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PROCEEDINGS OF THE WORKSHOP ON TARO AND TANIER MODELING

Edited by
Upendra Singh
IBSNAT Project

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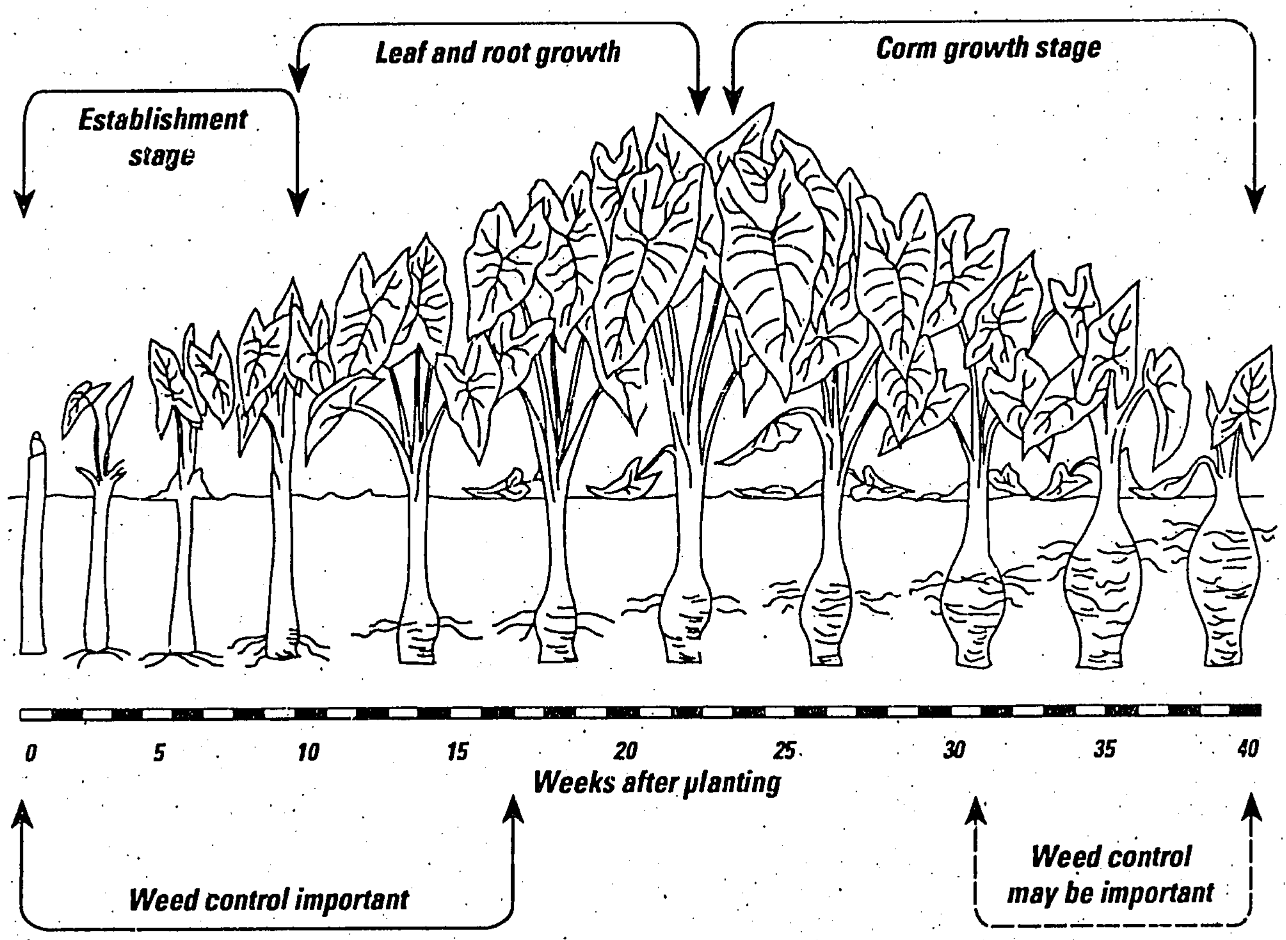

Critical Periods for Weeding

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IBSNAT, the International Benchmark Sites Network for Agrotechnology Transfer, is a group consisting of the contractor (the University of Hawaii) and several collaborators. Together they have created a prototype network of national, regional, and international agricultural research centers for the purpose of developing, validating, and using a scientific method for the effective transfer of agrotechnology among and within countries in the tropics and subtropics.

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Proceedings of the

Workshop on Taro and Tanier Modeling

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Upendra Singh

TABLE OF CONTENTS

Preface

The growing importance of aroids was reflected in the decision of scientists participating in the first IBSNAT workshop in 1983 to include it as one of the twelve crops for which a crop model should be developed. Much of the early work in IBSNAT was focused on the more traditional major crops, including maize, wheat, rice, soybean, peanuts, and dry bean. This was only natural because of the wealth of information and data sets available. This is not the case for aroids. Progress has been hindered not only by an unfamiliarity of the crop but by the lack of growth and development data sets.

It is anticipated, however, that lessons learned from the development of other crop models will provide the framework for developing one for aroids in a relatively shorter time. This workshop is the result of a planning meeting held in Muscle Shoals, Alabama in early 1991 to develop, calibrate, and validate a crop model for taro and tanier. It was organized to identify potential cooperators willing to share existing information and to collect minimum data sets to build an operational aroid simulation model. This model will be coupled to IBSNAT's Decision Support System for Agrotechnology Transfer (DSSAT) software.

The proceedings of this workshop represent current, past, and planned activities of the participants prior to the workshop. We trust some modifications will be made to accommodate the requirements necessary to build an operational model for taro and tanier. The appendices present additional information needed to develop, calibrate and validate the SUBSTOR-aroid model.

Taro Breeding in the South Pacific

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Abstract
Breeding programs for taro (*Colocasia esculenta* (L.) Schott) started only recently in the South Pacific. Results coming out of these programs from Fiji, Western Samoa and the Solmon Islands show that there is considerable potential to improve taro yield. The status of breeding programs, the progress made and future direction is presented.

Introduction

Edible aroids are widely grown throughout the tropics and subtropics, but assume their greatest importance in the Pacific region. Of the five species of aroids grown for food in the Pacific, taro (*Colocasia esculenta* (L.) Schott) is the most important.

Breeding work with taro was nonexistent until recently, but during the last 15 years major achievements have been made in developing techniques required for breeding taro and closely related edible aroids, *Xanthosoma*, *Alocasia*, and *Cyrtosperma*. This has been achieved through hybridization followed by selection of superior clones from the segregated seedling population. The early work in taro breeding has been reviewed by Wilson (1979a, 1979b). Recently, Sivan and Tavaiqia (1984) and Wilson, Sivan, and Munroe (1991), discussed the release of two taro hybrids to show that conventional breeding programs can produce improved high yielding cultivars that are acceptable to farmers.

In the past there were three taro breeding programs in the South Pacific: in Fiji, the Solomon Islands, and at the University of the South Pacific (USP) in Western Samoa. Of these, only the Solomon Island and USP programs are currently being continued, and although the actual breeding work in the Fiji program has now stopped, clones developed from earlier crossings are still under evaluation. This paper briefly describes the breeding and progress made in these programs.

The Taro Breeding Program in Fiji

The taro breeding program in Fiji was started in 1979 when open-pollinated seeds were collected for

Table 1. Performance of improved clones Samoa Hybrid and Samoa Green against local cultivars at Koronivia Research Station, Fiji.

Clone/Cultivar	1981/82	Yield (t ha^{-1}) 1982/83	1983/84	Mean	Suckers (No./plant)
Samoa Hybrid	23.7 a	16.4 a	26.4 a	21.8 a	5.6 b
Samoa Green	21.5 a	14.0 ab	22.2 b	19.2 b	6.8 a
Samoa (6)	13.0 b	13.4 abc	20.3 b	15.6 c	2.4 c
Samoa	11.0 b	11.5 bc	19.3 b	13.9 cd	2.8 c
Toakula	12.1 b	12.6 bc	14.7 c	13.1 d	6.8 a
Mean	16.3	13.8	20.6		

Treatments with different letters in a column are significantly different at 5% level according to Duncan's Multiple Range Test (Sivan and Tavaiqia, 1984).

Table 2. Performance of improved clone Samoa Hybrid against local cultivars on farms in Fiji.

Clone/Cultivar	Hill-land Farms 1	2	3	Mean	Alluvial Flatland Farms 1	2	3	Mean
Samoa Hybrid	25.0	21.1	19.4	21.8	20.8	22.7	19.8	21.1
Samoa	17.5	13.6	18.7	14.6	19.8	—	7.9	13.4
Toakula	—	—	—	—	—	15.0	11.8	13.4

(Sivan and Tavaiqia, 1984)

evaluation. In 1980 the first crossings were made among the ten best local cultivars selected for yield, quality, and suckering ability, to form the base population. A recurrent selection breeding method was employed in the program to develop improved clones. Unfortunately, since 1987 the breeding work has stopped. However, clones developed earlier are still being evaluated with assistance from the Institute of Research Extension and Training in Agriculture (IRETA)/University of the South Pacific (USP) Regional Taro Project.

Fiji was first to release an improved cultivar, Samoa Hybrid, from its breeding program. Details on the performance of this cultivar are given by Sivan and Tavaiqia (1984), and Wilson, Sivan, and Munroe (1991). Tables 1 and 2 show the performance of this cultivar against the best unimproved cultivars on the research station and on farmers' fields.

On average, Samoa Hybrid outyielded the best local cultivars by 40%. Consumers rated the quality of this hybrid as equal to the most popular and commonly grown cultivar, Samoa. Samoa Hybrid was released in Fiji in 1984 and is now widely grown there. Fiji's breeding program is now producing a number of other clones which are in the final stages of testing at the research station and on farms (Tables 3 and 4).

With the exception of one clone (106/5), the clones yielded higher than Samoa Hybrid in every trial. On average, at the research station, these clones yielded from 14 to 48% higher than Samoa Hybrid. The final series of trials is currently in progress, and following this a number of clones are expected to be released in Fiji.

Table 3. Performance of selected improved taro clones from the Fiji breeding program at Koronivia Research Station, Fiji.

Clone/Cultivar	Yield (t ha^{-1}) 1987	1988	1989	1990	Mean	Dry Matter (%)	Sucker Number
160/31	20.9	27.5	29.0	28.6	26.5	34.5	4.4
110/6	20.8	26.0	28.4	28.2	25.9	30.3	2.8
160/32	21.7	26.8	30.3	23.2	25.5	36.0	5.5
123/102	22.9	27.2	25.0	22.6	24.4	26.0	1.9
191/37	21.1	25.0	25.6	20.3	23.0	36.5	6.2
106/5	16.7	18.0	20.7	20.8	21.5	34.5	4.0
123/70	26.1	33.5	29.7	—	29.8	28.8	1.6
115/133	18.8	26.7	24.5	—	23.3	36.0	2.2
123/98	17.8	26.7	24.2	—	22.9	28.0	2.8
Samoa Hybrid	16.8	22.0	22.1	19.7	20.1	31.9	5.2

Table 4. Performance of selected improved taro clones from the Fiji breeding program on two farms in 1990.

Clone/Cultivar	Yield ($t\ ha^{-1}$)		
	Baulevu	Namara	Mean
160/31	29.1	25.3	27.2
110/6	25.9	19.0	22.5
160/33	25.7	19.0	22.4
123/102	22.5	19.6	20.9
191/37	23.4	19.3	21.4
106/5	20.0	13.9	17.9
123/70	27.1	19.2	23.2
123/98	23.3	25.7	24.5
115/133	—	20.8	20.8
Samoa Hybrid	17.5	18.9	18.2

The Taro Breeding Program at USP, Alafua, Western Samoa

This taro breeding project is one of the most important research projects undertaken by (IRETA), at the University of the South Pacific in Alafua. The main purpose of this project is to develop through sexual breeding, good quality clones that are high yielding, and disease and pest resistant. This project also employs recurrent selection breeding methods to concentrate and combine genes for desirable characteristics. The project was started in 1982 when the initial breeding population for this program was formed by intercrossing local cultivars with different characteristics. Every year a large number of crosses are made among the selected clones and cultivars, and seedlings derived from the crosses are evaluated in a series of trials in seedling, preliminary, intermediate, advanced, and on-farm trials.

The first improved cultivar arising out of this project, Alafua Sunrise, was released in 1988. All research station trials at Alafua were conducted without the application of fertilizer, irrigation, or chemicals for disease and pest control. In these trials, Alafua Sunrise consistently outyielded cultivar Niue, the most popular local cultivar in Western Samoa, by between 50 and 130%. Table 5 shows the performance of Alafua Sunrise against Niue and the more recently developed promising clones from the breeding program. Table 6 shows the performance of Alafua Sunrise against Western Samoa's two most popular local cultivars: Niue and Manua. Table 7 shows the performance of Alafua Sunrise on farms in Western Samoa.

Although Alafua Sunrise consistently outyielded Niue, the dry matter percentage and eating quality of Alafua Sunrise were consistently lower than Niue. Farmers indicated that the less-preferred yellow flesh and eating quality of Alafua Sunrise were offset by its impressive vigor and high yields. Alafua Sunrise is now rapidly propagated and distributed to farmers in Western Samoa.

In the early generation of seedling-derived clones from the breeding program, none of the clones was found to have the eating quality or corm color of the preferred Niue. However, the later populations of seedling-derived clones now emerging combine high yield with good quality and high dry matter. This is due to concentration and recombination of genes in the recurrent selection breeding program, and to deliberate crossing of high yielding clones with clones and cultivars of high eating quality. Clone 84045-9, a high yielding, high dry matter, and high eating quality taro (Table 5), has been obtained by crossing Alafua Sunrise with parents having high dry matter and high eating quality.

Two of these clones (86038-85 and 86038-38) yielded slightly lower than Alafua Sunrise, but had an eating quality equal to or higher than Niue, while yielding almost twice as much as Niue (Table 8).

Observations (not presented) also show that some improved cultivars (Alafua Sunrise, 84045-9, and 86038-85) are more tolerant to drought than Niue. In a study of drought resistance of improved versus unimproved cultivars, Wagatora and Jacobs (1990) found that Alafua Sunrise produced a greater volume of roots than Niue, and attributed Alafua Sunrise's greater drought tolerance to its ability to occupy greater soil volume with greater root mass.

The Taro Breeding Program in the Solomon Islands

The Solomon Islands and some other islands of the Melanesian group, such as Papua New Guinea, have a number of major disease and pest problems associated with taro. These problems have caused considerable decline in taro production. The major disease and pest problems include the taro leaf blight

Table 5. ***Performance of Alafua Sunrise and selected improved clones in advanced trial at Alafua, Western Samoa in 1990.***

Clone/Cultivar	*Yield (t ha $^{-1}$)*	*Suckers (no. plant^{-1})*	*DMV Score**	*Dry Matter %*	*Eating Quality***
Niue	5.8 c	7.2	1.4	33.5	3.1
Alafua Sunrise	10.3 a	6.2	0.4	33.2	2.9
34037-D	10.8 a	9.8	0.2	32.2	2.0
34014-5	10.0 ab	5.2	0.3	33.5	2.4
84045-9	8.9 ab	7.1	0.1	35.6	3.2
84016-183	8.1 b	8.6	0.1	35.8	2.9

Treatment with different letters in a column are significantly different at 5% level according to Duncan's Multiple Range Test.

* *Dashen Mosaic Virus subjective score of 0 to 3, with 0= no symptoms to 3= severe symptoms and distortion.*
** *Subjective score of 1 to 4 with 1=poor to 4=excellent by Western Samoa testers.*

(Wilson, Sivan and Munroe, 1991)

(*Phytopthora colocasia*), viruses Alomae and Bobone, and a nematode Mitimiti (*Hirachmaniella miticausa*). Ivancic, Liloqula, and Saelea (1990) have described the various attempts made at breeding disease-resistant taro in the Solomon Islands over the last decade. Three separate programs were started. The first was formed in 1979 to develop taro resistance to leaf blight using a disease-resistant cultivar from Thailand. The first crosses between this cultivar and local genotypes were backcrossed to selected local cultivars to develop acceptable clones. Unfortunately, the breeding work was stopped in 1988, and

Table 6. ***Performance of improved clones Alafua Sunrise and Samoa Hybrid against the two most popular local cultivars Niue and Manua at Alafua, Western Samoa.***

Clone/Cultivar	*Yield (t ha $^{-1}$) 1989*	*Yield (t ha $^{-1}$) 1990*	*Suckers (no. plant^{-1})*	*DMV Score*	*Eating Quality**
Niue	3.8b	5.0 c	8.1	0.7	3.1
Manua	7.3 a	8.6 b	6.8	0.7	—
Alafua Sunrise	8.8 a	10.6 a	7.8	0.8	2.9
Samoa Hybrid	6.3a	10.7 a	9.7	0.5	2.4

Treatments with different letters in a column are significantly different at the 5% level according to Duncan's Multiple Range Test.

**See Table 5 for DMV and Eating Quality score (Wilson, Sivan, and Munroe, 1991).*

Table 7. Performance of Alafua Sunrise on farms in Western Samoa 1986/87.

