowland taro reflect the fertilizers applied to the soil. Regression coefficients for exchangeable K and K contents of the plants were highly significant which indicates that both methods can be used in determining the K requirements of the crop. Luxurious K consumption by both upland and lowland taro is also evident, especially when the K content of control plants are compared with plants which received K fertilization in the upland. In the upland taro the K percentage in petioles of control plants was almost as high as the K content of fertilized plants. In the lowland taro concentrations of K in petioles and blades of control plants were slightly lower than those of fertilized plants, and this accounts for differences in yield. Among plants which received fertilization, yields did not differ significantly although there was a highly significant increase in K in the plants which is luxury consumption.

Soil analysis for K has long been used as a guide for the fertilization of crops. Fullmer and Stromberg (1964) found that exchangeable K can be used as a guide to K needs of cotton. Extractable soil K and K contents of the plant were highly correlated and both increased with increasing K fertilization. Schmitz and Pratt (1953) working with corn concluded that extraction of K by HNO_3 gave a better index for the K needs of the crop than exchangeable K. Richards and MaClean (1961) also found that extractable K correlated very well with K fertilization and uptake by alfalfa. Ramamoorthy and Paliwal (1965) used different methods for extracting soil K and found that availability of K in paddy soils can best be predicted by the methods of Woodruff and McIntosh, which employs extraction with Morgan's solution and ammonium acetate. In Mexico, Pack and Gomez (1956) used CO_2-soluble K and found that results obtained from use of this method correlated significantly with yield and plant K. Lorenz, Tyler and Fullmer (1964) used plant analysis for determining the nutritional status of potatoes and White and Leaf (1964, 1965) used the total free analysis technique and found significant correlations between acid-extractable K and tissue K.

Effects of K fertilization on yields of upland and lowland taro

Significant increases in yields of upland taro due to increased fertilization with K were obtained (Table 25) from the upland soil. Delayed harvesting gave a slight decrease in yields, but the effect was not statistically significant. In the lowland, there were no significant increases in corm yield due to fertilization with K. Yield increases due to delayed harvesting, however, were highly significant. Highest mean yields obtained from upland fields were from plots fertilized with 1120 kg/ha K and harvested at the age of 12 months (Table 25 and Figure 9). In the lowland, highest yields were obtained from plots which received 1120 kg/ha K,

Table 25. Yields in Tons Per Hectare of Upland and Lowland Taro as Influenced by K Fertilization

Treatments kg/ha K	Age at Harvest								
	12 Months			14 Months			15 Months		
	Main Plants	Suckers	Total	Main Plants	Suckers	Total	Main Plants	Suckers	Total
				Upland Taro					
0 (control)	6.12	0.57	6.69	5.68	0.50	6.18	5.82	1.50	7.32
0	10.77	6.13	16.90^{bc}	10.09	7.99	18.08^{abc}	7.99	6.86	14.85^{c}
280	12.76	5.82	18.58^{abc}	14.72	6.55	21.27^{abc}	13.97	6.66	20.63^{abc}
560	14.69	12.08	26.77^{ab}	13.87	11.65	25.52^{ab}	10.59	10.36	20.95^{abc}
1120	17.04	10.73	27.77^{a}	12.06	8.69	20.75^{abc}	13.60	9.49	23.09^{abc}
				Lowland Taro					
0 (control)	8.23	15.83	24.06	9.93	19.04	28.97	11.29	21.20	32.49
0	9.52	22.45	31.97^{n}	12.30	29.51	41.81^{m}	12.80	32.52	45.32^{m}
280	9.89	22.92	32.81^{n}	11.90	29.38	41.29^{m}	13.02	31.00	44.02^{m}
560	9.13	20.81	29.94^{n}	12.67	29.80	42.47^{m}	13.63	30.12	43.75^{m}
1120	10.00	22.26	32.27^{n}	12.98	28.34	41.32^{m}	15.19	30.80	45.99^{m}

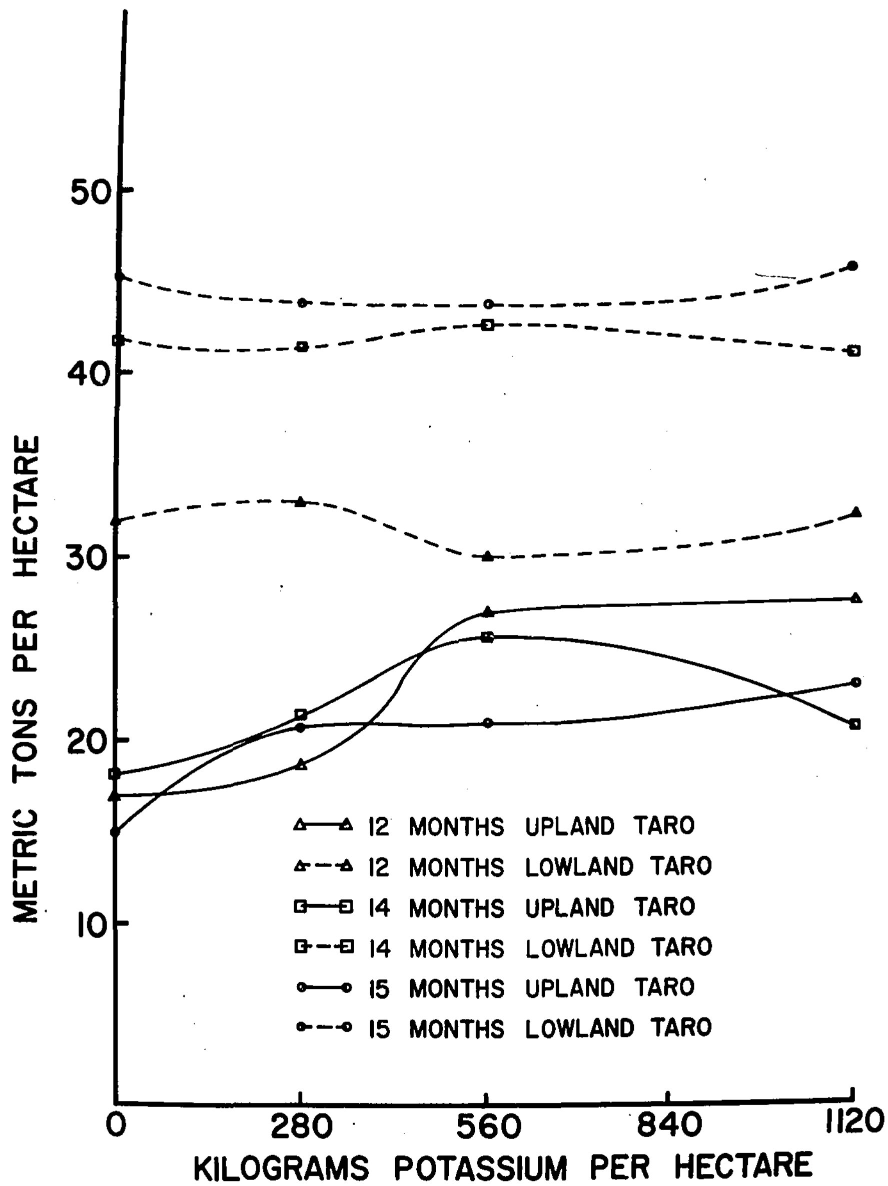

Figure 9. Effects of K Fertilization and Age on the Yields of Upland and Lowland Taro

but harvested at the age of 15 months. Yields obtained at 15 months from lowland plots or paddies which received 1120 kg/ha K were not significantly higher than those from the 0, 280, and 560 kg/ha K plots, but were significantly higher than yields obtained at 12 months.

Effects of K fertilization on quality of upland and lowland corms

The specific gravity of main corms and sucker corms of upland taro tended to decrease with K fertilization, and also tended to increase as harvesting was delayed from 12 months to 15 months; however, the effects of both factors were not significant. The main corms and sucker corms of lowland taro on the other hand, increased significantly with K applications and delayed harvesting. All increases in specific gravity of lowland corms were highly significant except the increase due to K on specific gravity of sucker corms which was not significant (Table 26).

Correlations between specific gravity and percent dry matter content of the core samples from the upland and lowland corms showed that while there were highly significant relationships between specific gravity and percent dry matter in upland corms, lowland corms did not show significant relationships (Table 27 and Appendix Table 10). Correlation coefficients for the apical and basal portions of the main corms of upland taro are 0.619^{**} and 0.746^{**}, respectively, and 0.751^{**} for sucker corms. For lowland corms, correlation coefficients were 0.11 and 0.184 for the

Table 26. Effects of Age and K Fertilization on the Specific Gravity of Upland and Lowland Taro Corms

Treatments kg/ha K	Age at Harvest					
	12 Months		14 Months		15 Months	
	Main Corms	Sucker Corms	Main Corms	Sucker Corms	Main Corms	Sucker Corms
			Upland Taro			
0 (control)	1.074	1.105	1.090	1.148	1.105	1.125
0	1.088	1.110	1.084	1.117	1.083	1.120
280	1.075	1.113	1.097	1.123	1.100	1.107
560	1.077	1.099	1.081	1.104	1.084	1.117
1120	1.073	1.087	1.082	1.117	1.081	1.116
			Lowland Taro			
0 (control)	0.994	1.064	1.071	1.137	1.105	1.157
0	0.987	1.058	1.080	1.136	1.075	1.146
280	1.003	1.065	1.094	1.142	1.096	1.142
560	1.000	1.057	1.084	1.141	1.099	1.154
1120	1.005	1.058	1.085	1.144	1.125	1.163

Table 27. Specific Gravity and Percent Dry Matter of Core Samples from Upland and Lowland Taro Corms

Treatments kg/ha K	Upland Taro						Lowland Taro					
	Apex		Base		Suckers		Apex		Base		Suckers	
	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.	Sp. Gr.	% D.M.
						12 Months						
0 (control)	1.202	39.6	1.158	35.8	1.153	34.8	1.116	45.1	0.954	43.0	1.114	43.0
0	1.152	38.0	1.153	37.1	1.161	37.7	1.124	44.7	0.844	31.5	1.097	43.8
280	1.115	36.7	1.142	35.4	1.133	36.3	1.133	44.9	0.860	37.2	1.070	43.3
560	1.131	36.2	1.134	33.8	1.152	34.4	1.113	43.0	0.873	38.6	1.101	43.0
1120	1.137	34.1	1.138	32.1	1.124	32.1	1.118	42.5	0.930	38.1	1.090	40.7
						14 Months						
0 (control)	1.104	31.4	1.089	29.6	1.098	27.2	1.167	42.6	1.007	38.9	1.196	42.0
0	1.097	32.8	1.081	30.6	1.111	32.5	1.159	43.6	0.976	34.4	1.142	42.8
280	1.103	32.6	1.093	29.4	1.084	30.9	1.183	41.3	1.001	36.5	1.177	41.8
560	1.084	31.0	1.069	27.0	1.102	30.1	1.177	41.4	0.965	34.8	1.156	41.3
1120	1.093	29.8	1.089	26.5	1.106	30.3	1.180	41.1	0.980	35.7	1.156	41.0
						15 Months						
0 (control)	1.139	31.0	1.129	30.6	1.129	32.7	1.133	43.7	0.964	37.0	1.108	42.3
0	1.109	26.4	1.084	27.8	1.137	29.0	1.130	45.2	0.906	30.1	1.129	42.8
280	1.132	30.9	1.107	27.0	1.111	28.6	1.134	41.9	0.976	34.9	1.122	40.6
560	1.128	28.5	1.096	24.4	1.077	26.4	1.108	41.9	0.937	33.4	1.104	41.4
1120	1.098	26.1	1.084	23.5	1.124	28.8	1.116	40.5	0.952	34.0	1.123	41.7

apex and base of the main corms, and -0.032 for sucker corms.

Nitrogen fertilization not only affected growth and yield of the taro crop but also influenced the nutrient content of the leaves of the plants. The exchangeable cations and soluble P in the soil were also affected by use of N fertilizer. Nitrogen applied as urea when converted to the NH_4^+-form is again readily converted to the NO_3^--form, especially under well-drained soil conditions. The change of ammonia to nitrate is an acid forming reaction and renders the soil more acidic (Tisdale and Nelson, 1966). Soil pH measurements in the soil samples collected from the upland field decreased as N applied was increased. Under lowland conditions, nitrification is quite slow or practically nil due to the reducing and anaerobic conditions existing (Ponnamperuma, 1955). The effect of N fertilization on the increase in soil acidity was not observed in the lowland, instead there was an increase in pH due to addition of urea. The dissolution of urea and conversion of N to the ammonia form not only reacted with water to increase the pH but also caused a release of exchangeable cations into the soil solution. This reaction resulted in the increase in soil pH.

Cation exchange capacity and N content of the roots of plants has been shown to be directly related to N fertilization (McLean, Adams and Franklin, 1956; Helmy and Elgabaly, 1958). The increase in cation exchange capacity of roots has two possible effects on the Ca and P levels in the soil and in the plants. First, if P in the soil is present mainly in the available form, the negative charges in the roots would repel it causing a decline in the P absorption by the plant. Second, if P is present mainly in the unavailable form such as less soluble calcium phosphates, the increased C.E.C. will cause more Ca to be taken up by the roots rendering the phosphates more available. In the present study, there was a decrease in the amount of P taken up by the N-fertilized plants. Since the plants received a basic application of treble superphosphate it would then be postulated that the decrease in P content of the leaves of taro which were fertilized with N is due to the first mechanism. This is supported by the increase in P content of the plants which received P fertilization but no N fertilization (0 kg/ha N) as compared to the control plants. In the lowland, the concentration of soluble P was quite high, an average of 319 ppm P compared to only 9 ppm P in the upland soil (Table 1). Addition of P fertilizer further increased the amounts of soluble P in the soil causing a slight increase in P uptake by the P-fertilized plants compared to the control. Dilution effects due to the increased growth of the plants contributed also to the decrease in concentration of P in the N-fertilized plants. Another mechanism which may have decreased the P content of the plants is nitrate-phosphate antagonism.

The decrease in the amounts of soluble P with age, especially in the plots fertilized with P, may have been due to plant removal in both upland and lowland fields, lateral leaching or washing-away in the lowland due to continuous irrigation and in the upland soil P-fixation due to the increase in the soil acidity and high amounts of iron and aluminum oxides. The decrease in soluble P from the control plots of both fields would essentially be due to crop removal since none of the effects of N fertilization were present.

No reasons have been given for the depressing effects of N on the concentration of K in citrus leaves (Smith, 1962), but dilution effect would essentially be the dominant factor involved since increased N fertilization increases vegetative growth and consequently the size of the different parts of the plant. Of the several functions of K, the most important are its role in the synthesis of proteins and carbohydrates (Evans and Sorger, 1966). Since it is acting as an activator or catalyst in these functions and in other enzyme systems where it is needed, K would not be needed in large amounts compared to the substrates and products of the reactions involved. Most of the K absorbed in luxurious proportions would be found in the sap or transpiration stream where it is probably being used to maintain ionic equilibrium (Briggs, Hope and Robertson, 1961).

Smith (1962) in a review on the analysis of plant tissues reported N fertilization increased N, Ca and Mg contents of citrus leaves while P, K, Cu, Zn and Mn contents were decreased. No explanations were given for these effects, however, the increase in Ca and Mg contents may be linked to the roles of these divalent cations in the plant tissues. The primary role of Ca as a cementing agent in the form of Ca-pectate in the middle lamella would account for its increase in the plant whenever growth is accelerated or increased. Magnesium is a component of chlorophyll together with N and its increase with N fertilization would very well be connected to this function. Aside from the functions mentioned, Ca and Mg are also involved in some enzyme reactions (Evans and Sorger, 1966).

The most important effect of P fertilization on the upland and lowland soils is the significant increase in soluble P and exchangeable Ca. The increase in exchangeable Ca especially in the upland soil is a consequence of the use of treble superphosphate which has high Ca content (ca 14% Ca).

The increase in exchangeable Ca and pH of the upland soil was due to displacement of hydrogen ions from the soil colloids and solutions by Ca which came from the fertilizer applied. In the lowland, exchangeable Ca was fairly high initially and applied Ca from the superphosphate did not have a considerable effect on the Ca status of the soil. Instead, the pH decreased slightly which was perhaps due to the sulfate which came with the fertilizer.

The only effect of P on the nutrient content of the tissues is the significant increase in P content of the petioles and blades of upland taro, while there were no significant increases in P content of lowland taro. The lack of increase in P content of lowland taro is due to high concentrations of soluble P originally present in the soil. Nevertheless, there were significant yield increases due to P fertilization in the lowland.

The depressing effects of P fertilizer on K and Mg and increase on P and Ca contents of citrus leaves (Smith, 1962) are paralleled by the results of the present study on taro.

The over-all residual effect of fertilizer P as shown by the relatively high amounts of soluble P especially in the upland soil at the later part of the experiment is of interest considering the fact that most Hawaiian soils have high phosphorus-fixing capacities (De Datta, Fox and Sherman, 1963; Plucknett and Fox, 1965; Younge and Plucknett, 1965). The high amount of soluble P in the lowland soil towards the latter part of the experiment was expected since initial soluble P content of the soil was inherently high.

Potassium fertilization had several important effects on exchangeable K, Ca, and Mg, soil pH and total N content of the soils and on composition of taro leaves. The depressing effect of K on exchangeable Ca and Mg had been observed by several investigators (Bear, 1965; Russell, 1961; Black, 1960) and is attributed to the displacement of Ca and Mg by K from the exchange sites of the soils rendering them susceptible to losses due to plant absorption, leaching and erosion. The upland soil is well drained making losses due to leaching and run-off during heavy rains appreciable. This displacement effect of K on Ca, Mg and other cations also caused an increase in soil pH. This effect was not very significant on the N content of the upland soil because the N fertilizer applied was readily converted to nitrates since the soil is well aerated.

In the lowland, the effect of K on Ca and Mg was not very striking due to the relatively high proportions of Ca and Mg already present in the soil so that mass action and complementary ion effects can not function to a high degree. The depression effect of K was more pronounced on N since N present was essentially in ammonia form due to lack of nitrification under the waterlogged conditions existing. The contributing effects of Ca and Mg on the N content of the lowland soil should also be considered since it is possible that their effect was even greater than that of K since Ca and Mg are divalent cations and have greater displacing capacities than K except when the ammonia being displaced is in the "fixed" position.

The influence of K on the soil nutrient contents was reflected in composition of taro leaves, especially for N. In upland taro, increase in N content of petioles and blades brought about by increased K uptake is a consequence of increased protein and carbohydrate metabolism attributed to K. Toward the middle of the experimental period, plants receiving high K fertilization were observed to be yellowing and deficient in N, an effect probably due to high requirements of the plants for N resulting from increased protein synthesis.

Depressed Ca and Mg uptake had been demonstrated in both intact and excised roots of several plants (de la Pena, 1964; Epstein, 1960, 1961; Epstein and Legget, 1954; Jacobson, Moore and Hannapel, 1960; Middleton and Russell, 1958). This effect is essentially an example of ion antagonism although under certain concentrations of Ca and Mg, K may also increase Ca and Mg uptake as per the Viets effect. The depressing effect of K on Ca and Mg absorption by taro is not a "one-way" effect as found by Oo (1965) in corn and Eastman (1963) in peanuts. In spite of the higher percentage of exchangeable K in the lowland soil, the K content of lowland taro is much lower than the K content of upland taro regardless of fertilizer treatments. This is due to the high amounts of exchangeable Ca and Mg in the lowland soil which when compared with that of the upland soil is about ten times as high. Initially, the exchangeable Ca and Mg in the lowland soil were 9.77 and 3.92 meq/100 g of oven dry soil, respectively, whereas in the upland soil exchangeable Ca and Mg were 1.54 and 0.45 meq/100 g oven dry soil, respectively. Percent exchangeable K in the lowland soil was 1.85% and in the upland soil, 1.06% yet the percentage of K in the upland taro leaves is higher than the percentage of K in the lowland taro leaves.

The depressive effects of Ca and Mg on K under the lowland condition is exerted both in the soil and plant. In the soil, Ca and Mg competed with K for exchange sites in the soil colloids exposing K to leaching and other losses due to continuous irrigation. In the plants, K uptake was decreased probably to a large extent by Mg ions. The K losses in the lowland soil are clearly illustrated by the rapid decline of exchangeable K in lowland soil regardless of fertilizer treatments. Exchangeable K in the lowland soil decreased rapidly with time compared to almost constant amounts of exchangeable K in the upland soil, because Ca and Mg in the upland soil were very low.

The competitive effects of K on ammonium ions in the lowland soil is shown by the decrease in N contents of the taro leaves.

The yield data presented in Tables 7, 15 and 20 for both upland and lowland taro show that there were significant increases due to N, P, and K fertilization. Figure 10 gives a more detailed picture on the source of the significant increases in yields, especially in the lowland. It should be noted from Figure 10 and the tables presented that in upland taro, the total yield increases were due chiefly to increases in weights of the main corms

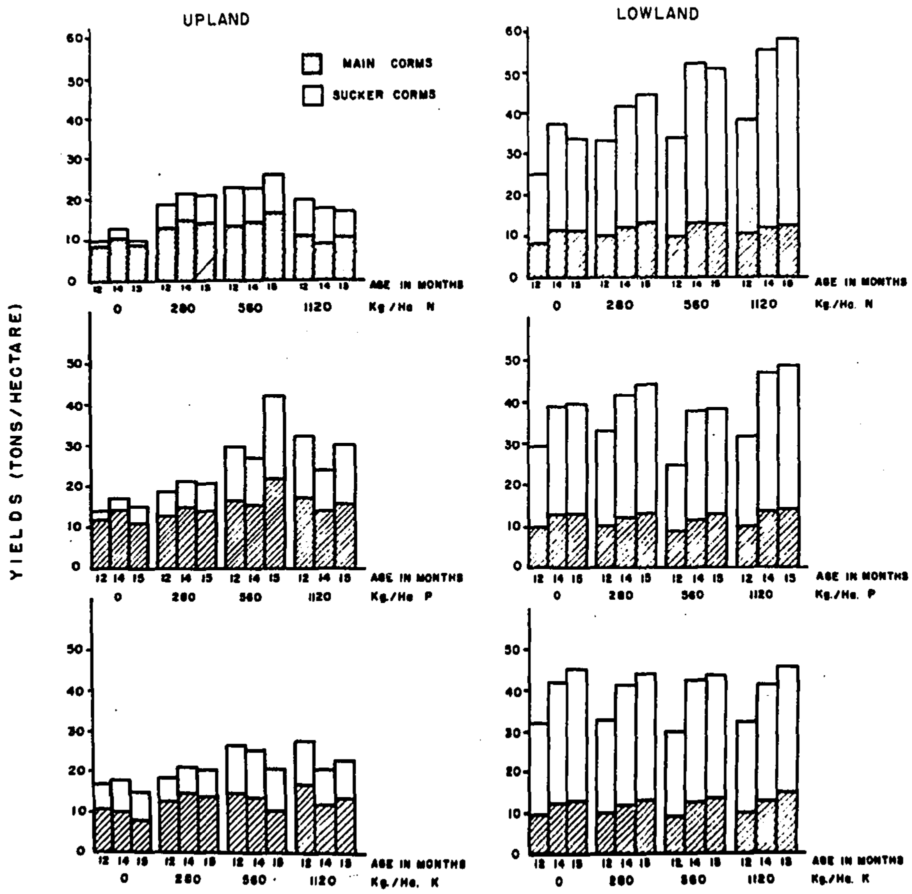

Figure 10. Yields of Upland and Lowland Taro Fertilized With N, P, and K With Main Corms and Sucker Corms Separated

brought about by fertilization. In the lowland, the increases in total yields are brought about by significant increases in weights of sucker corms. The higher number and weight of sucker corms in lowland taro was due to unlimited supply of moisture and higher fertility level of this soil. Another important feature clearly illustrated in Figure 10 is the relative degree of response of taro to fertilization, that is, in the lowland, the highest yields were obtained from the N treated plots and in the upland, the highest yields were obtained from the P treated plots.

The total weight of taro tops produced at 3, 6, and 9 months in both upland and lowland taro was calculated and used as a basis for a fertilizer guide in producing an estimated yield of 20 tons/ha of upland taro and 30 tons/ha of lowland taro. The amount of dry matter produced per hectare in upland and lowland taro is shown in Appendix Tables 16 and 17. The fertilizer guide in Table 28 was formulated by using the values obtained from the plant and soil analyses of plots which gave yields slightly better than the yield goals set. The values given in Table 28 are the theoretical values which must be obtained from either upland or lowland crops to be able to give yields aimed for.

The total amounts of nutrients removed by a 12-month crop of taro, both upland and lowland, was estimated from the total weight of tops and corms at the age of 12 months. Values obtained for total amount of nutrients in the tops at earlier stages of

Table 28. N, P and K Contents of Taro in Relation to Age

		Tops 3 mos. (kg/ha)	Tops 6 mos. (kg/ha)	Total 12 mos. (kg/ha)	Yield Goal[1/] tons/ha corms
Upland	N	34	11-17	180	20
	P	2.8-3.4	1.1	40	
	K	56-67	45	300	
Lowland	N	62	31-34	150	30
	P	10-11	9-10	60	
	K	100-105	78-85	200	

[1/]Fertilizer rates used in the present study which gave the values recommended to meet the goals set for upland and lowland taro are 280-560-280 kg/ha in upland, 280-0-280 kg/ha in lowland.

growth were higher than values obtained at the age of 12 months; however, it is assumed that most of the nutrients in the tops before harvesting time were returned to the soil as organic matter since leaves which fall off from the plants were never collected and taken out of the field. A large portion of the nutrients taken out of the soil by a crop of taro is found in the corms. It is therefore estimated that 180 kg/ha N, 40 kg/ha P, and 300 kg/ha K are removed from the soil for each crop of upland taro yielding about 20 tons/ha of corms and 150 kg/ha N, 60 kg/ha P, and 200 kg/ha K from lowland soil by a crop of lowland taro yielding about 30 tons/ha of corms. The slightly higher values for N and K in upland taro is due to higher concentrations of N and K in upland taro corms.