Clone/Cultivar	Farm Location: Tutulele Yield ($t\ ha^{-1}$)	Tutulele Suckers (no./plant)	Tutulele DMV Score	Alelea Yield ($t\ ha^{-1}$)	Alelea Suckers (no./plants)	Alelea DMV Score*
Niue	4.6	5.1	0.9	3.5	4.6	1.0
Alafua Sunrise	8.6	5.7	0.1	11.4	5.8	0.2
82002-56	7.0	9.1	0.1	8.6	8.4	0.1

*See Table 5 for DMV scores (Wilson, Sivan, and Munroe, 1991).

all except one genotype have been lost.

Parallel with the first program, another breeding program was started to develop the clones' resistance to the Alomae and Bobone virus diseases using local genotypes. However, none of the crosses coming out of this program showed resistance to these diseases. Still another program to develop the cultivars' resistance to the nematode (Mitimiti) was started in the early 1980s using a resistant swamp cultivar. Some of these clones showed resistance to the nematode but were of poor quality.

All breeding work in this program was stopped in 1985 when the FAO/UNDP appointed plant breeder left, but was restarted in 1989 when another FAO/UNDP plant breeder was appointed. The new program aims to develop, using the recurrent selection breeding method, clones resistant to the three main diseases and pests mentioned above. To date, using surviving hybrids from previous crosses of cultivated cultivars and the wild population, a base population comprising 2000 seedlings from 350 crosses has been established. The seedlings are being tested for leaf blight, viruses, and nematode disease resistance, separately. Selected seedlings will be crossed with the cultivated cultivars to form the new population for the next cycle of testing. This program is still in the very early stages of breeding and testing.

The Regional Taro Improvement Program

The IRETA/USP, in collaboration with the South Pacific Commission is currently implementing a regional taro improvement program in seven countries (Fiji, Tonga, Western Samoa, the Cook Islands, Vanuatu, Tuvalu, and Kiribati). This joint program has produced improved clones, and some high yielding cultivars from the region have been cleaned

Table 8. Performance of selected taro clones in the Intermediate Trial at Alafua, Western Samoa in 1990.

Clone/Cultivar	Yield ($t\ ha^{-1}$)	Suckers (no. $plants^{-1}$)	Specific Gravity	Eating Quality*
Niue	4.4 d	6.8	2.5	2.7
Alafua Sunrise	10.0 ab	7.1	2.5	2.5
88001-140	10.6 a	10.8	2.0	2.6
86021-113	9.7 ab	2.3	3.3	2.6
86020-37	8.7 bc	10.3	1.1	2.6
86038-85	8.4 bc	11.6	2.6	3.9
86038-38	7.5 c	6.8	2.7	2.7

*See Table 5 for eating quality score.

of diseases and distributed in tissue culture, where they are now being field tested in a first series of evaluations.

Before any decision is made concerning their release, these clones and cultivars will be evaluated for three to four seasons initially on research stations and later on farms. Some preliminary results show that improved clones also perform well in countries other than their origin. Samoa Hybrid, introduced to Western Samoa from Fiji, performed as well as the Alafua Sunrise and was much better than the existing local cultivars (Table 6). However, in addition to yield and adaptability, taste and consumer preference vary significantly between the South Pacific Islands, and these factors will need to be taken into account before any new clones are released.

Conclusion

Results coming out of the conventional taro breeding programs in Fiji and the University of the South Pacific, Western Samoa show that there is considerable potential to improve this crop. In Fiji, the improved cultivar Samoa Hybrid yields up to 40% higher than the best unimproved cultivars. Some more recently developed clones are yielding between 14 and 49% higher than Samoa Hybrid. In Western Samoa, the improved cultivar Alafua Sunrise gives between 50 and 130% higher yield than the most popular unimproved cultivar Niue. However, with further crossing and selection, some of the new clones in the advanced stage of the present testing are high yielding and have an eating quality equal to the cultivar Niue. This shows that both the yield and quality of taro can be improved by conventional breeding.

The improved clones coming out of the breeding programs are already being tested in a number of countries in the South Pacific Region. The benefits of these programs will become available to these countries in a few years' time.

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The University of Hawaii Taro Germplasm Nursery and Breeding Program

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Abstract

Taro breeding in Hawaii started only in 1988. The University of Hawaii, however, has been maintaining a taro germplasm nursery since the mid 1920s. Currently, a computerized data base, describing the characteristics of all the 427 accessions in the taro nursery is under development. The taro nursery, computerized data base and the breeding program will play a vital role in improving commercial production of taro.

Introduction

Taro, (*Colocasia esculenta* (L.) Schott), has long been a crop of importance in the Hawaiian Islands. Ancient Hawaiians used taro, not only as a staple crop but also for medicinal and ceremonial purposes (Handy, 1940). Taro is currently produced primarily for its corms which are made into "poi" or chips. The corms are also made into flour for bread and other bakery products. Taro corms sold as fresh taro, are boiled, baked, or steamed for table use (Plucknett and de la Peña, 1971).

Researchers at the College of Tropical Agriculture and Human Resources, University of Hawaii have conducted research on the production, management, weed, pest and disease control, post harvest physiology, processing, and utilization of taro. The modeling work initiated through the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Project will greatly enhance taro research in Hawaii and elsewhere. However, as yet there has been very little work on the improvement or breeding of taro in Hawaii and the world. Aside from the breeding work at the University of the South Pacific in Western Samoa, The Philippine Root Crop Research and Training Center in Leyte, Philippines, and the effort to breed for resistance to Alomae and Babone in the Solomon Islands, there is no other major improvement and breeding work on taro (de la Peña, 1990). The taro breeding program in Hawaii started without official support in 1988. Since then, extramural funding from the Governor's Agriculture Coordinating Committee (GACC) has been obtained to help support the taro breeding work.

The Taro Germplasm Nursery

The University of Hawaii has maintained a taro germplasm nursery that dates back to the mid 1920s. Using accessions collected from the various islands in Hawaii and the Pacific, Whitney, Bowers, and Takahashi (1939) described 84 distinct taro varieties. These made up the core of the germplasm nursery now in existence in Hawaii. Additions to the nursery were made from time to time as various individuals and institutions introduced other accessions from various sources. Of the original 84 varieties, only about 70 are still in the current nursery. However, a large number of new accessions have been added to the nursery making it one of the biggest collections of taro varieties (*Colocasia esculenta*) in the Pacific and Asia. Table 1 shows the breakdown of the various accessions by source or country of origin.

Of the 427 accessions in the Hawaii taro nursery, approximately 130 are in sufficient number to be used for variety evaluation trials. The remaining accessions are recent additions and are being multiplied for future experimental work. Variety evaluation experiments are in progress on Hawaii, Molokai, Oahu, and Kauai islands.

Efforts to expand and strengthen the taro germplasm nursery are continuing, and new accessions will be added as they become available. In order to utilize the new accessions in the variety evaluation experiments, the nursery's planting materials have to be increased. Other work involving the germplasm nursery is an attempt to characterize or describe each accession to help researchers in the identification of the materials (IBPGR, 1980). A preliminary list of characteristics has been developed to help identify present and future accessions to the nursery. A computerized data base will also be developed to help taro researchers keep track of the description and characteristics of all taro cultivars and varieties available. A sample of the descriptor is presented at the end of the paper (Figure 1). Comments or additions from those who have access to other taro nurseries and cultivars would be appreciated.

Table 1.	***Source and number of taro accessions in Hawaii.***
Source of Origin	***Number of Accessions***
Hawaii	*68*
Samoa (American&Western)	*22*
New Caledonia	*14*
Tahiti	*8*
Easter Island	*14*
Vanuatu	*108*
Fiji	*1*
Indonesia	*15*
Malaysia	*23*
Philippines	*125*
Japan	*4*
China	*2*
India	*3*
Others	*20*
Total	*427*

Taro Improvement and Breeding

As mentioned earlier, taro has been grown in Hawaii for many years, but no new varieties have ever been developed or introduced for commercial production (de la Peña, 1990). The present level of production has been insufficient, and a severe shortage of taro for the local market has resulted. Taro in Hawaii is used mostly for the manufacture of poi, followed by the manufacture of taro chips. The following are the main varieties used for poi: Lehua Maoli, Moi, Haokea, Api'i, and Piialii. Variety Bun Long is used to make taro chips. Bun Long is also the preferred commercial source of taro leaves or "luau." The breeding program is still in its early stage of development. Until a major project with ample funding support is obtained, no additional personnel can be added. The effort in Kauai is an attempt to develop a reliable technique of growing and inducing the various accessions to flower. In addition, the work on the introduction and maintenance of cultivars continues in Kauai. The new varieties developed will have the following characteristics:

- High yields for poi
- Suitable for the manufacture of taro chips
- High yielding abilities and good qualities for table and other uses.

Other desirable characteristics such as pest and disease resistance, long shelf life, and better eating qualities are also being considered in the selection process for developing new cultivars or hybrids. Currently, approximately 100 hybrids are being multiplied for further field evaluation. This year, several accessions in the taro germplasm collection have been induced to flower and are being used for additional cross pollinations.

Conclusion

With the increased local demand for taro and the renewed interest by the State of Hawaii, the taro breeding program and the taro germplasm nursery have vital roles to play in agricultural development in Hawaii. The taro model will be a valuable tool for evaluating existing varieties and the hundreds of improved clones coming out of the breeding program.

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Taro Variety Characterization

Acc. No.______________ Variety Name______________ Origin______________

Growth Habit: erect/spreading stolons/rhizomes/runners/suckers

Plant Size (maximum): dwarf<50 cm medium 50-100 cm tall>100 cm

Leaves: hastate/peltate/sagittate; clockwise/counterclockwise

Leaf shape: hastate/ovate/sagittate/other ______________

Lamina: droopy/erect/cup shaped. Margin: entire/undulated

Margin color: ______________ Lamina appendages: absent/present

Leaf color: ______________ Leaf surface: non-glossy/glossy (shiny)

Leaf variegation: absent/present, color ______________

Pike shape & color ______________ Sap color ______________

Vein pattern: V/I/Y/other Vein color ______________

Petiole color: top ______________ middle ______________ base ______________

Petiole basal ring color: ______________

Petiole stripes: absent/present, color ______________

Leaf sheath: open/closed Leaf sheath color ______________

Inflorescence: flowering/non-flowering No. leaf axis: ______________

Male: enclosed/exposed Spathe shape: hooded/keeled/flat

Spathe color: upper part ______________ lower part ______________

Feduncle color: ______________ Flag leaf color: ______________

Fruit color: unripe ______________ ripe ______________

Corm shape: ______________ Corm flesh color ______________

Fiber color: ______________ Skin color ______________

Culture: upland/lowland/both ______________ Pests and Diseases: ______________

Main Uses: table/poi/chip/luau/vegetable/flour/dessert/other

Miscellaneous: ______________

____

Figure 1. Taro descriptor sheet.

Taro Production in Thailand

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Abstract

Taro (*Colocasia esculenta* (L.) Schott) is planted as a second crop to rice and as the main crop only in areas where irrigation is available for year round production. The importance of taro in terms of areas under cultivation and total production is on the increase. It is fast becoming a high income export crop.

Introduction

Taro (*Colocasia esculenta* (L.) Schott), family Aracea, is a common species found in the low lying wet patches of Thailand's forests. In Thailand, taro is mainly consumed as a dessert and snack, and although it was once considered a poor man's crop, it has since become a lucrative cash crops due to high export demand.

Cultivated Area

The new agroeconomic zoning consensus divides Thailand into upper and lower Northern regions (N), upper and lower Northeast regions (NE), Central Highlands, Central Plain (C), Western region (W), Eastern seaboard (E), and upper and lower Southern Peninsular (S). Table 1 shows the production area and taro yield from these regions for 1987-88 and 1988-89 crop years.

Farmers' Practice

Planting Season

Taro is planted as a second crop after rice, but in some areas where irrigation is available for year round production, only taro is cultivated. As a second crop, taro is planted from December until the end of February, depending upon when the rice is harvested. The main planting season is in January.

Table 1. Area and production of taro in Thailand.

Agroeconomic Zone	Area (ha) 1987	Area (ha) 1988	Production 1987	Production 1988
N	262	287	3550	6812
S	106	100	1186	960
C	244	391	2602	4178
E	196	931	2662	14740
W	860	318	10775	4101
NE	146	104	1458	1270

Land Preparation

Land is tilled and harrowed to rid the area of weeds, and then raised into beds four to five meters wide, spaced one meter apart. The bed-length depends on the dimension of the land area. The interbed ditches serve as both irrigation and drainage channels. In some areas the soil is also limed to correct the pH and/or amended with burned rice husk to make it more friable.

Planting Material

The main taro in Thailand is dasheen (*Colocasia esculenta* var. esculenta). It produces one large corm and a few small cormels. Cormels used for propagation are cut, covered with rice straw, and kept under well-watered conditions. After about 20 days, when they have reached a height of 10 to 12 cm and have two to four leaves, they will be ready for transplanting. Care is generally taken to assure there is only one tip on each seedling.

Double-row planting at 0.5 m row-spacing and 0.5 m plant-spacing is the general practice. The seedlings are placed straight up in small holes and covered with just enough soil to cover the cormel. Daily irrigation is needed to keep the seedling well-watered and is accomplished with a watering hose or other means. When the leaves cover the soil, then irrigation is spaced out at longer intervals depending upon climatic conditions as judged by soil surface dryness. Farmers usually thin out the suckers, keeping the population to one plant per hill to assure large corms. Rapid corm growth begins three to four months after transplanting and requires soil covering at intervals as the corms grow larger.

Table 2. Grading and pricing of taro in 1988 and 1989.

	Weight ($g\ corm^{-1}$)	Price (U.S. $/ton)
Large	>500	200-250
Medium	300-500	120-150
Small	200-300	80-120
V. Small	<200	40-50

Fertilizer Application

Farmyard manure (300-500 g) is placed in the bottom of prepared holes at transplanting. Complete N-P-K mixed fertilizer grade 13-13-21 is generally used. The first application may be mixed with the farmyard manure at transplanting or applied separately one month after transplanting. The second application is usually spaced two months after the first application. Some farmers apply only N and P in the first application and complete fertilizer in the second application. On average they apply 80 kg N, 80 kg P_2O_5 and 130 kg K_2O per hectare.

Pests and Diseases

Leaf spot (a fungal disease) generally found during heavy rainfall periods, affects the leaf blade first and then spreads down the petiole to the corm. Farmers usually eradicate the infected plants or just the infected leaves, but sometimes also apply fungicide. Farmers usually spray insecticide every one to two months.

Harvest

Taro is harvested six months after transplanting. The corms are graded according to size, with larger sizes drawing higher prices. In 1988 and 1989 taro was graded and priced as shown in Table 2.

Market

Thai farmers cultivate taro according to the market demand. Exporters do their own extension work and generally contract farmers directly with guaranteed prices. Planting area is adjusted according to the world market trend.

Although there are still no real government research activities in this commodity, Phichit Horticultural Research Center in the Central Plain has a collection of 22 taro cultivars from various parts of the country.

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Response of Chinese Taro to Nitrogen Fertilization and Plant Population

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Abstract

Corm yield and corm size are sensitive to both nitrogen fertilization and plant population. The average weight of corm produced by cultivar, Bun Long increased with N application at lower population densitites. However, at highest plant population (16.1 plants m^{-2}) the corm size remained small independent of N fertilization. High corm yields were attained at high plant population and at 956 kg N ha^{-1} applications. The results presented also show that both plant population and N affected days to maturity.

Introduction

Taro chip processors of Chinese Taro [(*Colocasia esculenta*) (L.) Schott var. Bun Long] use equipment developed for white potatoes so that large taro corms must be cut into smaller pieces prior to processing. This produces sharp corners which result in waste when the corms are sliced into chips. Processors would prefer to have taro corms the size of potatoes to increase the efficiency of their operation and reduce waste.

Taro corm growth and development respond to both N fertilization and population density. de la Peña (1978) grew 'Lehua Maoli' in a range of population densities up to 109,000 plants per hectare under upland conditions, and corm weight declined sharply to less than 400 g at the highest density. Total yields, however, continued increasing to the highest density. The highest amount of N applied was 100 kg N ha^{-1}. The work of Silva et al. (1990) indicated that at commercial spacing of about 37,500 plants per hectare, more than 500 kg N ha^{-1} was required to maximize yields of Bun Long taro. Sato and Silva (1990) reported increased corm yields at their highest plant population of 54,000 plants ha^{-1} when N fertilization was increased from 360 to 540 kg N ha^{-1}. This suggests that the 100 kg rate of N applied in their earlier spacing trial was too low for optimum yields.

Materials and Methods

An experiment was designed to determine if corm size could be controlled by varying both the amount of nitrogen applied and the plant population (density). Three rates of N (560, 956, and 1344 kg N ha^{-1}) and three populations (3.7, 9.9, and 16.1 plants m^{-2} with plant spacing of 51.9, 31.8, and 24.7 cm, respectively) were combined factorially to give nine treatment combinations. The experiment was installed at the Maui Community College Molokai Farm in a randomized complete block design with three replications. The soil was an Ustollic Camborthid, Holomua series. A plot consisted of 25 data plants with a one-row border on all sides. Hulis were planted in a square configuration. Nitrogen was applied at planting for the 560 kg N ha^{-1} treatments, at planting and two months after planting for the 956 kg N ha^{-1} treatments, and at planting, and two and four months after planting for the 1344 kg N ha^{-1}. All treatments had the same amount of N (560 kg N ha^{-1}) at planting to provide adequate N for good early growth. Phosphorus and potassium were applied at planting at levels based on soil analysis. Plants were irrigated by drip irrigation.

The experiment was harvested at 8.3 months of age when the plants in the high population treatments reached maturity. The fresh weights of the top and corm of each plant were recorded, and the maturity of corms rated. The first block of the experiment was about 5 m from a Casuarina windbreak, which appeared to cause a marked reduction in growth. The growth reduction extended into parts of the second block. The yields reported are thus from plants harvested from the third block and those plants in the second block which were unaffected by the windbreak. These plants were considerably larger than those in the affected areas.

Results and Discussion

The average values for the measurements made are presented in Table 1 and discussed in the following paragraphs. The yield of tops, which is important because of its relationship to taro leaves sold, reached a maximum (58.7 Mg ha^{-1}) at the highest density (16.1 m^2) and 956 kg N ha^{-1} (Figure 1). There was a marked reduction in the yield of tops in the 16.1 m2 population with 1344 kg N ha^{-1}. This was attributed to the earlier maturity of this treatment. Maturity was

Table 1. Molokai N x population taro experiment Molokai T-1. Average values for large plants.

Nitrogen ($kg\ ha^{-1}$)	Population ($Plt\ m^{-2}$)	Top Weight ($g\ plant^{-1}$)	Corm Weight	Top Yield ($Mg\ ha^{-1}$)	Corm Yield	Maturity*	Surv. Percent
560	3.7	198	377	7.41	14.09	0.37	100
956	3.7	940	900	35.10	33.60	0.11	100
1344	3.7	834	803	31.13	29.99	0.08	100
560	9.9	128	216	12.74	21.42	0.41	100
956	9.9	456	661	45.24	65.56	0.32	100
1344	9.9	508	579	50.35	57.50	0.25	96
560	16.1	219	260	35.78	42.43	0.38	92
956	16.1	360	448	58.69	73.02	0.51	100
1344	16.1	127	283	20.69	46.14	0.78	68

*Mature = 1, Immature = 0
Spacing (square)

defined as the crop reached its "necking" stage when a constriction develops at the petiole-corm base or stump and leaf size begins to decrease.

The average weight per corm increased with N applied and reached a maximum of 900 g plant^{-1} with 956 kg N ha^{-1} and the lowest population (3.7 plants m^{-2}) (Fig. 2). Of interest to the chip processors is the fact that corms of 400 to 600 g were produced by the middle and high populations with the middle and high rates of N. The lowest rate of N (560 kg N ha^{-1}) generally produced smaller corms in all populations while with the highest rate of N (1344 kg N ha^{-1}) smaller corms were produced only at the highest density. The lowest population (3.7 plants m^{-2}) produced small corms with low N and large corms with the middle and high rates of N. It appears that N and population have marked effects on corm size and can be used to control it. The highest total corm yield (73 Mg ha^{-1}) was produced with the highest plant population and 956 kg N ha^{-1} (Fig. 3). This treatment also produced corms that were in the 400 to 600 g range, which is desired by chippers. The sharp decline in yield of this population with 1344 kg N ha^{-1} is due to its earlier maturity.

Another factor that must be considered, however, is the uniformity of corm size as it affects the amount of waste resulting from larger corms. The coefficient of variation (CV) is a measure of variability and is shown in Figure 4 for the combinations of population and N rate. The 16.1 plants m^{-2}, 956 kg N ha^{-1} treatment also had one of the highest CV (70%), which implies a greater range of corm size. The

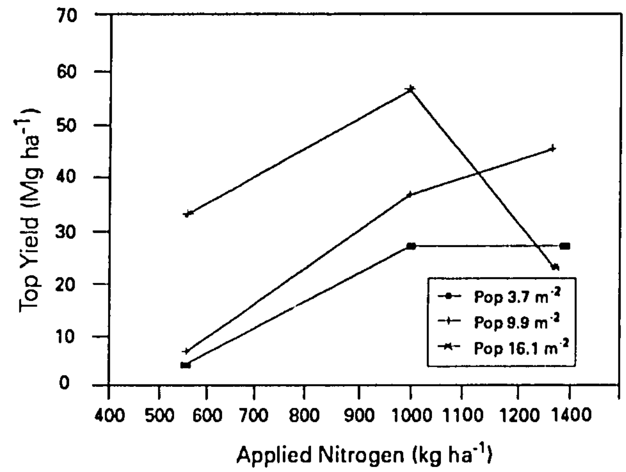

Figure 1. Top Yield and N by Population

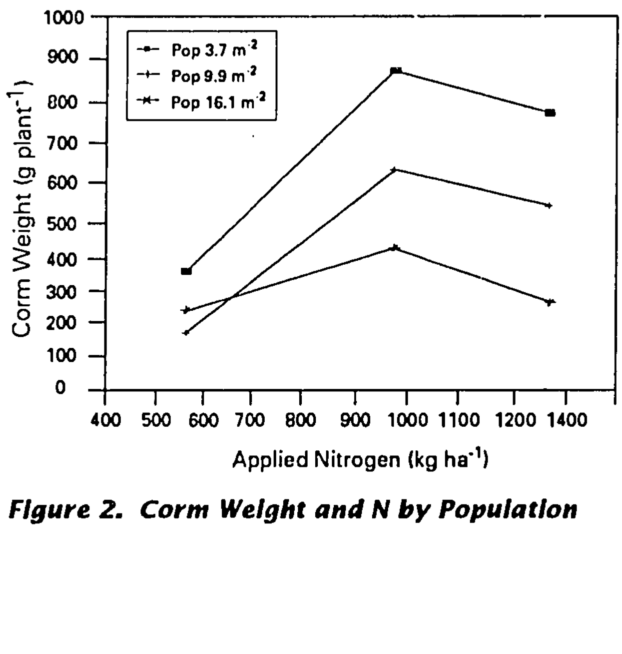

Figure 2. Corm Weight and N by Population

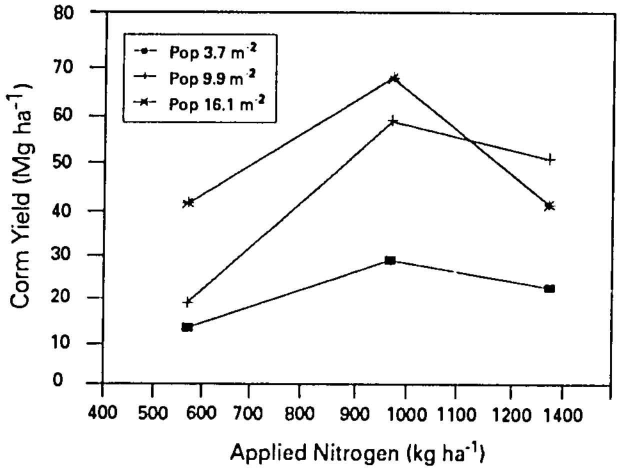

Figure 3. Corm Yield and N by Population

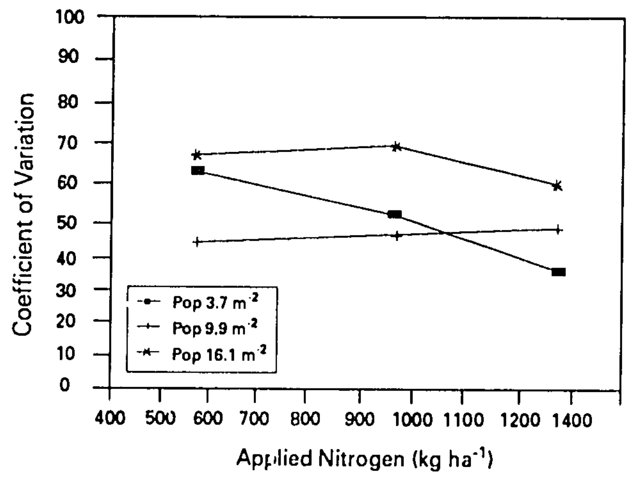

Figure 4. Coefficient of variation and N by Population

population of 9.9 plants m^{-2} had CV of about 50%, suggesting greater uniformity of corm size. This population with 956 and 1344 kg N ha-1 produced the second and third highest corm yields, 65.56 and 57.50 Mg ha^{-1}, respectively. In addition, the corm sizes were in the 400 to 600 g range. Thus, these two treatments appear to offer the greatest potential for producing a large quantity of corms that are relatively uniform in size (400 to 600 g) at the Molokai site.

Both population and N affected plant maturity (Fig. 5). With 3.7 and 9.9 plants m^{-2}, maturity decreased as applied N increased, but at 16.1 plants m^{-2}, maturity increased with increasing N. This resulted in the reduced yields mentioned previously. Plants in the low population and medium to high N were growing vigorously at the time of harvest.

The combination of high population density and high N resulted in vigorously growing plants which competed severely for light and nutrients. This resulted in lower survival of plants at harvest (Table 1).

A statistical model (Equation 1) was developed for the Molokai farm site to describe the response of corm weight to population and applied N, where Corm wt is in g plant^{-1}, N is applied N (kg ha^{-1}), and Pop is plant population (plants m^{-2}).

$$\text{Corm wt} = -1183 + 3.8492\,N - 3.41\,\text{Pop} - 0.0016\,N^2 + 0.6855\,\text{Pop}^2 - 0.0414\,N\text{Pop} \qquad (1)$$

$n = 18$, $df = 12$, $r^2 = 0.862$

Predicted corm weight for several population densities and rates of N is shown in Figure 6. It is

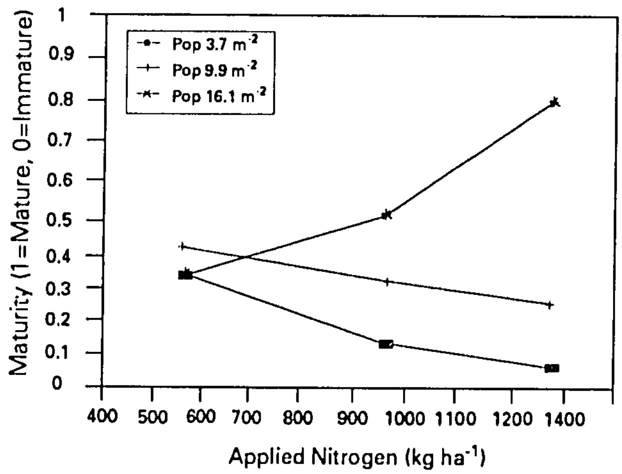

Figure 5. Maturity and N by Population

apparent that 400 to 600 g corm sizes can be produced with an appropriate combination of population densities and nitrogen applications.

A statistical model was also developed to describe the response of corm yield to population and applied N (Equation 2), where Corm yield is in Mg ha^{-1}.

$$\text{Corm Yld} = -145.44 + 0.3104\,N + 7.71\,\text{Pop} - 0.00014\,N^2 - 0.2154\,\text{Pop}^2 - 0.00125\,N\text{Pop} \qquad (2)$$

$n = 18$, $df = 12$, $r^2 = 0.769$

The combination that produces the largest yield of 400 to 600 g corms is a population of 12 to 16 plants m^{-2} with 900 to 1100 kg N ha^{-1} (Fig. 7). The uniformity of corm sizes should also be considered in making a

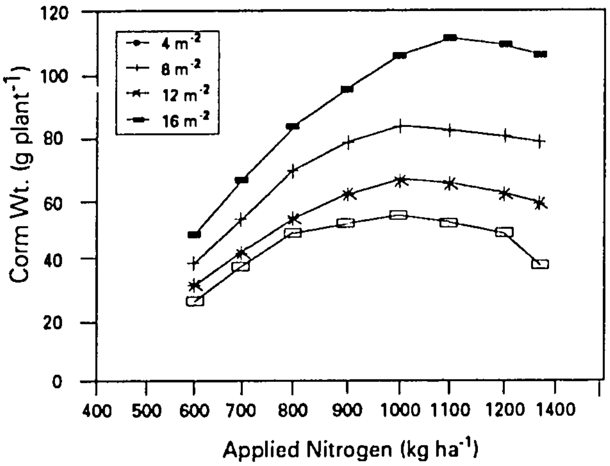

Figure 6. Predicted Corm weight and Nitrogen by population

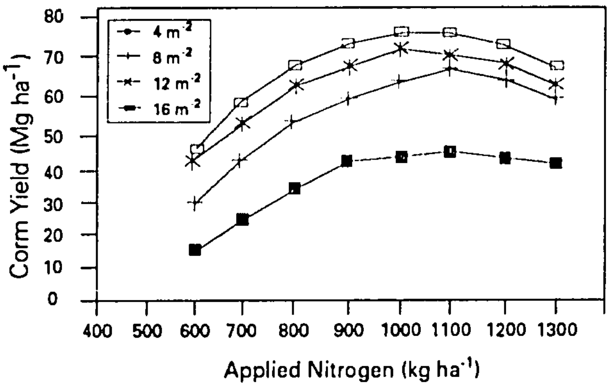

Figure 7. Predicted Corm yield and N x by Population

final decision. The ideal combination should be one that can produce the largest amount of uniform corms in the 400 to 600 g range at lowest cost in terms of plant population and rate of N. A second planting of this experiment is underway, and the results of the two experiments will be compared.

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Evaluation of Taro Germplasm for Tolerance to Acid Soils

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Abstract

Two taro (*Colocasia esculenta* (L.) Schott) cultivars, Lehua Maoli and Bun Long were grown in nutrient solution culture at six levels of aluminum (0, 2, 16, 24, and 36 mg Al L^{-1}) to characterize the differential response of taro cultivars to aluminum toxicity. Increasing aluminum levels, especially those greater than 12 mg Al L^{-1}, significantly reduced dry and fresh weights of taro leaves, petioles, and roots, as well as leaf areas and root lengths. Taro, a tropical crop species, appears to be more tolerant to aluminum than many temperate crop species. Lehua Maoli had significantly greater leaf fresh weights and root lengths than Bun Long. These results indicated that differential aluminum tolerance does occur within the taro germplasm. Also, leaf expansion parameters (i.e., leaf area), and root expansion parameters (i.e., root length), appear to be more sensitive indicators of differential aluminum stress in taro cultivars than dry matter accumulation. Based on the response of these two cultivars, an aluminum concentration in the range of 24 to 36 mg Al L^{-1} will be used to separate differential aluminum tolerance in the taro germplasm.

Introduction

Infertility of acid soils is a major factor limiting plant growth in as much as 40% of the world's cultivated soils (Haug, 1984). Aluminum toxicity, in particular, is probably the major nutrient stress restricting plant growth in soils with pH values below 5.0 (Foy, 1984). Liming to an optimum pH is frequently used to

Table 1. The effect of aluminum on dry weights (g) of the leaves, petioles, and roots of two taro cultivars.

Al^{3+}	Cultivar	Leaves	Petioles	Roots
mg L^{-1}				
0	Lehua Maoli	3.73 ± 0.16	2.72 ± 0.33	1.46 ± 0.18
3	Lehua Maoli	2.74 ± 0.31	2.66 ± 0.11	1.31 ± 0.38
6	Lehua Maoli	2.39 ± 0.40	2.05 ± 0.40	1.26 ± 0.41
12	Lehua Maoli	1.37 ± 0.26	1.74 ± 0.30	0.83 ± 0.31
24	Lehua Maoli	1.33 ± 0.36	1.46 ± 0.36	1.14 ± 0.21
36	Lehua Maoli	0.36 ± 0.13	0.39 ± 0.10	0.38 ± 0.11
0	Bun Long	3.05 ± 0.60	3.64 ± 1.07	1.66 ± 0.59
3	Bun Long	2.08 ± 0.56	2.37 ± 0.75	1.18 ± 0.58
6	Bun Long	2.70 ± 0.31	3.77 ± 0.82	1.46 ± 0.51
12	Bun Long	0.90 ± 0.60	1.40 ± 0.59	0.61 ± 0.28
24	Bun Long	0.79 ± 0.51	1.15 ± 0.56	0.52 ± 0.43
36	Bun Long	0.29 ± 0.11	0.62 ± 0.26	0.17 ± 0.14
<u>ANOVA: P</u>				
Al		0.0001	0.0001	0.0003
Al^2		0.0170	0.3800	0.6140
Cultivar		0.1540	0.2400	0.5420
Al * Cultivar		0.8230	0.2710	0.2700
Al^2 * Cultivar		0.8920	0.3730	0.4090

correct the problem of acid soil infertility; however, many farmers in the tropics cannot afford such a high-input solution (Gourley, 1987).

An alternative, low-input solution to this problem of acid soil infertility is to utilize the crop plants' genetic potential for tolerance to the mineral stresses associated with acid soils. Crop plants vary widely in their tolerance to soil acidity, and some of these differences are heritable (Foy, 1988).