In upland soils where extractable P is low (less than 10 ppm), P is the most critical factor and application of fertilizer P at planting time is recommended. In the present study, all of the fertilizer P was applied just before planting and only one-third of the N and K fertilizers were applied with the P fertilizer. The calculated values for exchangeable K in the upland may be reduced by 50% if adequate water supply is available enabling K to go into solution for plant use.

In paddy soils, extractable P and exchangeable K are usually high (Ayres, 1949; Ayres and Hagihara, 1952) and N is the most limiting factor among the elements studied. Early application of N fertilizer will enable the plants to develop rapidly and start the formation of suckers. Succeeding crops may have to be fertilized with P to replace the amount removed by the previous crops.

Amounts of fertilizers to be applied for a crop of upland or lowland taro will vary for each type of soil used. In this connection it may be valuable to consider the amounts of nutrients absorbed at given stages of crop development. For example, in upland taro, the total amount of N, P and K in the tops at age three months should be about 30, 3, and 60 kg/ha, respectively, for an estimated yield of 20 tons/ha. These values can be attained if at age three months the concentrations in the petioles of N, P, and K approach 2.0% N, 0.24% P and 9.0% K and for blades 4.2% N, 0.34% P and 5.7% K. In lowland taro, the petiole should have about 1.1% N, 0.38% P and 4.0% K and in the blades 4.3% N, 0.46% P and 4.1% K at three months to give a total amount of about 60 kg/ha N, 10 kg/ha P, and 100 kg/ha K in the tops for an estimated yield of 30 tons/ha.

Results of experiments conducted on upland and lowland taro show that plant tissue analysis and soil chemical analysis can be employed to predict the nutrient status of the taro crop. Aside from responses to the types of culture under which the crop is grown, there were highly significant responses to the fertilizers applied. The initially high fertility levels of the lowland soil was reflected in total yields of the crop.

Soil analyses showed that the lowland field was relatively more fertile than the upland field, especially in soluble P which averaged 319 ppm in lowland plot but only 9 ppm in upland plot. Consequently, response of taro to P fertilization was greatest at the upland location although total yields of lowland taro were higher. Control plots in the lowland field gave an average of about 29 metric tons/hectare of corms while in the upland the average yield of the control was only 6.5 metric tons/hectare. Differences in yield of the control plots from lowland and upland fields correspond to differences between soil analyses.

Exchangeable K was almost identical in both fields; however, the percent saturation due to K was higher in the lowland than in the upland soil because the upland soil had a higher C.E.C. In the lowland, taro did not respond significantly to K fertilization but in the upland there was a significant response to K. Again, average yields of K fertilized plots in the lowland were higher than those obtained from the upland soil.

Exchangeable Ca and Mg were much higher in the lowland than in the upland. Plant tissue analysis showed that the crops or plants did not absorb nutrients from the soil in the same proportions that the nutrients occurred in the soil or soil solutions. This phenomenon has been demonstrated not only under field conditions but also under controlled environment using culture solutions (Sutcliffe, 1962; Hoagland, 1948).

The inherently higher fertility level of the lowland field is attributed to several factors occurring under waterlogged conditions. Among these factors are the increase in soluble P due to reduction of ferric iron to the more soluble ferrous form resulting in the increase in solubility of iron phosphates (Savant and Ellis, 1964; Shapiro, 1958) and formation of CO_2 and organic acids which convert less soluble tri-calcium phosphates to the more soluble di- and mono-calcium phosphates (Mandal, 1964). Ponnamperuma, Martinez and Loy (1965) working on the chemistry of waterlogged soils found that waterlogging increases pH. They attributed the increase in pH to the iron system of the soil which is illustrated by the equation,

$$nFe(OH)_3 \longrightarrow nFe^{++} + nOH^-$$

When dominant in a soil, other systems such as the MnO_2 may release hydroxyl ions into the soil solution also.

Flooding was also found to increase the amounts of dissolved ions in the solution. Reed and Sturgis (1939) found higher amounts of soluble Na, Mg, Fe and Si in flooded soils, and Robinson (1930) analyzed soil solutions from flooded soils and also found high amounts of Fe, Mg, Ca, Mn, K and H_2S. Shapiro (1958) did not find effects of flooding on available N but noted that applied P and N were utilized more efficiently under flooded conditions. Okuda and Yamaguchi (1955, 1956) and

Okuda, Yamaguchi and Kamata (1956) worked on the nitrogen-fixing microorganisms in paddy soils and implied that contribution of blue-green algae, photosynthetic bacteria and non-sulfur purple bacteria on the N supply of paddy soils is of considerable importance.

A few salient features of results obtained from the present study regarding relationships among the cations include depression of K absorption by the taro plant under lowland conditions in spite of the relatively higher percentage of exchangeable K and fertilizer K applied. A closer look at Tables 2, 3, 9, 10, 18 and 19 shows that exchangeable Mg is much higher in the lowland soil than in the upland soil. Oo (1965) and Eastman (1963) found that K uptake by plants grown in soil under field and greenhouse conditions is greatly depressed by the addition of Mg. The depressing effects of Mg on K uptake by plants had also been demonstrated in excised roots which were allowed to absorb from culture solutions (Middleton and Russell, 1958; Nashar, Helmy, Hassan and Elgabaly, 1966; Jacobson, Overstreet, King and Handley, 1950). Calcium has also been found to affect K absorption by plants. In the presence of other monovalent cations like Na or Li, Ca enhances the absorption of K by excised roots (Epstein, 1961; Epstein and Legget, 1954; Epstein, Rains and Schmid, 1962; Jacobson, Moore and Hannapel, 1960; Jacobson, Hannapel, Moore and Schaedle, 1961; Kahn and Hanson, 1957;

Overstreet and Jacobson, 1952). The effects of Mg on K uptake had been attributed to ion antagonism and the enhancing effects of Ca had been linked with the role of Ca in increasing the rate of the reaction,

M + K	$\longrightarrow$	MK	$\longrightarrow$	M' + K
outside solution		carrier-ion complex		inside the cell

(where, M = metabolic carrier, K = potassium ion). In the soil system, Ca enhances the solution content of K and decreases amounts of Na in solution. Calcium displaces K ions from the exchange sites in the soil colloids making K more available for plant utilization while Na is held more tightly and rendered less available to plants (Bear, 1964; Black, 1960; Russell, 1961).

The effects of N on decreased P, K, Ca and Mg of the taro plant is mainly due to dilution effects brought about by rapid increase in vegetative growth of the plants which received N fertilization.

It is interesting to note that K content of taro leaves was slightly higher in the upland than in the lowland, yet there was a significant response of the crop to K fertilization in the upland and there was no response to K fertilization in the lowland.

The growth pattern of the taro plant and its tendency to absorb relatively high concentrations of nutrients from the soil at the early stages of development makes it important to program fertilization so that a large portion of the fertilizers for a cropping season will be applied within the first three months after planting. The formation of suckers begins at approximately 1-2 months in lowland and upland taro. Corm formation takes place at an early stage. The composition of the leaves of fertilized and unfertilized plants at the later stages of growth were almost the same, whereas, at the early stages of growth, the concentrations of N, P, and K were higher in the leaves of fertilized plants.

N x P x K Interactions

Leaf samples taken from the pot experiments to determine the interaction of N, P, and K show that N fertilization increased the N content of both petioles and blades of the index tissue (Table 29) and all leaves (numbers 1, 2, 3, and 4) harvested at six months (Table 31). At the age of two months the effect of fertilization was fully shown by the response in growth of the plants and N uptake. All plants which received N either singly or in combination with P and/or K were larger and had more vigorous growth than the control and other plants not receiving N. The leaf blades were broader and longer, the petioles were longer and with greater diameter and the suckers were more numerous in the N-treated plants. All plants which did not receive N fertilizer were generally yellow, stunted and had only few or no suckers. Results of tissue analysis at the age of two

Table 29. Analysis of Petioles and Blades of Taro Plants Grown in Pots[1/]

Treatments	Petioles		Blades	
	2 Months	4 Months	2 Months	4 Months
		Percent N		
Control	1.07	0.81	3.34	3.33
N	3.10	0.82	4.40	3.47
P	1.14	0.88	3.43	3.33
K	1.10	0.83	3.16	3.51
NP	2.42	0.89	4.70	3.35
NK	2.87	0.69	4.44	3.05
PK	0.98	0.83	3.38	3.22
NPK	2.72	0.88	4.71	3.62
		Percent P		
Control	0.75	0.89	0.41	0.53
N	0.16	0.25	0.28	0.31
P	1.39	1.46	0.66	0.83
K	0.75	0.81	0.41	0.52
NP	0.51	0.52	0.43	0.35
NK	0.14	0.19	0.28	0.27
PK	1.38	1.59	0.60	0.84
NPK	0.57	0.51	0.43	0.35
		Percent K		
Control	9.09	5.70	3.95	4.00
N	9.34	3.30	4.24	3.60
P	8.90	5.90	4.30	3.90
K	8.56	5.60	4.00	4.40
NP	7.04	2.70	3.70	2.90
NK	10.34	5.10	4.80	4.60
PK	11.08	6.70	4.42	3.80
NPK	10.14	5.92	4.80	4.20
		Percent Ca		
Control	1.12	0.18	1.60	1.66
N	1.12	0.97	1.59	1.62
P	1.05	1.27	1.64	1.95
K	1.00	1.03	1.38	1.49
NP	1.38	1.21	1.86	2.10
NK	1.07	0.92	1.32	1.43
PK	1.22	1.26	1.88	1.92
NPK	1.15	1.04	1.28	1.57

Table 29. Analysis of Petioles and Blades of Taro Plants Grown in Pots[1/] (Continued)

Treatments	Petioles		Blades	
	2 Months	4 Months	2 Months	4 Months
		Percent Mg		
Control	0.36	0.36	0.38	0.41
N	0.54	0.38	0.47	0.41
P	0.39	0.43	0.43	0.45
K	0.31	0.30	0.35	0.38
NP	0.66	0.58	0.53	0.53
NK	0.39	0.25	0.37	0.32
PK	0.43	0.40	0.40	0.39
NPK	0.44	0.30	0.34	0.37

[1/] Composite samples from three plants per treatment.

months showed that plants which were yellowing had only about 1% N in the petioles and about 3% N in the blades, whereas the N-treated plants had over 2% and 4% N in the petioles and blades, respectively.

Even after applying N at the age of two months, the plants at the age of four months all showed symptoms of N deficiency. The N-treated plants were also generally yellow; however, growth did not seem to be affected by the apparent N deficiency. Results of chemical analysis of tissues sampled at four months confirmed the N deficiency. All plants including those which received N fertilization had only about 0.8% N in the petioles and a little over 3% N in the blades. A few weeks after the last application of N (applied at four months), the leaves of the N-treated plants became greener and the growth became more vigorous. At the age of six months when the plants were harvested for analysis, leaves were yellowing again which seems to indicate a rapid loss of N from the soil. The only explanation for the apparent loss of N from the soil used is leaching because the plants were watered daily and the cans were provided with holes for drainage. In spite of the appearance of N deficiency the total corms, roots and tops of the plants were significantly increased by N.

Table 30 shows the weights of corms, roots and tops of the plants at the age of six months. Analysis of variance confirmed the highly significant increases in yields of corms and tops due to

Table 30. Weight of Corms, Roots and Tops of Six-Month Old Taro Plants Grown in Pots[1/]

Treatments	Corms fresh wt	Roots dry wt	Tops dry wt
		grams per plant	
Control	49.6	1.0	8.8
N	478.4	22.3	86.7
P	73.1	1.9	10.9
K	76.9	1.7	8.5
NP	654.5	22.5	67.4
NK	661.9	41.8	69.9
PK	70.7	2.4	11.5
NPK	771.7	26.4	64.3

[1/] Average of three replications. Corms, roots and tops from main plant and suckers. Tops include petioles and blades.

Analysis of Variance

Source of Variance	Df	Mean Square		
		Corms	Roots	Tops
Replications	2	3307	2	478
Treatments	(7)	301532**	712**	3445**
N	1	1976948**	4208**	23195**
P	1	34486	70	146
K	1	39752	227*	142
NP	1	27049	106	337
NK	1	28525	187*	154
PK	1	3458	95	80
NPK	1	503	90	60
Error	14			
Total	23			

**Significant at 1% level, *Significant at 5% level.

N fertilization and the lack of significant increase due to P and K fertilization. Phosphorus and/or K when added with N had additive effects on the increased weights of the corms and tops; however, only K had a significant interaction with N and this was on the increase in weight of roots. This significant effect is due to the greater increase in weight of roots of taro as a result of the greater proliferation of taro roots with addition of K fertilizer. Although there were no significant effects of P and K fertilization on yield the control plants had smaller corms than the P and K treated plants.

Analysis of roots and corms for N, P, and K again confirmed the findings that the lack of response to P and K are manifested in tissue composition for these elements. The only significant increases over the control were produced by N applications. Dilution effect of N on the P and K content of the roots, corms and leaves of the plants was clearly demonstrated. For example, at the age of six months, the average P content of the roots and corms of N-treated plants was about 0.10% and in the petioles and blades, 0.20% and 0.25%, respectively. The control and P- and K-treated plants had at least twice as much P in their tissues. The same was true with the K content of N-treated plants.

The fact that there did not seem to be an adverse effect of the appearance of N deficiency symptoms after plants were about three months old and also a month after the last fertilizer N was applied indicates that N was needed most by the plants at the early stages of growth, especially when the suckers were starting to form. It is also apparent that a more frequent addition of small amounts of N would be more beneficial to the plants because of losses of N through leaching and/or denitrification.

Luxury consumption of both P and K were evident since the tissue contents of P and K were much higher in the plants which received P and/or K fertilization, but there was no significant response to these nutrients either in corm yields or growth of roots and tops. This phenomenon was also observed in plants grown in the field (upland and lowland) where the K and P concentrations in petioles reached 10.3% and 0.6%, respectively.

Results of analysis for percent N, P, and K of individual leaves of plants harvested at six months are shown in Table 31. The improved appearance of the plants at time of harvest compared to their appearance at four months of age was shown by the slight increase in N content of petioles and blades of N-fertilized plants. Regardless of treatment, the N content of both petioles and blades decreased from the youngest to the oldest open leaf. Phosphorus content of petioles and blades followed the same trends as N content except for plants which received P fertilizers, including control plants. It seems that when P is limiting or when P content of tissues decreases due to increased growth of the

Table 31. Composition of the Petioles and Blades of Individual Leaves of Six-Month Old Taro Grown in Pots[1/]

Treatments	Petioles				Blades			
	Leaf Number				Leaf Number			
	1	2[2/]	3	4	1	2[2/]	3	4
				Percent N				
Control	0.88	0.84	0.84	0.79	3.16	3.29	3.00	2.53
N	1.02	0.86	0.81	0.77	3.67	3.60	3.27	2.83
P	0.95	0.93	0.89	0.85	3.51	3.63	3.19	2.85
K	1.16	0.93	0.89	0.82	3.84	3.52	3.49	3.01
NP	1.41	1.06	0.83	0.79	4.06	3.49	3.33	2.86
NK	1.10	0.95	0.87	0.85	3.77	3.65	3.36	2.69
PK	0.94	0.82	0.77	0.75	3.68	3.47	3.03	2.53
NPK	1.41	1.12	1.06	0.97	4.79	4.16	3.41	2.60
				Percent P				
Control	0.56	0.71	0.82	1.13	0.42	0.37	0.34	0.38
N	0.23	0.17	0.15	0.14	0.33	0.26	0.21	0.30
P	0.63	0.83	0.93	1.21	0.48	0.53	0.50	0.51
K	0.65	0.62	0.70	0.84	0.51	0.39	0.38	0.37
NP	0.62	0.48	0.44	0.45	0.48	0.33	0.30	0.27
NK	0.27	0.20	0.16	0.15	0.35	0.26	0.23	0.20
PK	0.73	0.74	0.87	1.21	0.52	0.52	0.49	0.55
NPK	0.64	0.59	0.56	0.54	0.56	0.39	0.33	0.25
				Percent K				
Control	4.20	4.55	4.40	4.95	4.05	3.64	3.00	3.00
N	2.52	1.84	1.46	1.16	3.24	2.60	2.15	1.68
P	4.20	4.05	3.80	3.90	3.80	3.64	3.08	2.75
K	5.68	4.90	4.90	4.74	4.80	4.45	3.56	3.56
NP	3.34	1.90	1.60	1.16	3.34	2.06	1.90	1.45
NK	5.96	5.10	4.55	4.55	4.00	4.20	3.65	3.90
PK	5.60	4.45	4.45	4.95	4.54	4.20	3.65	3.20
NPK	6.50	5.48	5.86	5.30	4.45	3.84	3.40	3.26

[1/] Composite samples from three plants per treatment.

[2/] Corresponds to "index tissue" sampled from the field experiments conducted.

plants, P moves from older leaves to younger leaves.

Potassium in leaves also decreased from the youngest to the oldest. Similarly, Twyford and Coulter (1964) found that N, P, and K in banana leaves decreased from the youngest to oldest leaves.

Results from the pot experiment confirms the nutritional behavior of the taro plant as observed in the field experiments. The plants in both cases tended to exhibit a rapid vegetative growth at the age of one to three months and then decline after the age of five months. The rapid vegetative growth is accompanied by a high concentration of nutrients in the tissues as also shown by the tissue analysis data. This tendency of the plant to take up fertilizer nutrients in relatively high amounts at an early stage of growth can be used to form a sound fertilization program where most of the fertilizers needed in a growing season has to be applied within the first three to five months after planting. If fertilizers were applied at the time of planting, remaining fertilization can be accomplished at regular and frequent intervals from two to five months after planting with the amounts of fertilizers applied calculated to maintain adequate amounts of nutrients in the soil for full development of the crop. The first fertilizer application will enable the plants to develop rapidly and form as many suckers as possible. The succeeding fertilizer applications will maintain the level of nutrients for the growth and development of the plants insuring a good yield both from the main plants and the suckers.

Effect of fertilization on specific gravity or density of corms was only slightly significant or not significant at all. Effect of fertilization on nutrient content of corms especially for N (protein), P and K, however, was highly significant. Corms from field experiments, both upland and lowland, and from pot experiments show that N fertilization increases the N content of corms which when multiplied by a factor of 6.25 for conversion to protein content becomes of considerable importance when food value of the corms is taken into consideration (Tables 32 and 33). In the pot experiment, there was an increase of about 250% in protein content of N-treated plants when compared with protein content of control plants representing an increase from 1.44% in the control plants to 5.06% protein in the N-treated plants. In upland and lowland taro, the increase in protein was only about 53.5% in plants which received 1120 kg/ha N over plants which did not receive N fertilizers.

Phosphorus and K in corms also increased with P and K fertilization. Values obtained from these experiments are much higher than published analysis of taro corms and leaves (Watt and Merrill, 1963; Miller and Branthoover, 1957).

Table 32. N, P and K Contents of the Roots and Corms of Six-Month Old Taro Grown in Pots

Treatments	Roots			Corms		
	% N	% P	% K	% N	% P	% K
Control	0.79	0.25	5.05	0.23	0.20	1.00
N	0.93	0.10	0.75	0.81	0.15	0.56
P	0.89	0.39	4.90	0.33	0.24	0.94
K	0.78	0.21	5.52	0.25	0.20	1.04
NP	1.07	0.29	0.48	0.71	0.23	0.52
NK	1.20	0.12	4.00	0.60	0.12	1.20
PK	0.89	0.40	5.88	0.38	0.24	1.02
NPK	1.20	0.28	3.40	0.60	0.21	1.17

Table 33. Composition of Upland and Lowland Taro Corms Harvested at the Age of 12 Months[1/]

Treatments kg/ha	Nutrient Contents % N	% P	% K	% Ca	% Mg
			Upland Taro		
0 (control)	0.65	0.12	1.03	0.28	0.072
0 N	0.58	0.18	1.19	0.26	0.067
280 N	0.79	0.17	1.04	0.20	0.059
560 N	0.79	0.16	0.88	0.28	0.050
1120 N	0.89	0.15	0.82	0.29	0.047
0 P	0.82	0.13	1.31	0.23	0.056
280 P	0.79	0.17	1.04	0.20	0.059
560 P	0.92	0.18	1.21	0.26	0.055
1120 P	0.70	0.20	1.22	0.30	0.053
0 K	0.70	0.16	0.75	0.25	0.066
280 K	0.79	0.17	1.04	0.20	0.059
560 K	0.65	0.17	1.22	0.22	0.063
1120 K	0.72	0.18	1.50	0.25	0.056
			Lowland Taro		
0 (control)	0.38	0.16	0.42	0.17	0.120
0 N	0.36	0.16	0.59	0.17	0.094
280 N	0.40	0.16	0.52	0.19	0.094
560 N	0.43	0.16	0.45	0.16	0.100
1120 N	0.55	0.16	0.40	0.18	0.084
0 P	0.37	0.16	0.41	0.14	0.095
280 P	0.40	0.16	0.52	0.19	0.094
560 P	0.38	0.17	0.49	0.15	0.095
1120 P	0.40	0.16	0.43	0.15	0.091
0 K	0.42	0.16	0.41	0.18	0.103
280 K	0.40	0.16	0.52	0.19	0.094
560 K	0.36	0.16	0.55	0.18	0.097
1120 K	0.41	0.15	0.64	0.17	0.094

[1/]Average of three replications. Each replicate a composite sample from three corms.

SUMMARY AND CONCLUSIONS

The effects of N, P, and K fertilization on growth, nutrient uptake, yield and quality of taro grown under upland and lowland conditions were studied on the Island of Kauai. The following rates were used: 0, 280, 560, and 1120 kg/ha of each element. In addition, the nitrogen-treated plants also received basic applications of 280 kg/ha each of P and K; the phosphorus-treated plants, 280 kg/ha each of N and K; and the potassium-treated plants, 280 kg/ha each of N and P. The control plants were not fertilized.

A 2 x 2 x 2 N-P-K interaction experiment was also conducted in pots using 0 and 15 grams of each element per plant.

Analysis of soil and plant samples collected periodically from field experiments showed the following important points:

1. Nitrogen fertilization increased N contents of taro leaves but decreased both P and K contents. The depressing effects of N on nutrient contents of taro plant is essentially due to a dilution effect brought about by the increased growth of the plants which were fertilized with N.

2. Nitrogen fertilization depressed the pH and exchangeable Ca of the upland soil. In lowland soil, only exchangeable K decreased significantly with N fertilization, an evidence of the K^{+}-NH_4^{+} ion competition for exchange sites in the soil.

3. Phosphorus fertilization increased P content of taro leaves but depressed K contents especially in the upland. Phosphorus fertilization did not have significant effects on P content of lowland taro leaves probably because of the high P content of the soil.

4. Soil pH, exchangeable Ca and soluble P increased significantly in upland soil. In lowland soil, significant effects of P fertilization were increases in total N, soluble P and exchangeable K only.

5. Potassium fertilization had several significant effects on composition of upland and lowland taro leaves. The K contents of leaves of both upland and lowland taro increased significantly with application of K fertilizer. Both Ca and Mg decreased significantly in the leaves. Total N in the upland taro leaves increased with K application but in the lowland total N decreased. The decrease in Ca and Mg in both upland and lowland taro leaves and total N in the lowland is due to competition among the cations Ca^{++}, Mg^{++}, K^{+}, and NH_4^{+}.

6. In the soil, only the pH and exchangeable K of the upland increased significantly with application of K fertilizer and in the lowland, only exchangeable K increased and total soil N decreased significantly.

7. The K contents of the lowland taro leaves were lower than the K content of the upland taro leaves regardless of treat-

ments. This observation is due to the high amounts of Ca and Mg in the lowland soil and the depressed K uptake by the taro plant is probably due to both Ca and Mg.

The following yield responses to fertilization were obtained from the field experiments:

1. Total yields of both upland and lowland taro increased significantly with N applications. The yields in metric tons per hectare of the plants which received 0 kg/ha N in the upland and lowland were 10.7 and 31.6, respectively, and the yields of the plants which received 560 kg/ha N in the upland was 23.5, and in the lowland the plants fertilized with 1120 kg/ha N yielded 50.2. The plants which received 1120 kg/ha N in the upland gave lower yields than those which received 560 kg/ha N. The control plants yielded 6.7 and 28.5 tons/ha in the upland and lowland, respectively. The tendency of the upland yields to decrease at the highest rate of nitrogen fertilization is due to the imbalance in nutrient contents of the soil resulting from the relatively low initial fertility of the upland soil compared to the lowland soil.

2. In both upland and lowland, the yields were also increased significantly by P applications. The yields of the plots which received 0 kg/ha P were 15.2 tons/ha from the upland and 35.7 tons/ha for the lowland. The plants which received 1120 kg/ha P yielded 28.7 and 42.3 tons/ha in the upland and lowland, respectively.

3. Potassium fertilization gave significant increases in the yields of the upland taro only. The yields of the plants which received 0 kg/ha K were 16.6 and 39.7 tons/ha in the upland and lowland, respectively. Those which received 1120 kg/ha K yielded 23.9 and 39.9 tons/ha in the upland and lowland, respectively.