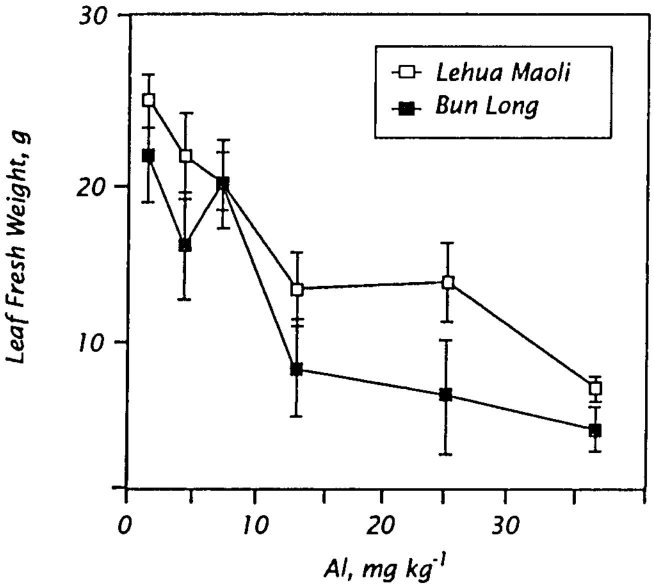

Figure 1. The effect of aluminum on the leaf fresh weights of two taro cultivars.

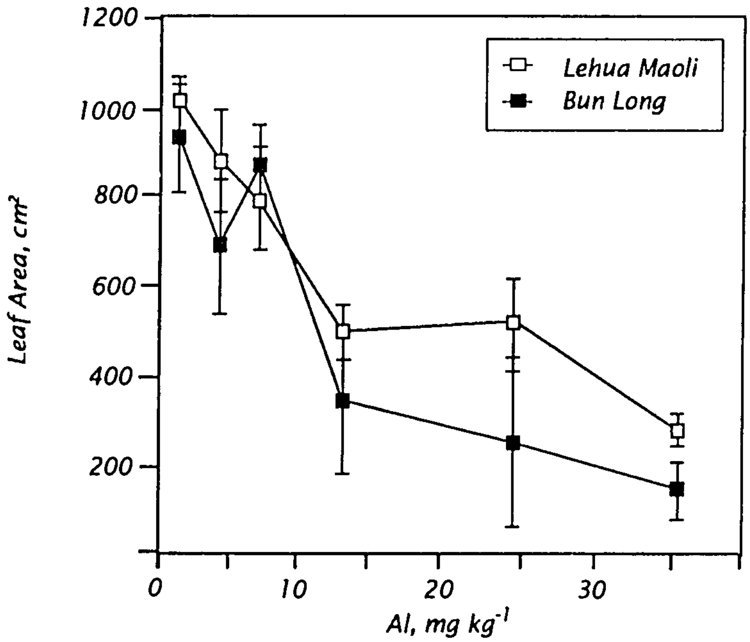

Figure 2. The effect of aluminum on the leaf areas of two taro cultivars.

Very little is known about the response of taro to acid soil infertility, although tropical crop plants are expected to be more tolerant of acid soils than temperate plants. For soils low in calcium (Ca), the beneficial effects of liming on taro growth have been reported (Plucknett et al., 1970; Yong, 1971). There is a need to characterize the response of taro to aluminum, and to determine the genetic variability of taro cultivars to aluminum toxicity. Thus, the objectives of this experiment were to determine the response of two taro cultivars to aluminum, and to identify the aluminum level that will differentiate aluminum tolerance within the taro germplasm.

Materials and Methods

Two taro cultivars, Lehua Maoli and Bun Long, were grown in aerated nutrient solution culture at six levels of aluminum (0, 3, 6, 12, 24, and 36 mg aluminum L^{-1}). The experiment consisted of a factorial combination of two cultivars and six levels of aluminum concentration, grown in blocks of four replicates in a greenhouse.

The basal nutrient solution was a modified Steinberg solution (Taylor and Foy, 1985) which contained (in mM): NH_4-N, 0.3; NO_3-N, 2.7, P, 0.1; K, 1.2; Ca, 1.0; Mg, 0.4; and S, 0.7. The solution also contained the following micronutrients (in uM): Mn, 2; B, 6; Zn, 1; Cu, 0.5; Mo, 0.1; Fe as FeEDDHA, 10.

Taro plants were grown from "hulis," or vegetative propagating materials which consisted of petioles with approximately one cm of corm. Harvesting was carried out at 27 days, when visible growth differences were observed among the aluminum treatments. Fresh weights of the leaves, petioles, and roots were determined, and then dry weights were taken following oven-drying at 75°C. Leaf areas and root lengths were measured using a digital image analysis system (Decagon Devices). The weights of corms were excluded from the statistical analyses because very little corm material was expected to have formed during the 27-day period.

Analysis of variance was determined, using SAS (Statistical Analysis Systems) programs. A probability level of 5% or less was considered to be statistically significant.

Results and Discussion

Dry Weights

Increasing aluminum levels significantly reduced dry weights of the leaves, petioles, and roots of both Lehua Maoli and Bun Long, especially at levels greater than 12 mg Al L^{-1} (Table 1). There was no significant effect of cultivar on dry weights of these plant parts.

Taro, as a tropical crop species, appeared to be more tolerant of aluminum toxicity than temperate crop species, such as wheat (Taylor and Foy, 1985) or snapbeans (Miyasaka et al., 1991). In a previous experiment on taro, aluminum levels up to 12 mg Al L^{-1} failed to show any significant aluminum effect.

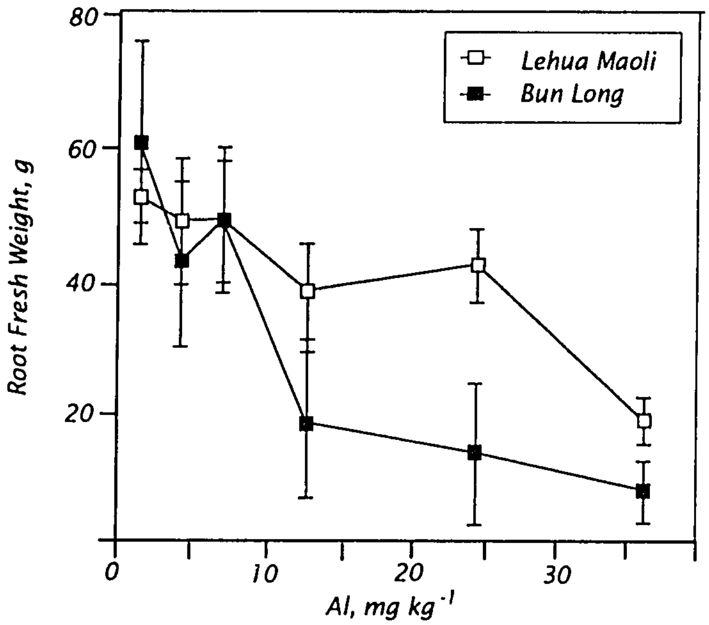

Figure 3. The effect of aluminum on the root fresh weights of two taro cultivars.

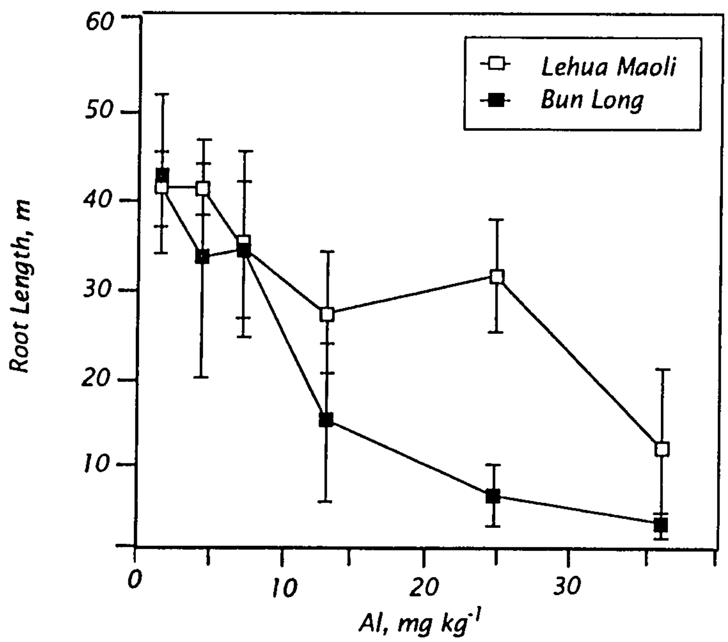

Figure 4. The effect of aluminum on the root lengths of two taro cultivars.

Leaf Fresh Weights and Leaf Areas

Increasing aluminum levels significantly reduced leaf fresh weights (Fig. 1: Linear Al effect, P = 0.0001; quadratic Al effect: P = 0.033). A significant cultivar effect was found for leaf fresh weights (P = 0.012), where Lehua Maoli had significantly greater leaf fresh weights than Bun Long across all Al levels (Fig. 1). The cultivar effect for leaf areas was not quite significant across all Al levels (Fig. 2: P = 0.071).

Apparently, parameters that involve leaf expansion are more sensitive in differentiating aluminum tolerance among taro cultivars. Preferentially, leaf areas should be determined because they provide a more stable parameter than leaf fresh weights. However, under conditions when leaf areas cannot be determined, leaf fresh weights could be used to separate cultivar differences in aluminum-stress tolerance. The best separation of cultivar differences in both leaf fresh weights and leaf areas was found at a range of aluminum levels between 24 and 36 mg Al L^{-1}.

Root Fresh Weights and Root Lengths

Increasing aluminum levels significantly reduced root fresh weights (Fig. 3: Linear Al effect , P = 0.0001) and root lengths (Fig. 4: Linear Al effect, P = 0.0001). A significant cultivar effect was found for root lengths (Fig. 4: P = 0.033), where the roots of Lehua Maoli were longer than those of Bun Long across all aluminum levels. The cultivar effect for root fresh weights was not quite as significant across all aluminum levels

(Fig. 3: $P = 0.079$).

Parameters measuring root expansion appear to be more sensitive to differences among cultivars in their tolerance to aluminum stress, similar to those measuring leaf expansion. Preferentially, root length should be measured because this is a more stable parameter than root fresh weight. However, root fresh weights could be used to separate cultivar differences under conditions when root lengths are difficult to measure. The best separation of cultivar differences in root fresh weights and root lengths was found at aluminum levels between 24 and 36 mg L^{-1}.

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Soil Moisture Related Stresses Affecting Aroid Development

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Abstract
Aroids in general produce higher yields in well watered environments. The water balance module used in SUBSTOR-aroid has been adapted from the CERES models. A description of field trial and the type of information needed to validate the water balance module in SUBSTOR-aroid is presented. Additional modifications to the water balance routine to simulate effects of soil impedance and aeration are discussed.

Aroids are known to have relatively high water requirements (Wilson, 1977; Onwueme, 1978; Plucknett, 1978; Shih and Snyder, 1984). Taro (*Colocasia esculenta* (L.) Schott) grows best under flooded conditions but can also be grown as an upland crop. Tanier, (*Xanthosoma* spp.), although it has high water requirements, has greater drought tolerance and is grown primarily under upland conditions.

Relatively few irrigation experiments on upland aroids have been reported in the literature. Irizarry et al. (1977) compared irrigated and unirrigated yields of 12 *Xanthosoma* cultivars on a Mollisol in the humid eastern region of Puerto Rico. High rainfall was recorded during the first 20 weeks after planting, roughly corresponding to the period required for maximum leaf development and initiation of rapid cormel growth. Somewhat drier conditions were reported from this period until harvest. In spite of the high total rainfall, mean yields for the irrigated crops exceeded unirrigated yields for all cultivars, in some cases by as much as 37%. Due to high variability between replications, traditional parametric statistical tests failed to show that irrigation had a significant (5% level) effect for any given variety. However, the fact that irrigated means were always higher than unirrigated means for 12 comparisons would seem to be highly significant on a nonparametric basis.

Lugo et al. (1987) compared *Xanthosoma* yields under three irrigation levels on a Mollisol, an Ultisol, and an Oxisol in Puerto Rico. Yields always increased with higher irrigation levels, in spite of the fact that total rainfall during the crop cycle considerably exceeded pan evaporation at the Oxisol and Ultisol sites. Susceptibility to root dry rot, a serious disorder affecting *Xanthosoma* production was responsible for the lower yields. Results such as these emphasize the need to consider the effects of seasonal moisture fluctuations in predicting aroid yields.

Fairly reliable water stress models have been developed for many crops. These models allow researchers to estimate the effects of different sequences of varying moisture deficits on crop development and yields (Doorenbos, and Pruitt, 1977; Doorenbos and Kassam, 1979; Hanks, 1983; Hiler and Howell, 1983; Jones et al., 1986). Model inputs include:

- available soil water storage capacity in the plant rooting zone
- root water extraction patterns
- potential evapotranspiration
- crop coefficients for relating potential evapotranspiration to crop water requirements
- crop sensitivity coefficients
- maximum (potential) yield under nonlimiting water supply.

The water-stress subroutine currently used in the SUBSTOR-aroid model is essentially the one used in the CERES models (Jones et al., 1986). This subroutine has been found to work well for many crops, but has not been tested with aroids. Model assumptions that need testing and, if necessary, modification, pertain to water extraction in the root zone, critical soil water depletion levels at which water stress ensues, crop coefficients that relate crop water requirements to atmospheric evapotranspiration demands, and crop sensitivity coefficients relating respiration deficits to yield development.

A factor that is currently not considered in SUBSTOR models, and may be important, is soil mechanical impedance. Cormel development in *Xanthosoma* has been found to be extremely sensitive to this parameter (Lugo et al. 1978). Mechanical impedance is in turn highly dependent on soil water content. Thus, fluctuations in soil moisture could be expected to result in fluctuating mechanical impedance as well. Jones et al. (1991) have outlined a general framework within which varying impedance data are available and upper and lower limiting thresholds for root and cormel growth are known. If a functional relation between soil moisture content and mechanical impedance were available, a mechanical impedance subroutine could be linked to the water balance subroutine in a relatively straightforward manner.

Poor soil aeration associated with excessive soil wetness may be another important factor. Although the preferred habitat of *Colocasia* is generally a flooded environment, *Xanthosoma* seems to behave differently. Silva and Irizarry (1979) observed a nearly 50% reduction in tanier yields when depth to water table was reduced from 45 to 15 cm. Jones et al. (1991) have proposed a means for modeling aeration effects on root growth. The aeration stress index they propose is a function of soil moisture content. Hence, as in the case of soil mechanical impedance, a soil aeration stress subroutine can in principle be linked to the water balance subroutine.

Research Program

A three-year research project, with the purpose of aiding in validation and, if necessary, improvement of the water stress subroutine of the SUBSTOR-aroid model, was initiated by the University of Puerto Rico's Agricultural Experiment Station in July of 1991. Emphasis of the study is on evaluating and modeling crop sensitivity of tanier to moisture stress at different growth stages. Since no results from the study are as yet available, this report will be limited to a summary of the research program.

The soil where the study will be conducted is a Coto clay (Typic Eutrustox, clayey, kaolinitic) situated in a climatic zone with alternating wet and dry seasons of approximately three months each. Due to its low water holding capacity, the Coto soil provides a sensitive environment for inducing water stress. Detailed phenological measurements for tanier under nonlimiting water supply have recently been obtained by Goenaga and Singh (in this proceedings) at this location.

Two successive crops of tanier will be subjected to water stress (as determined by natural rainfall and transpiration) at one each of three crop growth stages, with the remaining stages kept stress-free by irrigation. The three growth stages are, early slow development (0-80 d), rapid foliar development (80-180 d), and cormel development (180-300+ d). Two additional treatments will be included: one where water stress is allowed to occur during the entire growth season, and another where zero water stress is maintained by irrigating during the entire season. The latter will serve as the reference by which all other treatments can be compared on a relative basis. Prior to planting the crop, the soil will be intensively sampled and characterized in terms of chemical and hydraulic properties including soil impedance. During crop development, temperature, solar radiation, rainfall, and relative humidity will be monitored on a continuous basis with an automated weather station. Pan evaporation will be measured daily. Soil water depletion patterns in the root zone will be monitored by time domain reflectometry (TDR). Infrared thermometry measurements will be made to obtain indices of relative stress severity between treatments. Destructive sampling will be conducted at appropriate intervals, and crop phenological characteristics described in the IBSNAT Minimum Data Set (IBSNAT, 1988) will be measured. Data will be provided to IBSNAT personnel for improving and validating the water stress subroutine of SUBSTOR-aroid.

It is expected that the measured soil water content profiles and infrared thermometer measurements will provide important checks on the model's ability to simulate soil water balance in an aroid rooting environment, as well as resultant water stress severity. Should problems be encountered in model validation, these measurements could provide information on specific model components that need to be revised.

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Modeling Water Requirements for Wetland Taro Cultivation in Hawaii

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Abstract
Water for wetland taro cultivation in Hawaii is strongly protected by law, but the quantities and qualities of water to be protected are poorly defined. Current efforts to improve these definitions involve monitoring water use conditions and crop responses in contemporary pondfields, using these data to develop models of pondfield water requirements, and using modeling results to help quantify and qualify water rights.

Introduction

In Hawaii, the legal institution of appurtenant water rights guarantees to lands today the same quantities and qualities of water used upon them at a time (circa 1850) of drastic changes in Hawaii's land tenure systems (Penn and Tummons 1990; Chinen 1958). Because taro pondfields often relied upon constant throughflow of irrigation water, wetland taro cultivation accounts for most of the water reserved to appurtenant water rights. The State of Hawaii Commission on Water Resource Management (COWRM) is charged by law with assuring and preserving appurtenant water rights in the course of fulfilling its broader management responsibilities. Because most appurtenant water rights are not presently exercised, COWRM has difficulty assuring and preserving them in the face of current water demands. In its most active effort to fulfill its responsibilities to appurtenant water rights, COWRM provides equipment for our studies of wetland taro water requirements.

Factors Affecting Water Requirements

Pythium fungi, a major source of taro disease, are believed to proliferate in unsanitary fields and where water becomes warm and stagnant (Ooka, 1990). Thus, wetland taro cultivation commonly requires adequate circulation of water that is sufficiently clean, cool, and clear to inhibit *Pythium* infestation. However, field observations of water management/ *Pythium* relationships have not been documented since the 1960s, and then for only one location. These relationships have been documented for six taro growing environments exhibiting typical variation in climatic and edaphic regimes (Table 1) in the hope that subsequent models of wetland taro water requirements may be broadly applicable and based on representative samples of islandwide water use conditions.

Data Collection and Analysis

At each research station, an on-site data logger records hourly averages of variables sampled over the entire crop cycle. Water level recorders and aquatic thermistors installed at control sections sample the volume and temperature of water entering and leaving a taro pondfield via local irrigation and drainage systems. A third water level recorder monitors changes in pondfield water storage at each station. Aquatic thermistors arrayed vertically at the ponded water surface, mid-pond depth, and 2.5 to 7.5 cm beneath the soil surface (in the taro plant root zone) provide profiles of water and soil temperatures within the test pondfields. Microclimate stations on the pondfield banks sample net radiation above the crop canopy, as well as global radiation, wind speed, ambient temperature, humidity, and rainfall above the bank. Resultant data sets allow us to analyze relationships between irrigation flows, water/soil temperatures, and atmospheric conditions. They also serve as input for computing components of water and energy balances (such as evapotranspiration) and for developing models of pondfield physical processes.

Short-term data collection includes regular single-ring infiltrometer and seepage meter measurements to indicate pondfield water percolation losses. Although these losses may be insignificant, more rigorous field testing, laboratory analyses, and computational and graphic analyses may also be conducted to further estimate percolation losses and better characterize the seepage and drainage patterns occurring in the pondfields.

Canopy albedo (using two pyranometers), canopy temperature (using infrared thermometers), and taro plant transpiration (using stem flow gauges) on a rotational basis between the stations are also measured. Previous studies by Shih and Snyder (1984) used lysimeters to measure taro pondfield evapotranspiration and correlated changes in these measured values with changes in the leaf area of the

Table 1. Taro pondfield research station characteristics.

Location ***District, Island***	***Rainfall (mm yr $^{-1}$)***	***Pan Evaporation (mm yr $^{-1}$)***	***Soil Texture & Drainage***
Waimea, Kauai	*500-750*	*2030-2290*	*clay loam/good*
Waikoko, Kauai	*2000-3000*	*1520-1780*	*silty clay/poor*
Waianae, Oahu	*600-800*	*1780-2030*	*silty clay/good*
Waihe'e, Oahu	*1500-2000*	*1270-1520*	*silt loam/poor*
Honopou, Maui	*1500-2000*	*1780-2030*	*clay/good*
Keanae, Maui	*2500-3000*	*<1780*	*silt loam/poor*

taro plants. In this case, attempts are being made to define the evaporation/transpiration ratio by separating transpiration via stem flow measurements in selected taro plants and by phenomenological methods of modeling surface conductance suggested by Stewart (1988).

Crop growth and harvest information are tracked by measuring and recording leaf emergence rates and canopy geometry. Biomass samples are provided to University of Hawaii agronomists to obtain leaf area indices and plant part biomass fractions, and to look for *Pythium* infestation. Harvest inventories secure information about yields and *Pythium* occurrence, and participating farmers are regularly interviewed to keep track of management practices. This information helps us explore changes in water/soil temperatures and evapotranspiration rates as canopy cover increases and decreases, and occurrences of *Pythium* infestation and their relationships with water and soil temperatures and other variables.

A topographical survey of pondfield systems provides a basis for future mapping and simulations, and allows us to estimate contributions from overland flow to pondfield water balances.

Model Development

The taro pondfield hydrological system is characterized by its partitioning of energy (heat), water, and water vapor into separate flows by interconnected controlling processes. Veen and Dolman (1989) apply this characterization to the hydrological system of any vegetation. Each process can be modeled as a function of its related physical parameters providing the basis for time-dependent simulation of taro pondfield energy and water balances.

Analysis of these data allows us to model relationships between irrigation, water use, and local climatic and geohydrologic conditions. The models can then be used to estimate water requirements for uncultivated lands from local baseline conditions, and to estimate additional water requirements for cultivated lands where taro corm quality is unacceptable.

In modeling the entire system, the first consideration is that the pondfield floor is impermeable. Recorded data are then used to establish relationships between water/soil temperatures and *Pythium* infestation. The flows of water needed to maintain subcritical temperatures are then determined. These flows are the minimum required surface water outflows from the pondfield. Adjustment for evapotranspiration and percolation losses, and for seepage, rainfall, and overland flow gains, yields the amount of required surface water inflow to the pondfield. Once these relationships have been established on a monthly basis for each field research station, the monthly models for all sites can be combined into a time-dependent meta-model that predicts pondfield irrigation water requirements for any particular site in Hawaii.

Model Testing and Use

Baseline edaphic and climatic parameters for model input are obtained from published information and short-term data collection at pondfield research stations and other cultivated taro pondfields. Model runs generate estimates of irrigation requirements which are then compared against actual water flows, water temperatures, and *Pythium* infestation. The results of these analyses are used to go back and alter model algorithms and routines until the model functions satisfactorily over a wide range of climatic and edaphic conditions.

To further demonstrate model applications, accountings of appurtenant water rights within discrete watersheds are conducted. In these exercises, irrigation requirements estimated via the models are adjusted to account for systemwide transmission losses and other site-specific physical, human, and historical factors. This human and historical accounting is a difficult task, because we have very little detailed documentation of taro pondfield irrigation practices circa 1850. Nonetheless, the resulting estimates of water reserved to appurtenant water rights can aid the COWRM in processing water use permits. These estimates can also help establish instream flow standards by providing baselines for measuring the assurances and protection given to these rights. Model estimates could also aid landowners and water users in protecting existing water uses and in obtaining water for future uses. Knowledge of taro pondfield irrigation systems is also helpful to other kinds of assessments. For example, these systems dissipate flood waters and their energy, and thus an understanding of their engineering can inform those involved with contemporary flood control activities.

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Effect of Photoperiod and Temperature on Growth and Development of Taro (*Colocasia esculenta* (L.) Schott)

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Abstract

Development and growth response of taro (*Colocasia esculenta* (L.) Schott) to an increase in temperature and photoperiod has not been studied much, and little is known of photoperiod effects on leaf number, cormel number, and yield. A temperature-by-photoperiod experiment was conducted in the field on the island of Maui in the state of Hawaii at two elevations, 282 and 640 m during 1989-1990, to examine the effects of photoperiod and temperature on leaf number, cormel number, and yield, for cultivars Bun Long and Lehua Maoli. Under conditions of high nutrient fertility and adequate water supply, plants were grown at natural daylength (control), and control plus 0.5, 14, 17, and 20 h photoperiods. These photoperiods were artificially produced by extending the natural daylength with lamps. During the crop growth period, mean maximum air temperatures were 24.5 and 23.7 °C and mean minimum air temperatures were 17.2 and 15.9 °C at the 282 and 640 m sites, respectively.

Leaf tip appearance and leaf opening rate were unaffected by photoperiod, but maturity at 640 m was delayed by 44 days. At both elevations, there was little difference in corm yield with increased photoperiod. At lower elevations (282 m), higher cormel numbers were observed in both cultivars.

Introduction

The modeling of leaf appearance and growth of taro in the SUBSTOR-aroid model (Singh et al., in this proceedings) has been developed using data obtained from field experiments in Hawaii and Fiji. Tests of phenological predictions by this model have not been conducted yet.

The distribution of taro ranges from 30 °N to 30 °S of the equator (Purseglove, 1972). The growth period of taro ranges from 9 to 12 months, with growth occurring in more than one climatic season. Kay (1973) reported that the optimal water temperature for taro growth ranges from 21 to 27 °C. Plants grown at this temperature showed better plant growth and leaf area development and longer roots (Paradales, Melchor, and de la Peña, 1982). In general, very little work has been done on the effect of temperature on tropical root crops, especially taro.

The leaf appearance rate for taro is mainly described as a function of temperature (Singh et al., in this proceedings). Because development and growth response of taro to an increase in temperature and photoperiod has not been extensively studied, little is known of photoperiod effect on leaf number and corm yield.

This paper describes a temperature-by-photoperiod experiment conducted at two elevations (282 and 640 m) on the slope of Mt. Haleakala on the island of Maui in Hawaii during 1989-1990. The objective of this experiment was to examine plant growth and yield response of taro when subjected to temperature and daylength differentials in a tropical environment.

Materials and Methods

Taro cultivars, Bun Long and Lehua Maoli, were planted on 28 March 1990 at two experimental sites at similar latitudes (21 °N lat.). The sites were a) Kuiaha, elevation 282 m (Haiku series, clayey, ferritic, isohyperthermic Humoxic Tropohumults), and b) Haleakala, elevation 640 m (Makawao series, clayey, oxidic isothermic Humoxic Tropohumults) on the eastern slope of Mt. Haleakala.

A split-plot experimental design was used at both sites, with single replication, five photoperiod treatments (main plots), and two taro genotypes (subplots). The photoperiod treatments were control (natural daylength, (P0)), and control plus 0.5 (P1), 14 (P2), 17 (P3) and 20 (P4) h photoperiods. The main plots (13.5 x 14.0 m) were surrounded by a black 2.1 m high saran net (100% light interception) to prevent unwanted light from reaching adjacent plots. Photoperiods were produced by extending the natural daylength with four metal halide 500 W lamps on posts 2.4 m high, at both ends of the main plot at approximately 4.5 m from each other. For each

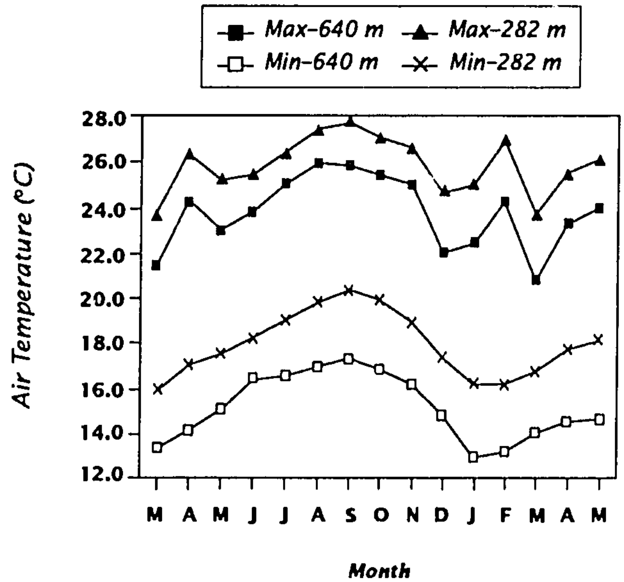

Figure 1. Mean maximum and minimum air temperatures during experimental period at 282 and 640m elevations.

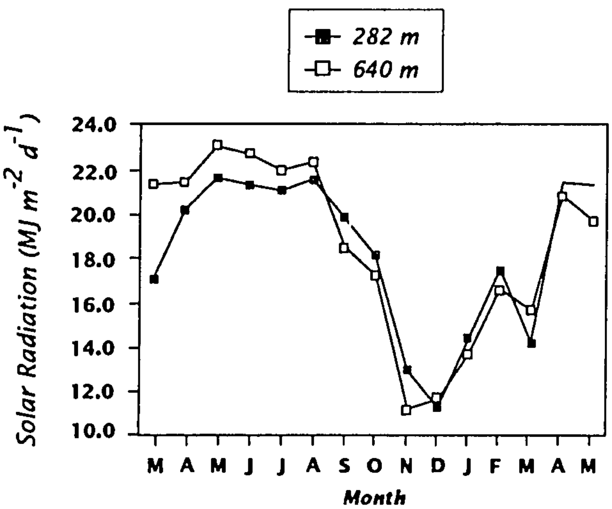

Figure 2. Mean solar radiation during experimental period at 282 and 640m elevations.

photoperiod treatment, the lights were turned on before sunrise for one-half of the period required to extend the daylength. At sunset, the lights were turned on for the remaining half.

The subplots with Bun Long and Lehua Maoli were 1.9 by 3.25m with three rows spaced 0.65 m apart. Hulis were planted about 20 cm deep. Plots were fertilized with 100, 160, and 160 kg ha^{-1} of N, P_2O_5 and K_2O, respectively, prior to planting. Two additional applications of 40 kg ha^{-1} of N each were applied at 6 and 10 weeks after planting, respectively. Planting date was 28 March 1990 at both elevations and all plots were drip-irrigated when necessary.

Soon after first leaf opening, three plants from each subplot were selected and marked for nondestructive measurements throughout the season. Each plant was measured for leaf emergence (last visible leaf tip) and last fully opened leaf. These measurements were collected from first leaf appearance to crop maturity.

Final harvest was made at maturity. It was assumed that maturity (distinguished by a bottleneck shape) occurred when 50% of plants had corms that had reached the bottleneck shape. At harvest, each of the three plants in the subplots was harvested by

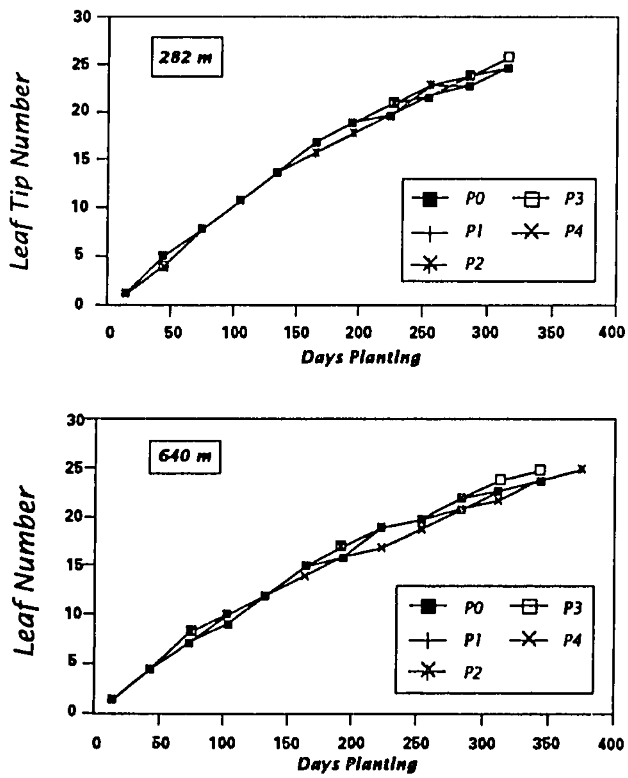

Figure 3. Leaf tip number of taro grown at two elevations under differing photoperiod regimes.

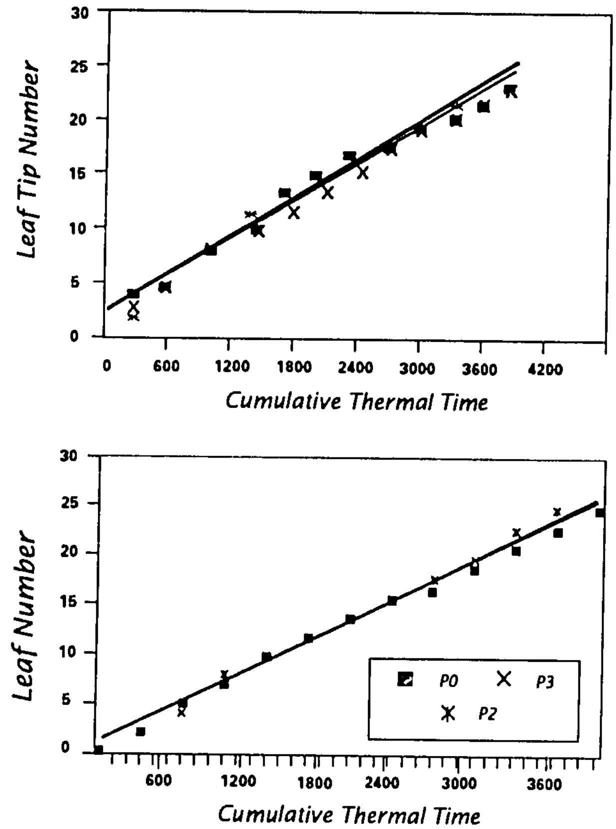

Figure 4. Relationship between leaf tip and leaf number and cumulative thermal time. The lines represent regression lines computed from equations given in Table 1.

digging an area of 0.42 m^{-2} around each plant to a depth of 30 cm. Plants were then pulled from the soil, washed, and separated into leaf blades, petioles, and corms, for suckers and main plants. Leaf blades were used for determination of leaf area using a LICOR LI-300 area meter. Samples were dried at 70 °C to constant weight for dry matter determination.