Based on the results of the field and pot experiments, it is recommended that fertilizers should be applied at the early stages of growth of the taro crop. Phosphorus fertilizer should be applied before planting together with parts of the N and K fertilizers. After the first applications, smaller quantities of N and K should be added at more frequent intervals to maintain adequate supply of these nutrients for the development of the plants with the last application at about five or six months after planting. In view of innumerable differences in soils used for taro production, rates of fertilization will vary; however, it is recommended that the total amount of nutrients in the tops of taro at the age of three months should be about 30 kg/ha N, 3 kg/ha P, and 60 kg/ha K in the upland, and about 60 kg/ha N, 10 kg/ha P, and 100 kg/ha K in the lowland.

Succeeding crops may not have to be fertilized with the same rates of fertilizers but sufficient fertilizers should be added to replace the amounts of nutrients removed by the previous crop from the soils. Additional fertilization may also be necessary whenever deficiency symptoms especially of N start showing up at early stages of growth and development of the crop, i.e. three to five months after planting.

In the pot experiment the following are the important observations:

1. Only N fertilization gave significant increases in the weights of the corms, roots and leaves of the plants.

2. Nitrogen deficiency characterized by general yellowing of the plants was observed in all plants which did not receive N fertilization, the symptoms appearing first at the age of one month.

3. No P and K deficiency symptoms were observed.

4. Root composition was also affected by the fertilizer treatments.

5. The N, P, and K contents of the petioles and blades of the individual leaves decreased from the youngest open leaf to the oldest, except for P which increased from the youngest to the oldest when the P supply in the soil was not limiting.

Fertilization also affected the specific gravity or density of the taro corms. Nitrogen fertilization decreased the density of both upland and lowland taro corms significantly. Phosphorus fertilization did not have significant effects on corm density. Potassium fertilization increased the specific gravity of the corms, especially in the lowland.

The nutrient quality of the corms is also influenced by fertilization. Protein content of the corms of upland and lowland taro which were fertilized with N increased by as much as 53.5% compared to the control. In the pot experiments, the increase in protein content was as high as 250%. The P and K contents of the corms also increased with P and K fertilization.

Results of the experiments showed that both soil chemical analysis and plant tissue analysis can be used to evaluate the fertilizer requirements of the taro crop. In soil analysis, however, another method of extracting soil N aside from the total N value should be used to give a reliable index for the nitrogen requirement of taro.

APPENDIX

Methods of Analysis for Plants and Soils

I. Ashing for P, K, Ca and Mg in plants.

Reagents:

1. Alcoholic-sulfuric acid - 50 ml of concentrated sulfuric acid (reagent grade) mixed with 950 ml of 95% ethyl alcohol.
2. 4N HCl - 1 part concentrated hydrochloric acid (reagent grade) added to 2 parts of distilled water.
3. Filter paper - No. 589, white ribbon.
4. Porcelain crucibles - Coors No. 0 or No. 1.

Procedure:

1. Weigh 0.5 g dry, ground samples into porcelain crucibles.
2. Cover samples with alcoholic-sulfuric acid mixture.
3. Ignite samples with bunsen burner preferably in a hood. (Do not use match or splinter directly over samples to avoid contaminations.) Allow samples to burn until the flame is gone.
4. Put samples in the muffle furnace and ash overnight at 500-550°C.
5. After ashing, allow the samples to cool then add a few drops of distilled water. Add 10 ml of 4N HCl and warm for 20-30 minutes on a hot plate to dissolve the ash.

6. Filter into 100-ml volumetric flasks and make to volume. This plant extract may be stored in 125-ml Erlenmeyer flasks for future analysis of P, K, Ca and Mg. Other elements including Na, Fe, Mn, etc., can be analyzed from this extract.

II. Total P in plants.

Reagents:

1. Barton's reagent - Dissolve 22.5 g of ammonium molybdate, $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$, in 400 ml water. Dissolve 1.25 g ammonium vanadate, NH_4VO_3, in 300 ml boiling water. Add the ammonium vanadate solution to the ammonium molybdate solution and cool to room temperature. Add 250 ml concentrated nitric acid (reagent grade) and dilute to 1 liter.
2. Phosphorus standard - Dissolve oven-dried (105°C) 0.2195 g KH_2PO_4 and dilute to 1 liter. This solution contains 50 ppm P or 50 μg P per ml.
3. Klett-Summerson photoelectric colorimeter set at 420 mμ.

Procedure:

1. Pipette 10 ml aliquots from the plant extracts into 50-ml. volumetric flasks.
2. Add 10 ml of Barton's reagent, make to volume with distilled water and shake well.

3. After 30 minutes, read density of color at 420 mμ on the colorimeter. Note: The color develops in several minutes. Usually 30 minutes is allowed for full color development. Color is stable for 2 months at high P concentrations; 5 ppm P is stable for 2 weeks.

4. Prepare a series of standards by taking aliquots from the P stock solution, i.e. 0, 2, 4, 6, 8, 10 ml into 50-ml volumetric flasks. Develop color similarly and read before unknown samples in the same colorimeter.

III. Total Ca in plants.

Reagents:

1. 50% triethanol amine - 1 part triethanol amine mixed with 1 part distilled water.

2. 2% KCN - 2 g potassium cyanide dissolved in 100 ml distilled water.

3. 2N KOH - 112 g potassium hydroxide dissolved to make 1 liter solution.

4. Calcon indicator - 0.20 g of Calcon dissolved in 50 ml methanol. Prepare fresh solution weekly for sharp end-point.

5. Standard Ca - Dissolve 0.5004 g of reagent grade $CaCO_3$ (dried at 105°C) in 5 ml of approximately 6N HCl and dilute the solution to a volume of 1 liter. This solution is 0.005M or 0.01N Ca. If desired, 0.005N

Ca may be prepared instead of 0.01N Ca.

6. Standard EDTA - Dissolve 1.0 g of disodium dihydrogen ethylene diamine tetraacetate and 0.05 g magnesium chloride hexahydrate in water and dilute to a volume of 1 liter. Standardize EDTA solution with the standard Ca using Calcon indicator. Approximately 0.005N EDTA.
7. Microburettes for standard Ca and EDTA.

Procedure:

1. Take 10 ml aliquots from the plant extract and add 2 ml of 50% triethanolamine, 1 ml of 2% KCN, and 5 ml of 2N KOH. Check the pH (add KOH if the pH is below 12).
2. Add about 20-30 ml distilled water.
3. Add 4 to 6 drops of Calcon indicator and titrate to permanent blue end-point with standard EDTA solution. Note: If the solution did not turn pink or purple upon addition of the indicator, add a few drops of 2N KOH until pink color appears. Lack of KOH is indicated by a blue starting color.

IV. Total Mg in plants.

Reagents:

1. 50% triethanolamine - 1 part triethanolamine mixed with 1 part water.

2. 2% KCN - 2 g potassium cyanide dissolved in 100 ml water.

3. 5% hydroxylaminehydrochloride - 5 g of hydroxylamine hydrochloride dissolved in 100 ml water.

4. 20% Na_2WO_4 - 20 g of sodium tungstate dissolved in 100 ml water.

5. Buffer solution - Dissolve 67.5 g of ammonium chloride, NH_4Cl, in 200 ml water. Add 570 ml of concentrated ammonium hydroxide, NH_4OH, and dilute solution to 1 liter.

6. Standard Mg - Dissolve 0.1216 g of purified magnesium ribbon in dilute HCl and dilute to a volume of 1 liter. This solution is 0.005M Mg or 0.01N Mg.

7. Eriochrome Black T indicator - Dissolve 0.2 g of Eriochrome Black T in 50 ml methanol. Prepare fresh every three weeks.

8. Methyl red - Dissolve 0.1 g of methyl red in 100 ml of 50% ethyl alcohol. This indicator is used only with Eriochrome Black T when a green end-point is preferred to a blue end-point which is the result of using Eriochrome Black T only.

Precedure:

1. Pipette 25 ml aliquots of the plant extracts into 150-ml beakers.

2. Add 20 ml of buffer solution.
3. Add 10-20 of 20% sodium tungstate solution (use 20 ml if Ca is expected to be high).
4. Cover beaker with watch glass and warm gently on a hot plate for about 2 hours. Do not boil.
5. Filter into 250-ml Erlenmeyer flasks using Whatman No. 42 filter paper. Wash filter paper with 1:20 buffer solution (1 part buffer solution to 20 parts water).
6. To filtrate, add 2 ml 50% triethanolamine, 1 ml 2% potassium cyanide, 0.5 ml 5% hydroxylamine hydrochloride, and 6-10 drops of Eriochrome Black T. Add 6-10 drops of methyl red for green end-point. Do not add too much indicators to avoid dark solutions which are hard to titrate. Titrate the solution with standard EDTA to a permanent green or blue end-point. If the initial color of the solution upon addition of Eriochrome Black T is not pink or purple, add a few ml of buffer solution to the filtrate to adjust the pH to approximately pH 10. Standard EDTA must have been standardized using Eriochrome Black T.

V. Total K in plant.

<u>Reagents and Apparatus</u>:

1. Standard K - Weigh 1.9069 g of dried potassium chloride, dissolve and dilute to 1 liter. This solution

contains 1000 ppm K and can be used as stock solution for a series of K standards, i.e. 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 ppm K in 0.4N HCl.

2. Flame photometer (Beckman DU) set at 768 mμ.

Procedure:

1. Run the series of K standards to obtain a working curve.
2. Run the unknown samples from the plant extract (dilute plant extracts if final concentration of K is higher than 5% oven dry basis).
3. Calculate concentration of K in the samples by interpolating flame photometer readings from the standard curve.

VI. Total N in plants and soils.

Reagents:

1. Sulfuric-salicylic acid solution - Dissolve 67 g of salicylic acid in 2 liters of concentrated sulfuric acid.
2. 50% or 1:1 NaOH - Dissolve 25 pounds of sodium hydroxide flakes in 11.4 liters of water. Allow solution to cool to room temperature before using.
3. Sodium sulfate crystals.
4. Sodium thiosulfate crystals.
5. Mossy zinc, large pieces.
6. Copper sulfate crystals.

7. Glass beads - ca 5 mm in diameter.

8. 4% boric acid - Dissolve 40 g of boric acid in 1 liter solution.

9. Standard H_2SO_4 - 0.0714N sulfuric acid, standardized with sodium carbonate.

10. Mixed indicator - Dissolve 0.20 g methyl red in 50 ml of 95% ethyl alcohol (grind in fine mortar if necessary). Dissolve 0.10 g of methylene blue in 50 ml of 95% ethyl alcohol. Mix both solutions for use.

Procedure:

1. Weigh 0.5 g of dried, ground plant samples into 800 ml Kjeldahl flasks (use 5-10 g of air dried soil samples).

2. Add 10 g of sodium sulfate crystals (about 1 teaspoon) into the samples.

3. Add 1.0 g of copper sulfate crystals.

4. Add 2-3 glass beads and 35 ml of concentrated sulfuric acid-salicylic acid mixture. Whirl the flask to mix the acid and samples. Let stand for 15-30 minutes.

5. Add 5-10 g of sodium thiosulfate crystals (about 1 teaspoon) and immediately put flask into digestion manifold. Turn on heat until samples begin to froth. Turn heat off and rotate flasks to prevent excessive frothing. Cool for about 15 minutes, then turn heat on and digest for 1 hour. Note: Some samples froth excessively

(especially soil samples), therefore, rotation of flasks and low heat at the start are necessary until danger of overflowing is over. Digested plant material should be clear, greenish blue. Soils when digested look yellowish gray or brown.

6. After digestion, turn heat off, cool flasks and add about 250 ml water.
7. After the digest solution has cooled to room temperature proceed with the distillation.
8. Into 500-ml Erlenmeyer flasks, put 50 ml of 4% boric acid. Add 4-5 drops of mixed indicator and set in the receiving end of the condensers with the condenser tube touching the boric acid solution.
9. Into the digest material add 70-80 ml of 50% sodium hydroxide solution, 2-3 pieces of mossy zinc and quickly connect the flask to the condenser.
10. Shake flask and contents and start distillation with a low heat or flame. After about one-half of the solution has been distilled, increase the heat or flame as long as there is no more danger of the samples boiling over into the condenser trap and tube.
11. Distill about 250 ml of solution before lowering the flasks. Allow the distillation to proceed a few more minutes to drain the tubes before turning off the flame or heat.

12. Titrate the distillate with standard sulfuric acid to a light pink or purple end-point.

VII. Cation exchange capacity of soils.

Reagents:

1. 1N ammonium acetate - Add 57 ml of glacial acetic acid into about 800 ml of distilled water. Slowly add 67 ml of concentrated ammonium hydroxide, stir and adjust the pH to 7.0 then dilute to a final volume of 1 liter. For large number of determinations, 18-20 liters of the solution may be prepared at a time.
2. Methyl alcohol.
3. 4% KCl - Dissolve 4 g potassium chloride in 100 ml of distilled water.

Procedure:

1. Weigh out 25 g of air-dried soil sample (20 mesh) and place it in a 500 ml Erlenmeyer flask. Add 200 ml of 1N ammonium acetate solution and shake well. Stopper flasks tightly and let stand for 24 hours with occasional shaking, or shake in an automatic shaker for 1 hour. Filter through on a Buchner funnel using Whatman No. 5 filter paper. Wash with another 200 ml of ammonium acetate solution using about 50 ml portions at a time.
2. Save filtrate plus washings for exchangeable K, Ca and Mg determinations.

3. Wash soil residue with 50 ml portions of methyl alcohol about four times. Discard the washings.

4. Transfer washed soil plus filter paper into the original flask (rinse flask with distilled water before transferring samples). Add 200 ml of 4% potassium chloride and shake for about 30 minutes. Filter on a Buchner funnel using Whatman No. 5 and wash three times with 50 ml portions of 4% potassium chloride.

5. Transfer filtrate into 800 ml Kjeldahl flasks and distill the ammonia (use 10 ml 50% NaOH only) as in the distillation process for total nitrogen (steps 8-12 for total N).

VIII. Exchangeable Ca in soils.

<u>Reagent</u>:

1. 50% triethanolamine - 1 part triethanolamine mixed with 1 part water.

2. 2% KCN - 2 g potassium cyanide dissolved in 100 ml water.

3. 2N KOH - 112 g potassium hydroxide dissolved to make 1 liter solution.

4. Calcon indicator - 0.2 g of Calcon ($2\text{-}HOC_{10}H_6\text{-}1\text{-}N{:}N\text{-}4\text{-}C_{10}H_5.3.OH.1.SO_3Na$) dissolved in 50 ml methyl alcohol. Prepare fresh solution weekly for sharp end-point.

5. Standard Ca - Dissolve 0.5004 g of reagent grade $CaCO_3$ (dried at 105°C) in 5 ml of approximately 6N HCl and dilute to a volume of 1 liter. This solution is 0.005M or 0.01N Ca.
6. Standard EDTA - Dissolve 1.0 g of disodium dihydrogen ethylenediamine tetra acetate and 0.05 g magnesium chloride hexahydrate in water and dilute to a volume of 1 liter. Standardize the solution with the standard Ca using Calcon indicator.
7. Microburettes for standard solutions.

Procedure:

1. Pipette 25 ml aliquots from filtrate (step 2, cation exchange capacity of soils) for exchangeable bases into 250 ml Erlenmeyer flasks. Note: Before taking aliquots, filtrate should be made up to convenient volume, i.e. 500 ml.
2. Add 15 ml of 2N KOH, 2 ml of 50% triethanolamine, 1 ml of 2% KCN, 4-6 drops of Calcon indicator and titrate to a permanent blue end-point with standard EDTA.

IX. Exchangeable Mg in soils.

Reagent:

1. 50% triethanolamine - 1 part triethanolamine mixed with 1 part water.
2. 2% KCN - 2 g potassium cyanide dissolved in 100 ml

water.

3. 5% hydroxylamine hydrochloride - 5 g of hydroxylamine hydrochloride dissolved in 100 ml water.

4. 20% Na_2WO_4 - 20 g of sodium tungstate dissolved in 100 ml water.

5. Buffer solution - Dissolve 67.5 g of ammonium chloride in 200 ml water. Add 570 ml of concentrated ammonium hydroxide, NH_4OH, and dilute solution to 1 liter.

6. Standard Mg - Dissolve 0.1216 g of purified magnesium ribbon in dilute HCl and dilute to a volume of 1 liter. This solution is 0.005M or 0.01N Mg.

7. Eriochrome Black T indicator - Dissolve 0.2 g of Eriochrome Black T in 50 ml methyl alcohol. Prepare fresh every three weeks.

8. Methyl red - Dissolve 0.1 g methyl red in 100 ml 50% ethyl alcohol. This indicator is used only with Eriochrome Black T when a green end-point is preferr to a blue end-point which is the result of using Eriochrome Black T only.

<u>Procedure</u>:

1. Pipette 25 ml aliquots from the filtrates for exchangeable cations (step 2, cation exchange capacity of soils) into 150 ml beakers and add 25 ml of buffer solution, 10-20 ml 20% sodium tungstate solution.

2. Cover beakers with watch glass and warm gently on a hot plate for about 2 hours. Do not boil.

3. Filter into 250-ml Erlenmeyer flasks using Whatman No. 42 filter paper. Wash filter paper with 1:20 buffer solution (1 part buffer solution to 20 parts water).

4. To filtrate, add 2 ml 50% triethanolamine, 1 ml 2% potassium cyanide, 0.5 ml 5% hydroxylamine hydrochloride, and 6-10 drops of Eriochrome Black T. Add 6-10 drops of methyl red for green end-point. Do not add too much indicator to avoid dark solutions which are difficult to titrate. Titrate the solution with standard EDTA to a permanent green or blue end-point. Note: If the initial color of the solution upon addition of Eriochrome Black T is not pink or purple, add a few ml of buffer solution to the filtrate to adjust the pH to approximately pH 10.

X. Exchangeable K in soils.

<u>Reagents and Apparatus</u>:

1. Standard K - Weigh 1.9069 g of dried potassium chloride, KCl, dissolve and dilute to 1 liter. This solution contains 1000 ppm K and can be used as stock solution for a series of K standards. The final standards should be diluted with 1N ammonium acetate.

2. Flame photometer (Beckman Model DU) set at 768 mμ.

Procedure:

1. Run the series of K standards to obtain a working curve.

2. Run the unknown samples from the filtrate for exchangeable cations (step 2, cation exchange capacity of soils). Note: Filtrate must be re-filtered if solution is cloudy or if there is danger of clogging the flame photometer burner.

3. Calculate concentrations of K in the samples by interpolating the readings from the standard curve.

XI. Extractable P in soils.

Reagents:

1. Extracting solution 0.02 N H_2SO_4 containing 3 g ammonium sulfate, $(NH_4)_2SO_4$, per liter.

2. Ammonium molybdate-sulfuric acid solution - Dissolve 25 g ammonium molybdate in 200 ml water. Dilute 275 ml concentrated sulfuric acid, H_2SO_4, to 750 ml. Allow to cool, add ammonium molybdate solution slowly and with stirring to the sulfuric acid solution. After combined solution has cooled, dilute with water to 1 liter.

3. Stannous chloride solution - Dissolve 2.5 g of stannous chloride, $SnCl_2 \cdot 2H_2O$, in 10 ml of concentrated hydrochloric acid in Erlenmeyer flask, warming if necessary

to dissolve. Dilute to 100 ml. This solution is prepared fresh each time. If longer use of a large amount of prepared solution is desired, precautions must be taken to keep solution from going to the stannic form.

4. Standard P - Dissolve 0.2195 g of recrystallized potassium dihydrogen phosphate, KH_2PO_4, and dilute to 1 liter. This solution contains 50 ppm P and a second stock solution containing 2 ppm P is prepared by diluting 20 ml of the base stock solution to 500 ml.

Procedure:

1. Place 2 g of 20-mesh soil in an Erlenmeyer flask and add 200 ml of the extracting solution. Place on a shaker and shake for 30 minutes.
2. Filter through a Whatman No. 40 filter paper, refiltering first portions if turbid.
3. Pipette an aliquot from the filtrate into 50-ml volumetric flask.
4. Add 2 ml ammonium molybdate-sulfuric acid solution, make up to volume with the extracting solution and add 3 drops of stannous chloride solution, mix and read in the colorimeter with a 660 mμ filter. The reading must be done within 10-12 minutes after the addition of the stannous chloride solution.

5. Calculate concentration of unknown solutions by interpolating the readings in a curve derived from a series of standard.

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Appendix Table 1
Correlation Coefficients (r) of Upland and Lowland Soils
from Plots Fertilized With Nitrogen[1/]
df = 46, r = 0.288 (5%), r = 0.372 (1%)

	pH	Exch. K	Exch. Ca	Exch. Mg	Total N	Ext. P
			Upland Soil			
pH						
Exch. K	0.396**					
Exch. Ca	0.638**	0.281				
Exch. Mg	0.207	0.394**	0.392**			
Total N	-0.463**	-0.144	-0.314*	-0.081		
Ext. P	-0.048	0.299*	0.250	-0.010	-0.034	
			Lowland Soil			
pH						
Exch. K	0.100					
Exch. Ca	0.781**	0.198				
Exch. Mg	-0.644**	-0.083	-0.689**			
Total N	-0.165	0.170	0.091	0.227		
Ext. P	0.260	0.576**	0.418**	-0.154	0.0419	

[1/] Observations from control plots were not included in the statistical analysis.

Appendix Table 2
Correlation Coefficients (r) of Leaves
of Upland and Lowland Taro Fertilized With Nitrogen[1/]
df = 46, r = 0.288 (5%), r = 0.372 (1%)

	% N	% P	% K	% Ca	% Mg
Upland Taro			Petioles		
% N					
% P	-0.386**				
% K	0.467**	0.089			
% Ca	0.451**	0.021	0.547**		
% Mg	0.157	-0.211	-0.108	-0.124	
			Blades		
% N					
% P	0.140				
% K	0.248	0.220			
% Ca	-0.150	0.350*	-0.120		
% Mg	0.119	0.191	-0.462**	0.178	
Lowland Taro			Petioles		
% N					
% P	0.380**				
% K	0.404**	0.777**			
% Ca	0.322*	0.257	0.243		
% Mg	0.605**	0.107	0.070	0.133	
			Blades		
% N					
% P	0.868**				
% K	0.380**	0.642**			
% Ca	-0.079	-0.051	0.001		
% Mg	0.578**	0.315*	-0.109	0.012	

[1/]Data from control plots were not included in the statistical analysis.

Appendix Table 3
Correlation Coefficients (r) of Soils and Plant Analyses
from Upland and Lowland Taro Plots Fertilized With Nitrogen[1/]
df = 46, r = 0.288 (5%), r = 0.372 (1%)

Soil Analysis	Petioles					Blades				
	% N	% P	% K	% Ca	% Mg	% N	% P	% K	% Ca	% Mg
Upland Taro										
pH	-0.256	0.459**	0.460**	0.020	0.103	-0.185	0.480**	0.459**	0.165	-0.116
Exch. K	0.300*	-0.204	0.436**	0.203	0.062	0.305*	0.094	0.515**	-0.390**	-0.315*
Exch. Ca	-0.003	0.291*	0.683**	0.414**	-0.183	-0.043	0.527**	0.456**	0.405**	-0.247
Exch. Mg	0.210	0.069	0.294*	0.354*	-0.183	0.063	0.158	-0.022	0.026	0.155
Total N	-0.085	0.009	-0.243	-0.041	-0.393**	-0.305*	-0.324*	-0.182	-0.100	-0.246
Ext. P	0.237	-0.403**	0.199	-0.019	0.009	0.329*	-0.002	0.281	-0.190	-0.282
Lowland Taro										
pH	0.071	-0.162	-0.013	0.326*	-0.220	0.187	0.080	0.028	0.273	0.016
Exch. K	0.393**	0.299*	0.620**	0.291*	0.372**	0.576**	0.533**	0.471**	0.049	0.554**
Exch. Ca	-0.010	-0.130	-0.001	0.377**	-0.231	0.105	0.038	0.044	0.282*	-0.007
Exch. Mg	0.065	0.247	0.081	-0.307*	0.068	0.011	0.132	0.106	-0.263	-0.111
Total N	-0.166	0.153	-0.019	-0.014	-0.044	-0.112	0.082	0.048	0.035	-0.092
Ext. P	0.280*	0.124	0.384**	0.270	0.201	0.496**	0.373**	0.307*	0.116	0.448**

[1/]Data from control plots were not included in the statistical analysis.

Appendix Table 4
Correlation Coefficients (r) of Upland and Lowland Soils from Plots Fertilized With Phosphorus[1/]
df = 46, r = 0.288 (5%), r = 0.372 (1%)

	pH	Exch. K	Exch. Ca	Exch. Mg	Total N	Ext. P
			Upland Soils			
pH						
Exch. K	0.327*					
Exch. Ca	0.446**	0.069				
Exch. Mg	-0.666**	-0.126	-0.163			
Total N	-0.247	-0.071	-0.176	0.062		
Ext. P	0.177	-0.061	0.847**	-0.108	-0.142	
			Lowland Soils			
pH						
Exch. K	0.124					
Exch. Ca	0.779**	0.263				
Exch. Mg	-0.716**	-0.014	-0.672			
Total N	0.056	0.251	0.320*	0.108		
Ext. P	0.302*	0.719**	0.443	-0.155	0.246	

[1/]Data from control plots were not included in the statistical analysis.