Weather data were measured with a LI-1200 automated weather station (LICOR, Lincoln, NE), which was established near the experimental plot at each site to record daily weather data during the crop growth period.

In order to quantify the effects of temperature on leaf tip and leaf opening, daily thermal time (DTT) and cumulative thermal time (CTT) were computed from the minimum and maximum air temperature and a base temperature of 10 °C. The STEPWISE routine (SAS Institute, 1987) was used for model analysis to relate leaf number with CTT.

Results

Differences in taro growth under the five photoperiods at the two elevations were assumed to be primarily due to changes in daylength, and decrease in temperature associated with increasing elevation. During the crop growth period, mean maximum air temperatures were 24.5 and 23.7 °C, and mean minimum air temperatures were 17.2 and 15.9 °C at the 282 and 640 m elevations, respectively (Fig. 1). Differences in solar radiation were less than the differences in air temperature. Mean solar radiation values during the crop growth period were 18.24 and 18.52 MJ m^{-2} d^{-1} at 282 and 640 m, respectively (Fig. 2). The differences in temperature and irradiance between elevations apparently had an influence on the response of taro plants to the various photoperiod treatments. Leaf tip and leaf number per plant were influenced by elevations throughout the growing season.

The number of days to first leaf appearance were similar at the two elevations despite the temperature differential between elevations. Taro plants at 640 m took longer to reach the end of initial growth, end of maximum growth, and maturity than did those grown at 282 m.

Leaf Number

The leaf tip number vs. time response was essentially linear up to the end of maximum growth at the 20th leaf stage (Fig. 3). There was only negligible difference during the crop growth period, for leaf tip appearance and leaf number per plant under different photoperiods.

Leaf Number vs. Temperature and Photoperiod

The time interval over which all equations were applicable was from planting to maturity (Table 1). Of the variables examined, CTT accounted for up to 99% of the variation in leaf number when data were combined over both elevations. Within elevations, CTT was the main factor controlling leaf number at 282 and 640 m.

The regression coefficients for the relationships between leaf tip and CTT were relatively constant with changes in photoperiod (Table 1), suggesting that leaf tip appearance rate was not affected by photoperiod. Regression coefficients for the relationship between leaf opening and CTT were less constant with changes in photoperiod. Much of the variability may be attributed to our inability to identify the leaf opening date accurately.

The data in Figure 4 for specific leaf number indicate that for the 20th leaf, thermal units from first leaf opening were 2658, 2619, and 2545 °C for the control, 14, and 20 h photoperiod, respectively.

Table 1. Regression equations expressing the effects of temperature and photoperiod on taro leaf number.

Dependent Variable		Equation*	R^2
All Elevations			
Leaf tip		*Y = 1.9260 + 0.0069 * CTT*	0.99
Leaf open		*Y = 1.5079 + 0.0068 * CTT*	0.99
Elevations			
282 m			
Leaf tip		*Y = 1.9780 + 0.0068 * CTT*	0.99
Leaf open		*Y = 1.3205 + 0.0070 * CTT*	0.99
640 m			
Leaf tip		*Y = 1.8790 + 0.0069 * CTT*	0.99
Leaf open		*Y = 1.6958 + 0.0066 * CTT*	0.99
Varieties			
Lehua Maoli			
Leaf tip		*Y = 1.6240 + 0.0071 * CTT*	0.99
Leaf open		*Y = 1.0560 + 0.0072 * CTT*	0.99
Bun Long			
Leaf tip		*Y = 2.1490 + 0.0074 * CTT*	0.98
Leaf open		*Y = 1.9380 + 0.0064 * CTT*	0.98
Photoperiods			
P0			
	Leaf tip	*Y = 1.9000 + 0.0069 * CTT*	0.99
	Leaf open	*Y = 1.3441 + 0.0069 * CTT*	0.99
P1			
	Leaf tip	*Y = 2.1300 + 0.0067 * CTT*	0.99
	Leaf open	*Y = 2.1677 + 0.0061 * CTT*	0.98
P2			
	Leaf tip	*Y = 2.0090 + 0.0069 * CTT*	0.99
	Leaf open	*Y = 1.4560 + 0.0069 * CTT*	0.99
P3			
	Leaf tip	*Y = 1.8790 + 0.0071 * CTT*	0.99
	Leaf open	*Y = 1.3680 + 0.0070 * CTT*	0.99
P4			
	Leaf tip	*Y = 1.7220 + 0.0068 * CTT*	0.99
	Leaf open	*Y = 1.1706 + 0.0069 * CTT*	0.99

** CTT = Cumulative thermal time*

Table 2. The main effect of photoperiod on cormel number and yield of taro.

Photoperiod	Cormel Number	Dry Weight (g plant $^{-1}$) Corm	Cormel	Total Biomass
P0	16.9	397.3	500.4	989.8
P1	18.7	367.9	541.9	1023.6
P2	21.0	406.4	568.0	1073.3
P3	20.4	428.3	583.7	1098.7
P4	22.3	361.8	572.5	1002.2

Yield at Harvest

Days to maturity increased with lower temperature, with no difference between photoperiod treatments.

Leaf numbers at maturity were the same (28) for all photoperiods at both elevations. Cormel number per plant increased concomitantly with increase in photoperiod, with 16.9 for control, and 22.3 for the 20 h daylength (Table 2).

Both the cultivars, Bun Long and Lehua Maoli produced greater cormels per plant at 282 m than at 640 m elevation (Table 3).

The effects of photoperiod on cormel number and yield of taro at harvest for cultivars Bun Long and Lehua Maoli are given in Table 4. This table shows that cultivar Bun Long produced more cormels per plant than Lehua Maoli at all photoperiod levels.

Discussion

The required thermal time for leaf tip appearance and leaf opening in this study was 137.7 and 142.5 °C per leaf, respectively. This thermal time was the same at both elevations: at 282 m with a mean irradiance of 18.24 MJ m^{-2} d^{-1}, and at 640 m with a mean irradiance of 18.52 MJ $m^{-2}d^{-1}$. The natural daylength during the growing season at both elevations ranged from 11.7 to 14.2 h. Extending the photoperiod had no noticeable effect on leaf appearance rate.

Changes in photoperiod at the 640 m elevation did have an effect on corm, cormel, and total dry weight per plant, and was lowest for the 20 h photoperiod (Table 5). The effect of elevation on maturity was particularly striking. At 640 m, it took 44 more days for plants to reach maturity compared with plants grown in similar photoperiods at 282 m.

In the experiment reported here, increases in

Table 3. The effect of varieties on cormel number and yield of taro at harvest at two elevations (282 and 640 m).

		Cormel Number	Dry Weight (g plant $^{-1}$) Corm	Cormel	Total Biomass
282 m					
	Bun Long	34.3	398.3	682.1	1165.3
	Lehua Maoli	11.8	431.0	553.1	1045.1
640 m					
	Bun Long	25.9	321.0	704.3	1161.5
	Lehua Maoli	7.4	419.0	273.7	778.1

Table 4. The effects of increasing photoperiod on cormel number and yield of taro at harvest for cultivars Bun Long and Lehua Maoli.

	Photoperiod	Cormel Number	Dry Weight (g plant $^{-1}$) Corm	Cormel	Total
Bun Long	P0	24.7	366.5	656.7	1138.9
	P1	28.8	416.0	754.1	1318.1
	P2	31.7	341.6	600.3	1044.5
	P3	30.7	352.2	729.2	1178.6
	P4	34.8	321.9	725.5	1136.9
Lehua Maoli	P0	9.2	428.2	344.1	840.8
	P1	8.5	319.8	329.7	728.9
	P2	10.3	471.2	535.7	1102.1
	P3	10.2	504.3	438.1	1018.8
	P4	9.8	401.7	419.4	867.5

photoperiod increased the number of cormels per plant for Bun Long (Table 4).

Summary

This study provided an opportunity to contrast the effects of daylength and temperature on growth and development of taro. Results reported here show that the duration of leaf appearance and leaf opening was longer at sites characterized by lower temperatures when planted under optimum conditions. Leaf appearance, leaf opening, and dry matter production were unaffected by increasing photoperiod. There was an effect in cormel number per plant between the two elevations, with a greater numbers of cormels being produced at lower elevation or higher temperature. It can be assumed that the rate of leaf tip appearance is a function of temperature when taro is grown as a sole crop under optimum soil fertility and adequate water supply.

Table 5. The effect of increasing photoperiod on cormel number and yield of taro at harvest at two elevations.

Site	Photoperiod	Cormel Number	Dry Weight (g plant $^{-1}$) Corm	Cormel	Total Biomass
282 m					
	P0	20.6	400.0	581.9	1062.5
	P1	20.2	362.8	547.7	995.7
	P2	23.5	390.4	514.7	970.8
	P3	24.3	499.1	696.1	1270.9
	P4	26.7	421.0	747.6	1225.9
640 m					
	P0	13.2	394.6	418.9	917.2
	P1	17.2	373.0	536.1	1051.3
	P2	18.5	422.4	621.3	1175.7
	P3	16.5	357.5	471.3	926.5
	P4	18.0	302.6	397.4	778.4

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Accumulation and Partition of Dry Matter in Tanier (*Xanthosoma* spp.)

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Abstract

The accumulation and partitioning of dry matter in three tanier cultivars were determined to characterize growth patterns and productivity in an effort to establish growth analysis data from which a tanier growth model can be developed. Tanier plants were planted in the field and harvested for biomass production about every 30 days during the growing season. At each harvest, plants were separated into various plant parts and their dry matter content was determined. The first 68 days after planting (DAP) were characterized by low rates of dry matter accumulation with only leaves and petioles showing substantial growth. A grand growth period followed in which leaves, petioles, and roots rapidly accumulated dry matter until 223 DAP. Thereafter, total dry matter continued to increase but mainly as a result of corm and cormel growth. Cormel dry matter content peaked to an average of 46% of the total plant dry matter by 251 DAP in cultivar Kelly, and by 313 DAP for cultivars Morada and Blanca. Partitioning of dry matter to corms decreased from 35 to 161 DAP in Kelly and Morada, whereas it increased linearly during the growing season in Blanca. Cultivar Kelly initiated sucker development at 251 DAP, whereas Blanca and Morada did so at 342 and 417 DAP, respectively. The number of suckers per plant also varied between cultivars. Regression models describing the effects of plant age on dry matter partitioning to various plant parts are presented.

Introduction

Tanier (*Xanthosoma* spp.) is an important root crop and food staple for inhabitants in tropical countries. Because of the low research priority given to this crop in the past, the National Academy of Sciences (1978) has classified it as a neglected food crop with promising economic potential. Yield potential of tanier is seldom accomplished mainly because knowledge is lacking on diseases, proper management practices, and physiological constraints that may limit growth

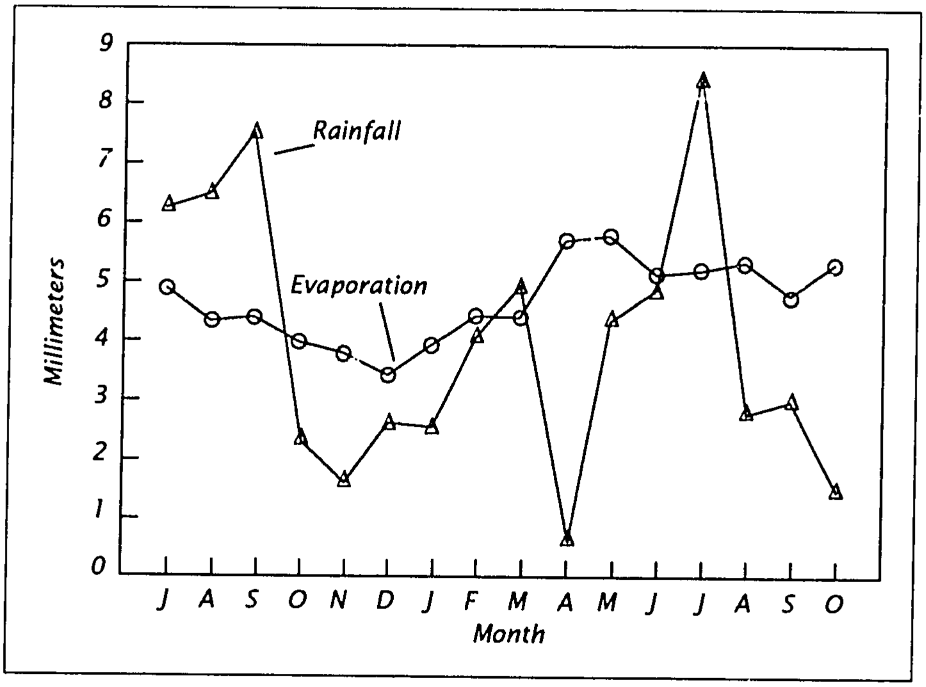

Figure 1. Mean monthly Class A pan evaporation (○) and rainfall (△) from field planting on July 1989 until termination of the experiment on October 1990.

and development.

To improve agricultural production of tanier, and transfer that technology to other production sites, plant scientists need to reassess traditional research approaches. Crop simulation models have increased in popularity as research tools and have promoted a more comprehensive understanding of the complex physical and biological interactions affecting yield performance of crops. The development of a tanier growth and production model will provide a better understanding of how harvestable yield is affected by various agronomical, physiological, and environmental factors.

This study was undertaken as an initial effort to establish growth analysis data from which a tanier model can be developed, and with the objective of determining dry matter accumulation and partitioning to various plant parts during growth and development of three tanier cultivars.

Materials and Methods

The experiment was conducted at the Isabela Research Farm of the Tropical Agriculture Research Station in Puerto Rico. The soil is a well-drained Oxisol (Typic Eutrustox) with pH 5.4, bulk density 1.4 g cm^{-3}, organic carbon 2.0%, and exchangeable bases 8.3 cmol(+) kg^{-1} soil. Soil nitrate and ammonium at the 0-15 cm depth were 8.1 and 14.9 ug g^{-1} (ppm) of soil, respectively. Figures 1 and 2 show mean monthly rainfall, Class A pan evaporation, maximum, minimum, and mean air temperatures, and mean daily solar radiation during the experimental period.

The plants were established in a screenhouse from excised corm buds with fresh weights of about 16 g (2.7 g dry weight) and planted in jiffy pots containing Pro-Mix growing medium. The three tanier cultivars used for the experiments were Blanca de Pais (*Xanthosoma caracu*), Kelly, and Morada (*Xanthosoma violaceum*). Kelly produces yellow-fleshed cormels and is considered an early type cultivar with highest yields obtained about eight months after planting. Blanca produces white-fleshed cormels and Morada produces purple-fleshed cormels. These cultivars attain maximum yields at about 12 and 16 months after planting, respectively.

On July 6, 1989, plants at the 1-leaf stage were transplanted to the field. The mainplots (cultivars) replicated seven times, were split to accommodate 14 biomass harvests. Each subplot contained 20 plants spaced .91 x .46 m apart from which the inner six were sampled. Plots were drip irrigated when the soil water tension, measured with tensiometers at a depth of 15 cm, exceeded 20 K Pa. Fertigation was supplied every two weeks at the rate of 5.6 and 7.0 kg ha^{-1} of N and K, respectively, using urea and potassium nitrate as the nutrient sources. Each plant received 3.5 g of granular P provided as triple superphosphate at planting time.

Plants and biomass measurements were collected at 35, 68, 98, 131, 161, 195, 223, 251, 285, 313, 342, 377, 417, and 460 days after planting (DAP) except for cultivar Kelly in

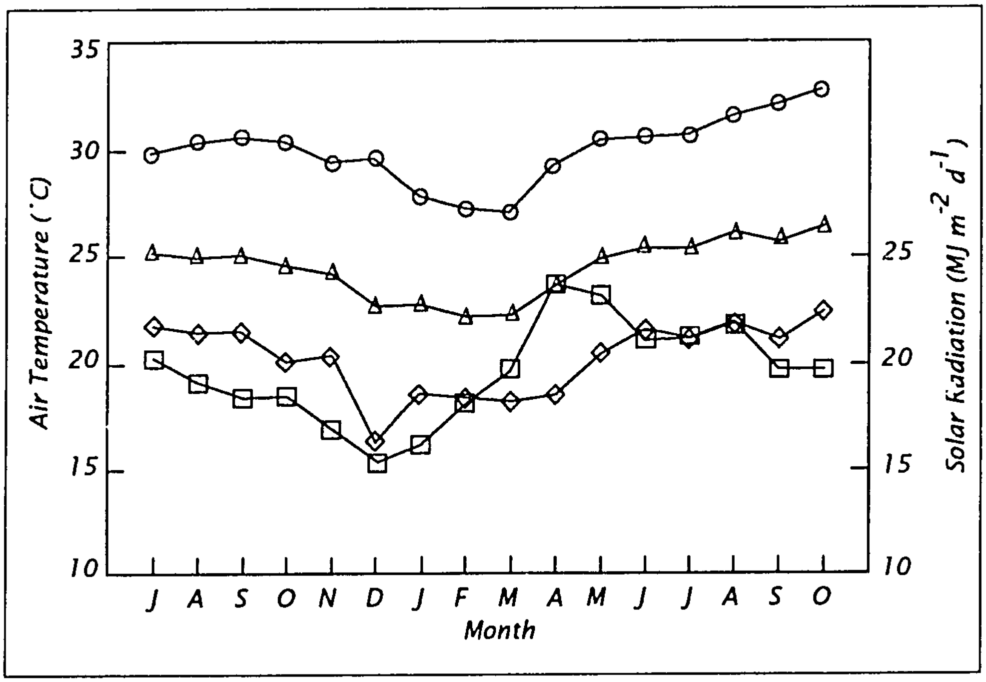

Figure 2. Mean monthly maximum (○), minimum (◇), and mean (△) air temperatures and mean monthly solar radiation (□) during the experimental period.

which the last biomass harvest was made on 377 DAP.