Appendix Table 5
Correlation Coefficients (r) of Leaves
of Upland and Lowland Taro Fertilized With Phosphorus[1/]
df = 46, r = 0.288 (5%), r = 0.372 (1%)

	% N	% P	% K	% Ca	% Mg
Upland Taro			Petioles		
% N					
% P	-0.098				
% K	0.842**	-0.251			
% Ca	0.660**	0.168	0.505**		
% Mg	-0.061	-0.049	-0.165	-0.036	
			Blades		
% N					
% P	0.195				
% K	0.400**	-0.083			
% Ca	0.106	0.258	-0.214		
% Mg	0.030	0.210	-0.534**	0.215	
Lowland Taro			Petioles		
% N					
% P	0.490**				
% K	0.818**	0.748**			
% Ca	0.264	0.436**	0.326*		
% Mg	0.562**	0.212	0.447**	0.168	
			Blades		
% N					
% P	0.902**				
% K	0.737**	0.824**			
% Ca	-0.410**	-0.218	-0.249		
% Mg	0.596**	0.362*	0.259	-0.275	

[1/] Data from control plots were not included in the statistical analysis.

Appendix Table 6
Correlation Coefficients (r) of Soils and Plant Analyses
from Upland and Lowland Taro Plots Fertilized With Phosphorus[1/]
df = 46, r = 0.288 (5%), r = 0.372 (1%)

Soil Analysis	Petioles					Blades				
	% N	% P	% K	% Ca	% Mg	% N	% P	% K	% Ca	% Mg
					Upland Taro					
pH	-0.138	0.084	-0.175	-0.130	0.112	-0.042	-0.021	-0.003	-0.082	-0.058
Exch. K	0.495**	-0.284	0.537**	0.173	-0.140	0.472**	-0.098	0.576**	-0.117	-0.419**
Exch. Ca	0.100	0.391**	-0.912**	0.236	-0.018	0.108	0.590**	-0.076	0.258	-0.081
Exch. Mg	0.288*	0.108	0.271	0.386**	-0.342*	0.056	0.167	-0.055	0.171	0.098
Total N	-0.163	0.131	-0.167	0.072	-0.204	-0.471**	-0.117	-0.198	-0.033	-0.222
Ext. P	0.004	0.374**	- 0.156	0.112	0.063	0.081	0.573**	0.082	0.253	-0.041
					Lowland Taro					
pH	0.226	-0.210	0.010	0.012	-0.255	0.332*	0.190	0.074	-0.203	0.092
Exch. K	0.748**	0.237	0.580**	0.284	0.565**	0.791**	0.668**	0.593**	-0.346*	0.607**
Exch. Ca	0.186	-0.140	-0.028	0.203	-0.189	0.319*	0.228	0.037	-0.092	0.029
Exch. Mg	-0.184	0.187	0.050	-0.046	0.091	-0.241	-0.176	0.030	0.153	-0.066
Total N	-0.120	-0.078	-0.177	0.139	-0.245	-0.055	-0.017	-0.086	0.234	-0.158
Ext. P	0.574**	0.009	0.300	-0.033	0.248	0.605**	0.437**	0.327*	-0.284	0.453**

[1/] Data from control plots were not included in the statistical analysis.

Appendix Table 7
Correlation Coefficients (r) of Upland and Lowland Soils
from Plots Fertilized With Potassium[1/]
df = 46, r = 0.288 (5%), r = 0.372 (1%)

	pH	Exch. K	Exch. Ca	Exch. Mg	Total N	Ext. P
			Upland Soil			
pH						
Exch. K	0.614**					
Exch. Ca	0.249	0.034				
Exch. Mg	-0.277	-0.122	0.169			
Total N	-0.297*	-0.094	0.038	0.215		
Ext. P	0.088	0.194	0.494**	-0.190	0.092	
			Lowland Soil			
pH						
Exch. K	0.062					
Exch. Ca	0.714**	0.132				
Exch. Mg	-0.690**	-0.018	-0.763**			
Total N	-0.091	-0.122	0.075	0.144		
Ext. P	0.102	0.477**	0.260	-0.096	0.030	

[1/]Data from control plots were not included in the statistical analysis.

Appendix Table 8
Correlation Coefficients (r) of Leaves
of Upland and Lowland Taro Fertilized With Potassium[1/]
df = 46, r = 0.288 (5%), r = 0.372 (1%)

	% N	% P	% K	% Ca	% Mg
Upland Taro			Petioles		
% N		—			
% P	-0.344*				
% K	0.674**	-0.209			
% Ca	0.226	0.017	-0.188		
% Mg	0.155	-0.187	-0.590**	0.312*	
			Blades		
% N					
% P	0.080				
% K	0.342*	-0.045			
% Ca	0.138	0.142	-0.625**		
% Mg	-0.001	0.193	-0.760**	0.498**	
Lowland Taro			Petioles		
% N					
% P	0.486**				
% K	0.583**	0.592**			
% Ca	0.371*	0.357*	-0.125		
% Mg	0.440**	0.204	-0.034	0.347*	
			Blades		
% N					
% P	0.844**				
% K	0.408**	0.506**			
% Ca	-0.183	-0.030	-0.635**		
% Mg	0.602**	0.365*	-0.075	0.067	

[1/] Data from the control plots were not included in the statistical analysis.

Appendix Table 9
Correlation Coefficients (r) of Soils and Plant Analyses
from Upland and Lowland Taro Plots Fertilized With Potassium[1/]
df = 46, r = 0.288 (5%), r = 0.372 (1%)

Soil Analysis	Petioles					Blades				
	% N	% P	% K	% Ca	% Mg	% N	% P	% K	% Ca	% Mg
					Upland Taro					
pH	0.496**	-0.418**	0.511**	-0.072	-0.090	0.448**	-0.262	0.489**	-0.058	-0.358*
Exch. K	0.707**	-0.290*	0.796**	-0.254	-0.451**	0.313*	-0.197	0.716**	-0.424**	-0.642**
Exch. Ca	0.313*	-0.096	0.309*	0.544**	-0.134	0.374**	0.378**	0.102	0.350*	-0.068
Exch. Mg	0.122	0.273	-0.009	0.270	-0.082	-0.171	0.415**	-0.142	0.109	0.168
Total N	-0.239	0.334*	-0.135	0.072	-0.149	-0.520**	0.010	-0.129	-0.035	-0.155
Ext. P	0.092	-0.177	0.192	0.232	-0.172	0.201	0.088	0.122	0.017	-0.192
					Lowland Taro					
pH	0.190	-0.196	-0.146	0.212	-0.200	0.206	0.048	-0.182	0.061	-0.072
Exch. K	0.510**	0.298*	0.800**	-0.145	0.001	0.494**	0.440**	0.711**	-0.568**	0.274
Exch. Ca	0.139	-0.186	-0.002	0.250	-0.308*	0.263	0.086	0.008	-0.146	-0.096
Exch. Mg	-0.068	0.359*	0.144	-0.054	0.122	-0.166	0.052	0.176	0.090	-0.049
Total N	-0.121	0.053	-0.233	0.299*	0.097	0.004	0.065	-0.240	0.319*	0.064
Ext. P	0.591**	0.054	0.448**	0.061	0.129	0.659**	0.464**	0.464**	-0.420**	0.410**

[1/] Data from the control plots were not included in the statistical analysis.

Appendix Table 10
Relationship Between Specific Gravity and Percent Dry Matter of Core Samples from Upland and Lowland Taro Corms[1/]

Samples	Treatments		
	N	P	K
Upland Taro			
main corms: apex	0.626**	0.439**	0.619**
base	0.681**	0.605**	0.746**
sucker corms	0.761**	0.455**	0.751**
Lowland Taro			
main corms: apex	0.069	-0.166	0.111
base	0.085	-0.119	0.184
sucker corms	0.110	0.094	-0.032

[1/] Data from control plots were not included in the statistical analysis.

Appendix Table 11
Correlation Coefficients (r) of Nutrient Contents
of Petioles and Blades of Upland and Lowland Taro Leaves
n = 48

Nutrient Composition	Fertilizer Treatments		
	N	P	K
		Upland Taro	
% N	0.751**	0.677**	0.576**
% P	0.520**	0.688**	0.419**
% K	0.780**	0.701**	0.878**
% Ca	0.542**	0.256 n.s.	0.820**
% Mg	0.458**	0.535**	0.776**
		Lowland Taro	
% N	0.899**	0.946**	0.918**
% P	0.707**	0.690**	0.753**
% K	0.929**	0.954**	0.938**
% Ca	0.612**	0.168 n.s.	0.506**
% Mg	0.767**	0.784**	0.751**

Appendix Table 12
Regression Coefficients (b), "a" and "t" Values for Regressions of Nitrogen Fertilizer and Age on Some Properties of the Upland and Lowland Soil

Soil Properties	Upland			Lowland		
	a	b	t	a	b	t
pH	4.61	-0.000418N	8.01**	6.51	0.00104N	0.90
		-0.00941A	0.95		-0.0161A	1.13
Exch. K		-0.0000453N	0.07	0.43	-0.0000692N	3.55**
	0.74	-0.0376A	3.67**		-0.0226A	9.40**
Exch. Ca	3.22	-0.00139N	5.27**	8.90	-0.000233N	0.23
		0.00000048N	2.19*		-0.129A	1.05
		-0.288A	5.59**			
		$0.0145A^2$	4.29**			
Exch. Mg	0.52	-0.000068N	1.59	6.37	-0.000203N	0.25
		-0.00049A	1.42		0.114A	1.15
Total N	0.21	0.00000808N	1.15	0.21	0.0000607N	1.94
		0.00049A	0.57		$-0.0000000716N^2$	2.77*
					0.000883A	0.82
Ext. P		0.00329N	0.83		-0.176N	1.15
	38.93	-0.0123A	2.55*	417.71	-8.99A	4.74**

* = significant at 5% level. ** = significant at 1% level. Not significant regression coefficients are included to show trends only. "a" values are given for significant regression coefficients only. Equations are of the general form: $Y = a + bX$.

Appendix Table 12a

Regression Coefficients (b), "a" and "t" Values for Regression of Nitrogen Fertilizer and Age on Nutrient Contents of Upland and Lowland Taro

Tissue and Nutrient Contents	Upland Taro			Lowland Taro		
	a	b	t	a	b	t
Petioles						
% N	2.78	0.000635N	4.55**	1.34	0.000315N	3.99**
		-0.444A	4.54**		-0.0702A	7.22**
		$0.0234A^2$	3.64**			
% P	0.29	-0.000552N	6.15**	0.01	-0.000111N	4.18**
		$0.00000034N^2$	4.59**		0.173A	9.25**
		0.0113A	3.65**		$-0.0122A^2$	9.95**
% K	14.64	-0.00211N	5.24**	2.38	-0.00189N	6.10**
		-0.0154A	5.45**		1.03A	4.75**
		0.0701A	3.78**		$-0.0886A^2$	6.23**
% Ca		-0.0000224N	0.51		0.0000057N	0.11
	1.50	-0.213A	7.05**	0.83	-0.021A	3.34**
		$0.0128A^2$	6.43**			
% Mg	0.12	0.0000127N	1.03	0.55	0.0000864N	2.50*
		0.000472A	0.31		-0.024A	5.63**

Appendix Table 12a (Continued)
Regression Coefficients (b), "a" and "t" Values for Regression of Nitrogen Fertilizer and Age on Nutrient Contents of Upland and Lowland Taro

Tissue and Nutrient Contents	Upland Taro			Lowland Taro		
	a	b	t	a	b	t
Blades						
% N	4.19	0.000683N	5.31**	4.23	0.000511N	4.84**
		-0.105A	6.64**		0.0445A	0.60
					$-0.0151A^2$	
% P	0.41	-0.000107N	3.37**		0.0000041N	0.22
		$0.000000069N^2$	2.62*	0.38	0.0394A	3.06**
		-0.0228A	3.69**		$-0.00388A^2$	4.58**
		$0.00138A^2$	3.39**			
% K	6.20	-0.000624N	3.25**	2.97	-0.0011N	5.84**
		-0.15A	6.31**		0.629A	4.78**
					$-0.0495A^2$	5.73**
% Ca	2.11	-0.00028N	3.76**	1.30	-0.000087N	1.08
		-0.29A	5.54**		0.00203A	0.20
		$0.0194A^2$				
% Mg	0.21	0.0001N	2.22*		0.0000445N	1.83
		$-0.000000076N^2$	2.00*	0.94	-0.137A	7.85**
		-0.023A	2.61*		$0.00697A^2$	6.08**
		$0.0019A^2$	3.29**			

* = significant at 5% level. ** = significant at 1% level. Not significant regression coefficients are included to show trends only. "a" values are given for significant regressions only. Equations are of the general form: Y = a + bX.