At each harvest, leaves of plants were cut at the midrib-petiole intersection and brought to the laboratory for leaf area determination using a LICOR 3000A area meter. Each of the six plants in the subplots was harvested by digging an area of .42 m^2 around each plant and to a depth of 30.5 cm. Due to the labor required during the root sampling operation, only two of the six plants were used for that purpose. Plants were then pulled from the soil, washed, and separated into petioles, corms, cormels, roots, and suckers. Samples were dried at 70 °C to constant weight for dry matter determination.

Weather data were measured with an LI-1200S automated weather station (LICOR, Lincoln, NE) installed at the experimental site. Class A pan evaporation was recorded from an evaporimeter located nearby.

Best fit curves were determined using the General Linear Model (GLM) procedures of the Statistical Analysis System (SAS) program package (SAS Institute, 1987). The SAS procedure, STEPWISE, indicated that dry matter partitioning was related to plant age but not to mean temperature or solar radiation. Only coefficients significant at $P \leq 0.05$ were retained in the models.

Results and Discussion

Dry Matter Accumulation

A summary of statistical (FLSD) values to determine significant cultivar effects within biomass harvests for dry weights of various plant parts is given in Table 1. Data representative of these dry weights are presented in Figure 3.

Based on total dry matter accumulation in plants, three growth stages (GS1, GS2, GS3) were identified for each cultivar. GS1 was similar in duration for all cultivars and was characterized by low rates of total dry matter production during the first 68 days after planting (Fig. 3). Rates of total dry matter accumulation during this period were 0.41, 0.23, and 0.19 g plant $^{-1}$ day $^{-1}$ for cultivars Blanca, Kelly, and Morada, respectively. By 68 DAP, leaves and petioles accounted for over 70% of the total dry matter produced in all cultivars (Fig. 3).

The first growth stage was followed by a grand growth period (GS2) in which total dry matter increased almost linearly until about 223 DAP as a result of increased rates of dry matter accumulation in all plant components (Fig. 3). Thereafter, the increase in total dry matter was mainly the result of corm and cormel growth (Fig. 3). Although cormel development was initiated at 98 DAP in all cultivars, the rates of cormel dry matter accumulation indicated

Table 1. Summary of protected LSD values for statistical comparison of dry weight of various plant parts at each biomass harvest shown in Figure 3.

Days after planting	*Total*	*Leaves*	*Petioles*	*Roots*	*Corms*	*Cormels*
	Dry weight (g plant $^{-1}$) — FLSD[a]					
35	1.3	0.6	0.3	NS[b]	0.2	—
68	6.5	4.0	2.4	1.2	1.0	—
98	NS	NS	NS	NS	NS	NS
131	NS	6.5	NS	NS	11.7	11.1
161	41.2	10.9	19.2	4.9	11.4	NS
195	73.5	19.7	32.9	NS	27.7	NS
223	NS	17.6	31.8	NS	36.5	NS
251	93.0	13.9	30.7	NS	23.9	50.0
285	88.8	8.3	14.5	NS	24.5	56.5
313	61.1	9.8	28.4	NS	41.2	52.6
342	139.1	13.7	31.7	NS	61.2	68.4
377	210.2	20.4	34.8	NS	129.6	71.9
417	NS	NS	NS	NS	NS	139.8
460	149.2	NS	NS	NS	NS	NS

[a] *Protected LSD, significant at the 0.05 probability level.*
[b] *NS = no significant difference.*

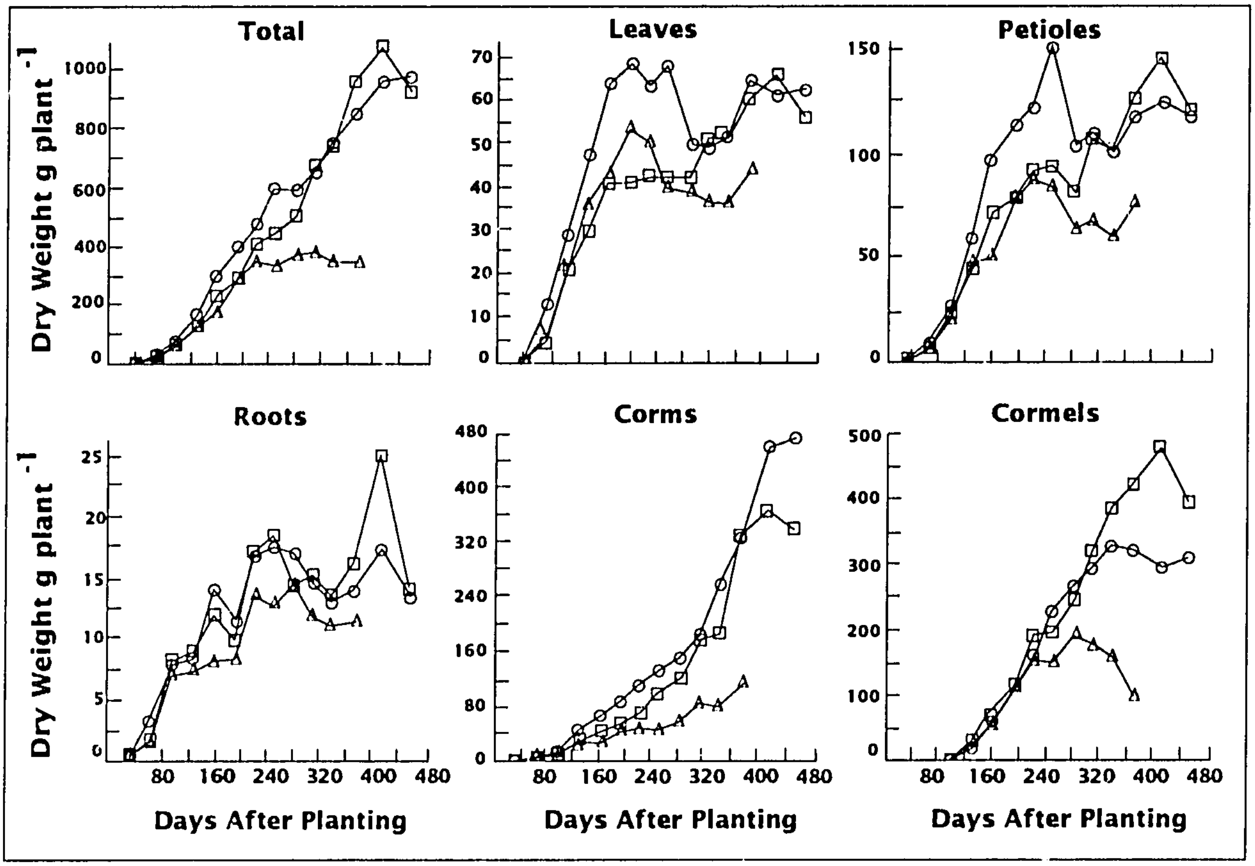

***Figure 3.** Dry weight of plant components of three tanier cultivars as influenced by plant age. Data for cultivar Blanca are represented by (○), (△) for Kelly, and for Morada by (□).*

that the duration of the cormel-bulking period varied between them. These rates remained high until 285, 342, and 417 DAP, respectively, for cultivars Kelly, Blanca, and Morada, and then leveled off or declined (Fig. 3).

It is noteworthy that cormel dry matter accumulation continued after leaf area indices (LAIs) in most cultivars had peaked at about 195 DAP (Figs. 3 and 4). This response was similar to that obtained by Igbokwe (1983). In our study, however, higher LAIs were obtained and the growing season was almost three times longer. Several investigators (Milthorpe, 1967; Spence, 1970) have suggested that cormel bulking during periods of declining LAIs may occur from assimilates of current photosynthesis moving preferentially into these organs or that assimilates are translocated from senescing leaves. It is most probable that both mechanisms are taking place, with older senescing leaves contributing assimilates to the storage organs (corms and cormels) and products of current photosynthesis being translocated to new leaves and petioles as well as storage organs.

Although cormels represented the major sink for assimilates during GS2, particularly after 195 DAP, it is interesting to note that corm dry matter production increased until late in the growing season (Fig. 3). This is of particular importance because in contrast to other aroids (e.g., *Colocasia* spp.), tanier corms are usually not edible and they may compete for assimilates with the cormels. Spence (1970) suggested a structural relationship between leaf production and corm growth, and proposed that a reduction in leaf production might reduce corm growth and benefit cormel yield. However, a reduction in the rate of leaf production may only be advantageous if leaf longevity could be increased in order to maintain optimum leaf area. It is also noteworthy that, in contrast with Spence's results in which corm and cormel yields were similar, cormel dry matter content at peak periods was between 20 and 70% greater than for corms in this study. Nevertheless, Spence's suggestion of decreasing tanier corm size should be further explored since this organ accounts for a large percentage of the total plant dry matter content.

The third growth stage followed immediately after cormel dry matter accumulation commenced to

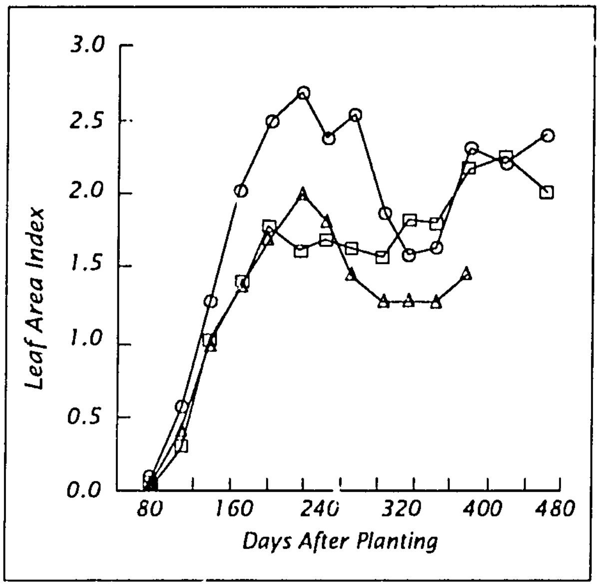

Figure 4. Leaf area index of cultivars Blanca (○), Kelly (△), and Morada (□) as influenced by plant age.

decline (Fig. 3). This period coincides with cormel sprouting and consequent sucker development, which renders the cormels non-marketable. At this point a new biological cycle is initiated at GS1 for each sprouted cormel is considered a corm of a new plant.

Cultivar Kelly initiated sucker development at 251 DAP, whereas Blanca and Morada did so at 342 and 417 DAP, respectively. The number of suckers per plant in Kelly ranged from 0.05 at 251 DAP to 4.0 at 377 DAP. In Blanca this number ranged from 0.12 at 342 DAP to 1.8 at 460 DAP. It should be noted that under normal cultural practices, cultivar Kelly would be harvested at about 285 DAP. Extending the growing season beyond this point reduces commercial yields as a result of sucker development.

The fact that, cormel initiation occurred at 98 DAP in all cultivars, cormel sprouting and consequent sucker development was uneven among them, suggests some type of regulatory control exerted over sucker development but not on cormel formation.

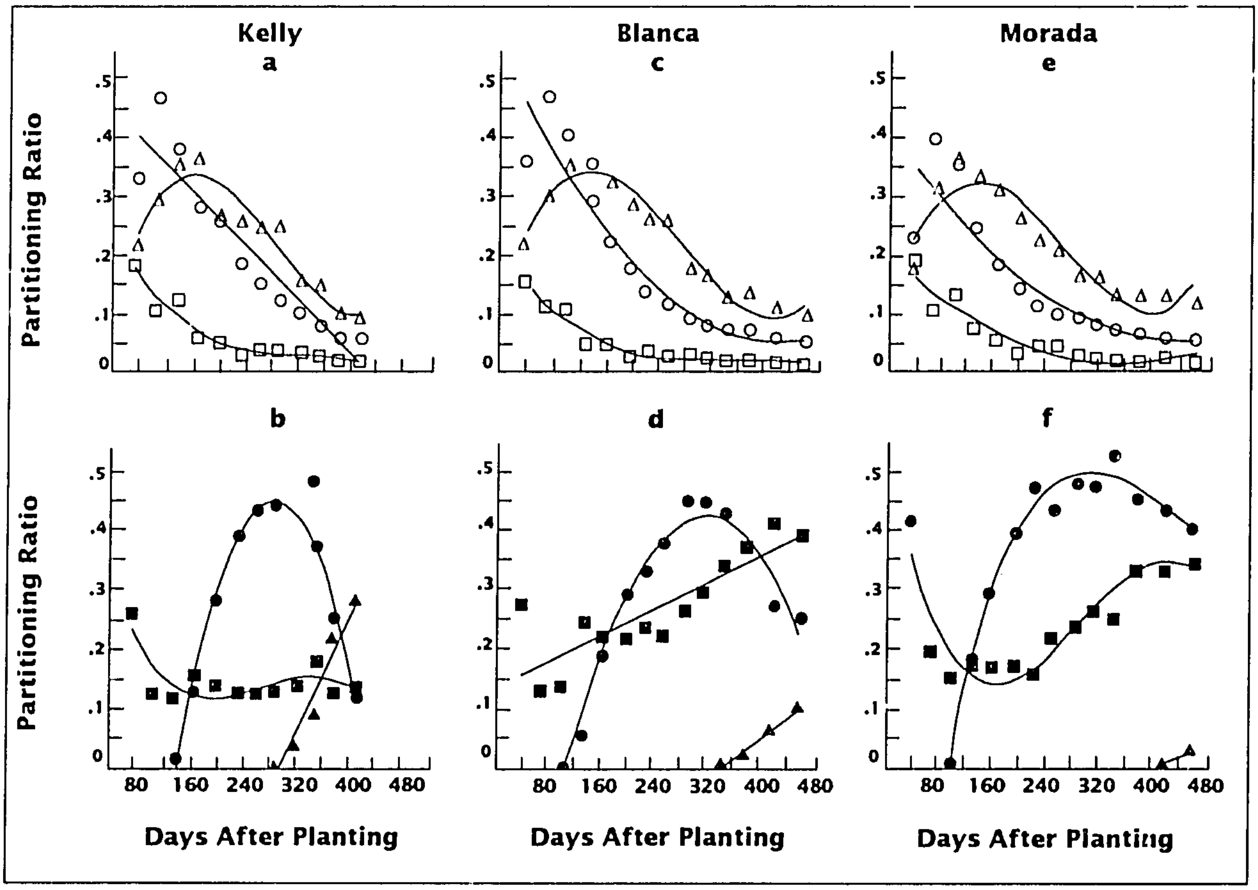

Figure 5. Relationtionship between dry matter partitioning to different plant components and days after planting in three tanier cultivars. Symbols for data: (○) leaves, (△) petioles, (□) roots, (■) corms, (●) cormels, and (△) suckers.

Dry Matter Partitioning

Ratios of dry matter partitioning to leaves, petioles, roots, corms, cormels, and suckers as a fraction of total plant dry matter are presented in Figure 5 (A-F). Regression models of dry matter partitioning under optimum management to the various plant components in each cultivar are shown in Table 2. Early in the growing season, plants allocated a greater percentage of their dry matter to leaves and petioles; these organs accounted for over 55% of the total dry matter in plants. This response is expected during early growth, as plants become autotrophic and less dependent on stored assimilates from the planting material for growth. As plants matured, the partitioning ratio decreased significantly in leaves, petioles, and roots, but increased in corms, cormels, and eventually suckers (Fig. 5 a-f).

Dry matter partitioning to cormels increased almost linearly between 98 and 251 DAP (Figs. 5b,5d,5f). However, the sink demand of cormels during the bulking period varied among cultivars. By 131 DAP, about 17% of the total dry matter in Kelly and Morada had been allocated to cormels, whereas only 3% has been allocated in Blanca. These values peaked to an average of 46% by 251 DAP for Kelly, and 313 DAP for Morada and Blanca. The decline in the partitioning ratio after 251 DAP in Kelly was mainly the result of cormel sprouting and consequent sucker development.