Appendix Table 13
Regression Coefficients (b), "a" and "t" Values for Regressions of Phosphorus Fertilizer and Age on Some Properties of the Upland and Lowland Soil

Soil Properties	Upland			Lowland		
	a	b	t	a	b	t
pH	4.43	0.000151P	4.11**	6.69	-0.000149P	1.23
		-0.00442A	0.84		-0.0145A	0.97
Exch. K	0.90	-0.0000545P	0.84	0.41	0.0000396P	2.01*
		-0.0504A	6.35**		-0.0264A	10.82**
Exch. Ca	2.63	0.0015P	11.23**	9.58	0.000188P	0.16
		-0.368A	3.94**		-0.166A	1.16
		0.0225A^2				
Exch. Mg		-0.0000185P	0.58	6.04	-0.000094P	0.12
	0.64	-0.0609A	2.73**		0.106A	1.12
		0.00375A^2				
Total N	0.22	-0.00000352P	0.58	0.19	0.000132P	3.90**
		0.000394A	0.52		-0.000000104P^2	3.70**
					0.000767A	0.65
Ext. P	4.98	0.113P	10.3**	428.05	0.0595P	2.94**
		0.533A	0.39		-12.0A	4.81**

* = significant at 5% level. ** = significant at 1% level. Not significant regression coefficients are included to show trends only. "a" values are given for significant regressions only. Equations are of the general form: $Y = a + bX$.

Appendix Table 13a

Regression Coefficients (b), "a" and "t" Values for Regressions of Phosphorus Fertilizer and Age on Nutrient Contents of Upland and Lowland Taro

Tissue and Nutrient Contents	Upland Taro			Lowland Taro		
	a	b	t	a	b	t
Petioles						
% N		-0.000112P	1.03		0.0000209P	0.39
	3.49	-0.548A	7.13**	1.42	-0.0651A	9.93**
		$0.0296A^2$	5.86**			
% P	0.25	0.000131P	4.58		-0.00000245P	0.09
		-0.0505A	2.51*	-0.007	0.169A	8.52**
		$0.00416A^2$	3.15**		$-0.0121A^2$	9.31**
% K	14.59	-0.00123P	3.51**	3.22	-0.000741P	2.09*
		-1.526A	6.20**		0.753A	3.02**
		$0.0678A^2$	4.19**		$-0.0756A^2$	4.63**
% Ca	1.43	-0.000316P	2.11*		-0.00000595P	0.16
		$0.000000279P^2$	2.25*	0.42	0.0962A	3.36**
		-0.185A	6.36**		$-0.00727A^2$	4.18**
		$0.113A^2$	5.91**			
% Mg	0.11	-0.00000136P	0.11		-0.000000935P	0.03
		0.00217A	1.46	0.59	-0.0232A	6.93**

Appendix Table 13a (Continued)
Regression Coefficients (b), "a" and "t" Values for Regressions of Phosphorus Fertilizer and Age on Nutrient Contents of Upland and Lowland Taro

Tissue and Nutrient Contents	Upland Taro a	Upland Taro b	Upland Taro t	Lowland Taro a	Lowland Taro b	Lowland Taro t
Blades						
% N		0.0000202P	0.13		-0.0000142P	0.12
	4.42	-0.0834A	4.56**	5.18	-0.182A	13.01**
% P	0.36	0.000161P	3.96**		0.00000773P	0.42
		-0.000000069P	4.28**	0.44	0.0276A	2.16*
		-0.0338A	2.06*		$-0.00316A^2$	3.77**
		$0.00219A^2$	4.23**			
% K		-0.000135P	0.91		-0.000338P	1.83
	6.24	-0.177A	9.65**	3.51	0.360A	2.71**
					$-0.0349A^2$	4.01**
% Ca		0.0000876P	1.26		-0.00000119P	0.02
	1.66	-0.203A	4.14**	1.07	0.0255A	3.44**
% Mg		-0.0000127P	1.00		-0.000009P	0.45
	0.23	-0.0266A	2.99**	0.87	-0.124A	8.96**
		$0.00229A^2$	3.92**		$0.00653A^2$	7.17**

* = significant at 5% level. ** = significant at 1% level. Not significant regression coefficients are included to show trends only. "a" values are given for significant regressions only. Equations are of the general form: Y = a + bX.

Appendix Table 14

Regression Coefficients (b), "a" and "t" Values for Regressions of Potassium Fertilizer and Age on Some Properties of the Upland and Lowland Soil

Soil Properties	Upland			Lowland		
	a	b	t	a	b	t
pH	4.52	0.0000867K	2.19*	6.56	-0.0000849K	0.62
		-0.0152A	3.11**		-0.00331A	0.20
Exch. K	0.57	0.00066K	7.24**	0.38	0.000259K	8.71**
		-0.0416A	3.69**		-0.0291A	7.95**
Exch. Ca	3.18	-0.000019K	0.17	8.75	0.000458K	0.41
	3.18	-0.406A	5.23**		-0.146A	1.06
		$0.0222A^2$	4.35**			
Exch. Mg		-0.000029K	0.78	6.79	-0.00036K	0.41
	0.62	-0.0538A	2.08*		0.089A	0.82
		$0.00345A^2$	2.04*			
Total N	0.22	-0.00000101K	0.16	0.23	-0.0000248K	2.78**
		0.00095A	1.22		-0.000072A	0.06
Ext. P		0.0024K	0.52		0.023K	1.45
	43.08	-1.29A	2.34*	434.67	-10.86A	5.39**

* = significant at 5% level. ** = significant at 1% level. Not significant regression coefficients are included to show trends only. "a" values are given for significant regressions only. Equations are of the general form: Y = a + bX.

Appendix Table 14a
Regression Coefficients (b), "a" and "t" Values for Regressions of Potassium Fertilizer and Age of Nutrient Contents of Upland and Lowland Taro

Tissue and Nutrient Contents	Upland Taro			Lowland Taro		
	a	b	t	a	b	t
Petioles						
% N	2.36	0.000378K	3.10**		-0.0000038K	0.07
		-0.289A	3.38**	1.36	-0.058A	8.77**
		0.0143A^2	2.55**			
% P		0.000016K	0.54		0.0000026K	0.09
	0.08	0.0192A	5.31**	-0.02	0.171A	8.66**
					-0.012A^2	9.35**
% K	6.33	0.0139K	7.15**	1.78	0.00311K	6.61**
		-0.00000799K^2	4.95**		0.786A	2.38*
		-0.42A	6.28**		-0.795A^2	3.67**
% Ca	1.57	-0.00062K	3.02**	0.61	-0.00018K	4.80**
		0.00000036K^2	2.14*		0.513A	1.94
		-0.187A	4.71**		-0.0000417A^2	2.40*
% Mg	0.20	-0.000265K	5.02**	0.61	-0.000134K	4.17**
		0.0000002K^2	3.60**		-0.02A	5.03**
		0.000667A	0.36			

Appendix Table 14a (Continued)
Regression Coefficients (b), "a" and "t" Values for Regressions of Potassium Fertilizer and Age on Nutrient Contents of Upland and Lowland Taro

Tissue and Nutrient Contents	Upland Taro			Lowland Taro		
	a	b	t	a	b	t
Blades						
% N		0.00017K	1.45		-0.00013K	1.21
	4.39	-0.0913A	6.17**	5.11	-0.186A	14.05**
% P		0.00000092K	0.11		-0.000019K	1.02
	0.39	-0.0275A	4.62**	0.38	0.0382A	3.00**
		$0.0018A^2$	4.58**		$-0.00379A^2$	4.53**
% K	4.61	0.00595K	6.02**	2.34	0.0045K	5.97**
		$-0.0000037K^2$	4.53**		$-0.00000245K^2$	3.91**
		-0.164A	4.84**		0.368A	2.50*
					$-0.0344A^2$	3.56**
% Ca	2.39	-0.00166K	4.32**	1.25	-0.000358K	6.27**
		$0.000001K^2$	3.15**		0.0204A	2.89**
		-0.248A	3.30**			
		$0.0152A^2$	3.09**			
% Mg	0.24	-0.000309K	4.37**	0.93	-0.00043K	5.10**
		$0.0000002K^2$	3.11**		$0.0000003K^2$	4.38**
		0.00553A	2.28*		-0.107A	6.52**
					$0.00523A^2$	4.85**

* = significant at 5% level. ** = significant at 1% level. Not significant regression coefficients are included to show trends only. "a" values are given for significant regressions only. Equations are of the general form: Y = a + bX.

Appendix Table 15
Regression Coefficients (b), "a" and "t" Values
for Regressions of Nitrogen, Phosphorus, and Potassium Fertilizers and Age
on the Total Yields and Specific Gravity of Upland and Lowland Taro

Fertilizers, Yields and Specific Gravity	Upland Taro			Lowland Taro		
	a	b	t	a	b	t
<u>Nitrogen</u>						
Total yields	10.85	0.0402N	5.44**	-444.5	0.0318N	4.45**
		$-0.0000304N^2$	4.96**		$-0.0000135N^2$	2.28*
		0.216A	0.31		66.27A	2.78**
					$-2.28A^2$	2.57*
Main corms	1.01	-0.0000192N	2.17*	-1.43	-0.0000175N	1.75
Sp. gr.		0.0065A	2.21*		0.332A	2.76**
					$-0.0109A^2$	2.43*
Sucker corms	1.13	-0.000043N	2.06*		-0.0000025N	0.26
Sp. gr.		0.00736A	1.07	-1.99	0.434A	3.78**
					$-0.015A^2$	3.51**
<u>Phosphorus</u>						
Total yields	13.90	0.0424P	3.51**		0.00468P	1.90
		$-0.000026P^2$	2.57*	-26.85	4.56A	5.57**
		0.72A	0.52			
Main corms	1.17	-0.0000132P	0.77		0.0000053P	1.01
Sp. gr.		-0.00609A	1.07	-1.59	0.361A	5.73**
					$-0.012A^2$	5.18**
Sucker corms	1.14	0.0000143P	1.35		0.0000049P	0.85
Sp. gr.		-0.00337A	0.96	-1.78	0.403A	5.79**
					$-0.0139A^2$	5.36**

Appendix Table 15 (Continued)
Regression Coefficients (b), "a" and "t" Values
for Regressions of Nitrogen, Phosphorus, and Potassium Fertilizers and Age
on the Total Yields and Specific Gravity of Upland and Lowland Taro

Fertilizers, Yields and Specific Gravity	Upland Taro a	Upland Taro b	Upland Taro t	Lowland Taro a	Lowland Taro b	Lowland Taro t
Potassium						
Total yields	18.14	0.00637K	2.54*		0.000146K	0.08
		-0.83A	0.99	-21.17	4.43A	7.56**
Main corms	1.05	-0.0000077K	0.88	-1.23	0.000019K	3.28**
Sp. gr.		0.0029A	1.02		0.307A	4.47**
					$-0.0101A^2$	3.96**
Sucker corms	1.05	-0.0000087K	0.71		0.0000075K	1.10
Sp. gr.		0.0047A	1.15	-1.13	0.303A	3.73**
					$-0.0101A^2$	3.34**

* = significant at 5% level. ** = significant at 1% level. Not significant regression coefficients are given to show trends only. "a" values are given for significant regressions only. Equations are of the general form: $Y = a + bX$.

Appendix Table 16
Total Nutrients in Tops of Upland Taro in kg/ha at 3, 6 and 9 Months of Age

Treatments kg/ha	Nitrogen			Phosphorus			Potassium		
	3 mos.	6 mos.	9 mos.	3 mos.	6 mos.	9 mos.	3 mos.	6 mos.	9 mos.
Control	4	2	6	0.2	0.2	0.6	10	7	11
0N	3	3	9	0.4	0.4	2	11	9	30
280N	18	16	11	2	2	2	45	48	35
560N	66	22	22	5	2	2	131	50	45
1120N	75	24	22	5	2	3	122	47	44
0P	8	7	15	0.4	0.4	1	18	17	42
280P	18	16	11	2	2	2	45	48	35
560P	34	11	27	3	1	4	77	29	74
1120P	43	13	22	5	1	4	97	39	59
0K	8	4	8	0.7	0.4	1	9	6	15
280K	18	16	11	2	2	2	45	48	35
560K	29	18	17	3	1	2	78	53	48
1120K	50	20	19	4	1	2	140	57	49

Appendix Table 17
Total Nutrients in Tops of Lowland Taro in kg/ha at 3, 6 and 9 Months of Age

Treatments kg/ha	Nitrogen			Phosphorus			Potassium		
	3 mos.	6 mos.	9 mos.	3 mos.	6 mos.	9 mos.	3 mos.	6 mos.	9 mos.
Control	21	14	15	2	3	3	22	26	19
0N	25	19	28	4	6	8	50	58	68
280N	62	32	32	10	9	9	105	85	69
560N	87	50	54	15	12	12	120	102	81
1120N	84	108	55	10	21	9	81	150	54
0P	59	34	22	9	9	6	104	78	35
280P	62	32	32	10	9	9	105	85	69
560P	66	38	38	11	11	9	105	86	60
1120P	74	36	34	12	10	7	118	75	45
0K	80	34	22	10	8	6	64	44	22
280K	62	32	32	10	9	9	105	85	69
560K	78	39	34	13	11	8	177	112	72
1120K	67	47	26	11	12	7	186	157	67

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