Partitioning of dry matter to corms varied considerably between cultivars. From 35 to 131 DAP, the corm/total dry matter ratio in Kelly plants declined from 23 to 12% but remained stable afterwards at about 14% (Fig. 5b). In Morada plants this ratio declined from 36% at 35 DAP to 14% at 161 DAP, however, in contrast to Kelly, this ratio increased considerably after 161 DAP (Fig. 5f). The partitioning of dry matter to Blanca corms, unlike

Table 2. Regression equations describing the effect of days after planting (DAP) on dry matter partitioning to leaves, petioles, roots, corms, cormels, and suckers of three tanier cultivars.

Plant part	*Equation*	*R^2*
Cv. Blanca		
Leaves	$Y = 0.533 - 228\ e^{-2}(DAP) + 0.269e^{-5}(DAP)^2$	0.92
Petioles	$Y = 0.131 + 0.353e^{-2}(DAP) - 0.178e^{-4}(DAP)^2 + 0.217e^{-7}(DAP)^3$	0.96
Roots	$Y = 0.203 - 0.159e^{-2}(DAP) + 0.470e^{-5}(DAP)^2 - 0.470e^{-8}(DAP)^3$	0.96
Corms	$Y = 0.133 + 0.553e^{-3}(DAP)$	0.70
Cormels	$Y = -0.530 + 0.606e^{-2}(DAP) - 0.964e^{-5}(DAP)^2$	0.96
Suckers	$Y = -0.282 + 0.831e^{-3}(DAP)$	0.98
Cv. Kelly		
Leaves	$Y = 0.446 - 0.116e^{-2}(DAP)$	0.88
Petioles	$Y = 0.112 + 0.412e^{-2}(DAP) - 0.225e^{-4}(DAP)^2 + 0.304e^{-7}(DAP)^3$	0.94
Roots	$Y = 0.251 - 0.232e^{-2}(DAP) + 0.834e^{-5}(DAP)^2 - 0.103e^{-7}(DAP)^3$	0.94
Corms	$Y = 0.321 - 0.305e^{-2}(DAP) + 0.145e^{-4}(DAP)^2 - 0.205e^{-7}(DAP)^3$	0.58
Cormels	$Y = -0.818 + 0.0102(DAP) - 0.205e^{-4}(DAP)^2$	0.97
Suckers	$Y = -0.612 + 0.237(DAP)$	0.96
Cv. Morada		
Leaves	$Y = 0.402 - 0.159e^{-2}(DAP) + 0.182e^{-5}(DAP)^2$	0.79
Petioles	$Y = 0.121 + 0.348e^{-2}(DAP) - 0.181e^{-4}(DAP)^2 + 0.232e^{-7}(DAP)^3$	0.88
Roots	$Y = 0.190 - 0.992e^{-3}(DAP) + 0.139e^{-5}(DAP)^2$	0.90
Corms	$Y = 0.513 - 0.507e^{-2}(DAP) + 0.211e^{-4}(DAP)^2 - 0.237e^{-7}(DAP)^3$	0.84
Cormels	$Y = -0.769 + 0.010(DAP) - 0.2878e^{-4}(DAP)^2 + 0.230e^{-7}(DAP)^3$	0.98
Suckers	$Y = -0.215 + 0.530e^{-3}(DAP)$	1.0

that for Kelly and Morada increased linearly throughout the growing season (Fig. 5d).

Dry matter partitioning to roots was very similar in all cultivars. The root/total dry matter ratio declined during the first months of growth but then levelled off and remained stable at about 2-3% (Figs. 5a,5c,5e).

The amount of dry matter allocated to suckers of Kelly was significantly higher than for other cultivars (Figs. 5b,5d,5f). By 377 DAP, suckers of Kelly accounted for 27% of the total dry matter in plants. Although leaves and petioles were well developed by this date in Kelly suckers, most of their dry matter was associated with the sucker corms (previously cormels).

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Modeling Growth and Development of Taro and Tanier

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Abstract

A dynamic crop growth simulation model, SUBSTOR-aroid, for edible aroids taro (*Colocasia esculenta* (L.) Schott) and tanier (*Xanthosoma* spp.) is presented. The model simulates growth and development of aroids as affected by environmental factors and cultural practices under nonlimiting nutrient and ideal pest and disease control conditions. The key environmental factors affecting growth and development in the model are temperature, solar radiation, and rainfall. The model also simulates the effect of irrigation, planting date, planting density, row spacing, and the method of planting on plant growth and yield. SUBSTOR-aroid describes the dynamics of leaf and sucker production and the growth of roots, leaves, petioles, corm, and cormels. The model results are compared with data from a 1989-1990 taro experiment from Hawaii, and 1989-1990 tanier data from Puerto Rico. The need for the model's improvement and future research on aroids is discussed.

Introduction

Edible aroids taro (*Colocasia esculenta* (L.) Schott) and tanier (*Xanthosoma* spp.) are an important staple in many Pacific islands, as well as an important food source in Africa, the Caribbean, Southeast Asia, and Asia. Production of taro and tanier amounts to more than six million tonnes annually (FAO, 1990). Aroids are grown as a commercial crop only in Hawaii, Nigeria, Indonesia, the Philippines, Egypt, and a host of islands in the Pacific and Caribbean. In spite of the fundamental role these crops play in the diets of people from these areas, policy makers and researchers have only recently become interested in them. Today the considerable potential of aroids as an abundant energy source that could play a vital role in the fight against hunger, is commanding attention. This current interest is highlighted by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Project at the University of Hawaii and the International Fertilizer Development Center (IFDC), who in collaboration with institutions from the Pacific and the Caribbean, are developing a crop model for edible aroids.

For most agricultural systems, the time of peak production does not necessarily coincide with that of peak demand. Agriculture also requires a seasonal peak supply of labor, with severe unemployment at other times. However, a steady supply of aroids can be achieved through well-planned planting and harvesting schedules, and on a given land area, highly efficient utilization of labor and other inputs can thus be realized. The ability to constantly utilize a supply of labor by efficiently planning aroid production systems has social implications which may far exceed the purely economic importance of these crops.

Taro is prized in the Pacific Islands, while tanier is generally preferred in the Caribbean. Tanier is grown only under upland conditions, whereas the more versatile taro can be cultivated under widely varying hydrological regimes, ranging from flooded fields with continually flowing water to upland cropping with supplemental irrigation. Both crops have a long flexible growing season and no definite maturation time. The length of the growing season is influenced by environmental, management, and socioeconomic factors. Because of this, predicting a definite maturity date is difficult. Thus, aroids provide greater flexibility in harvesting time without causing serious yield decline. When yield reductions do occur they are usually due in taro to corm rot, and in tanier to cormels sprouting. The aroids' edible and marketable organs are corms and large cormels for *Colocasia* and unsprouted cormels in *Xanthosoma*.

Although the potential of aroids as a food and energy source is now being realized, yields for taro and tanier under farm conditions are still very low ranging from 1400 to 6000 kg ha^{-1} (Lyonga and Nzietcheung, 1986). Under research conditions, yields of 50-75 t ha^{-1} for both upland (Silva et al., in this proceedings) and lowland taro and 40 t ha^{-1} for tanier have been recorded. Increasing yield will require a thorough understanding of the physiology and development of the crop, as well as the impact of various abiotic, biotic, and management factors on crop growth and development. A discussion of the status of the Simulation of Underground Bulking Storage Organs (SUBSTOR) model for aroids, version 1.0, follows.

Modeling Philosophy

The models developed under the auspices of the IBSNAT Project are characterized by interdisciplinary team effort and balance between all of the model's parts. The models' predictions are limited to the detail level of the least understood part. Thus, the model cannot be made more accurate by including information from disciplines that are better understood. The SUBSTOR-aroid model v.1.0 treats development and growth processes in aroids with equal importance, although there is a dearth of information pertaining to development. To produce realistic predictions, growth and development must be treated in balance, because these processes are affected by environment and stresses in different ways.

A model's usefulness, particularly in the developing countries, is limited by the availability of data for running and validating it. The SUBSTOR-aroid model uses the minimum data set (MDS) concept as identified by the IBSNAT Project (IBSNAT, 1988). Accurate input information is a prerequisite for reliable simulations.

Spatial variability in plant size (and belowground organs) is more widespread in root and tuber crops than in cereals. The factors that lead to such variability must be understood before developing a more complex and detailed aroid model.

Minimum Data Set Requirement

The data used to develop the SUBSTOR-aroid model were collected from upland taro experiments conducted from 1987 to 1989 in Fiji and Hawaii, and tanier experiments in 1989-1990 in Puerto Rico. The details of one of the taro experiments (Prasad and Singh, in this proceedings) and a tanier experiment (Goenaga and Singh, in this proceedings) are also presented.

The experiments were conducted under well-managed conditions and strictly within the bounds of the assumptions of the model. The SUBSTOR-aroid model assumes that all essential nutrients and micronutrients are nonlimiting, and that there is no pest and disease effect, no damage due to wind and other catastrophic events, and no growth limitation due to soil physical and chemical constraints. The type of data collected from each experiment is presented in Table 1. The minimum data set requirement for the aroid experiments was based on IBSNAT (1988 and 1990).

Model Description

SUBSTOR-aroid is a dynamic crop growth model that simulates the growth and development of taro and tanier on a daily basis from planting to harvest. The model can simulate plant growth for any of the following methods of planting: transplanting, direct planting of petiole-corm cuttings or hulis, and direct planting of mini-setts or buds.

The model is written in FORTRAN 77 and runs on IBM-compatible microcomputers. It has a structure similar to the CERES-rice model (Godwin et al., 1990) and shares the rice model's water and nitrogen balance routines. The SUBSTOR-aroid model is a component of the Decision Support System for Agrotechnology Transfer (DSSAT) v.2.1 package (IBSNAT, 1989). The aroid model user thus has access to the Data Base Management System and Model Retrieval programs for model input and the Weather Estimator and Strategy Evaluation programs for long-term simulations.

The current version of the SUBSTOR-aroid (v.1.0) is designed to simulate growth and development of aroids 1) at potential productivity, or 2) as limited only by the availability of water. The nitrogen version of the model is currently under development. Figure 1 shows a flowchart of the model under ample water and nutrients (potential productivity) conditions (Production Level 1) and with limited water availability (Production Level 2) for growth and development. The water balance model has been described in detail by Ritchie (1985). The water balance model used in SUBSTOR-aroid also has a lowland component with the ability to simulate a flooded field with a bund. A detailed description of the crop development, crop growth, and root growth submodels follows.

Table 1. Crop model input and validation data requirements at three production levels.*

Production Level 1: Potential Productivity		
Input	*Daily Weather*	*solar radiation (MJ m^{-2} d^{-1})*
		maximum and mininium temperature (°C)
	Cultivar	*variety name (varietal characteristics)*
	Management	*beginning date*
		planting/transplanting date
		plant population, row spacing
		seeding depth
		seedling age (transplanted only)
Validation	*Development*	*first new leaf emergence, maturity, and leaftip appearance date; leaf number, sucker number*
	Growth	*LAI, biomass, corm and cormel weight, leaf weight, petiole weight with time*
		final corm (corm + cormel) yield and biomass
Production Level 2: Productivity Under Water Limiting Conditions		
Input	*Daily weather*	*rainfall (mm)*
	Management	*irrigation amounts and schedules*
	Site	*soil albedo, runoff curve number, drainage rate, stage 1 evaporation*
	Soil (layer)	*depth of each layer*
		lower limit of plant-extractable water and drained upper limit
		saturated soil water content, bulk density, initial soil water content
		rooting preference factor
Validation	*Water Balance*	*soil water content with time*
Production Level 3: Productivity Under Water and Nitrogen Limiting Conditions		
Input	*Management*	*residue type, amount, and depth of incorporation*
		N fertilizer schedules, source, amount, depth and method of incoporation
	Soil	*initial soil NO_3^- and NH_4^+ content*
		initial soil pH and organic C (%)
Validation	*Nitrogen Uptake*	*corm, cormel and shoot N uptake with time*
		final N uptake for corm, cormel and shoot

* *These data requirements are additive, i.e., to run the model at Production Level 2, inputs for both levels 1 and 2 are required. Similarly, to run the model at Level 3, inputs for levels 1, 2 and 3 are required and validation at any of the levels can be performed.*

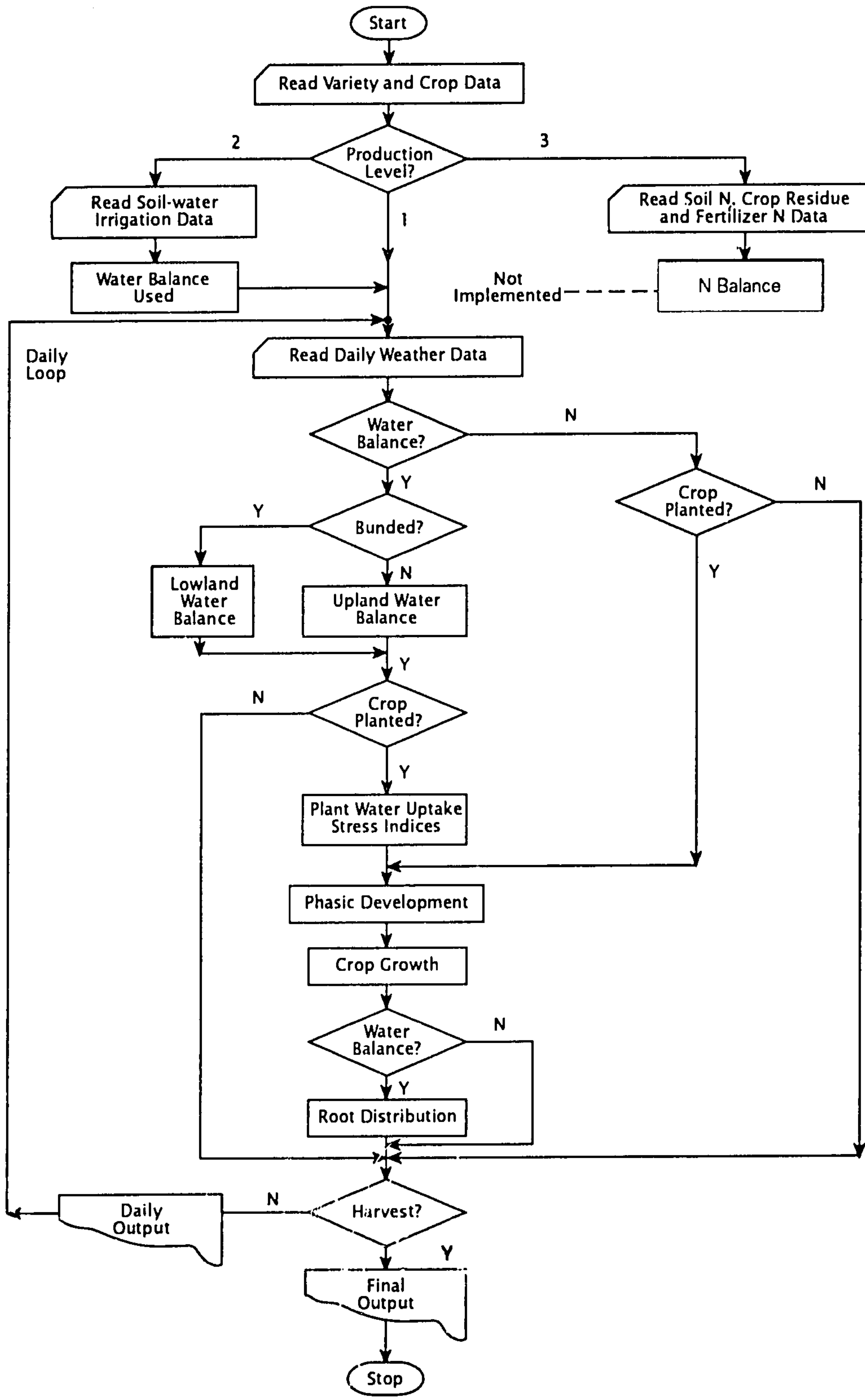


Figure 1. Simplified flow diagram of SUBSTOR - aroid v.1.0.

Crop Development

Crop development has two distinct features: phasic development, and morphological development (organogenesis).

Phasic Development

Phasic development in the SUBSTOR-aroid model is concerned with the duration of growth stages. The growth stages are organized around times in the plant life cycle when changes occur in partitioning of assimilates among different plant organs. The growth stages in aroids are not as well-defined or as clearly distinct as those in cereals and grain legumes.

Five main growth stages have been identified in taro and tanier: 1) root formation, 2) first leaf emergence, 3) the establishment stage, 4) the rapid dry matter accumulation stage (more pronounced in the tops), and 5) the predominant corm and cormel growth to maturity stage. Phasic development is highly sensitive to environment and genotype. In SUBSTOR-aroid, temperature is the primary variable influencing development when aroids are grown as a sole crop under optimum soil fertility and adequate water supply. Development rates are assumed to be directly proportional to temperature when the daily minimum temperature (TEMPMN) is greater than the base temperature (TBASE) of 10 °C, and the daily maximum temperature (TEMPMX) is less than 33 °C. Under such conditions, the daily temperature accumulation or thermal time for a day is:

$$\text{THERMAL TIME} = (\text{TEMPMX} + \text{TEMPMN})/2 - \text{TBASE} \quad (1)$$

The above equation provides reasonable accuracy for modeling growth stages and leaf development. Four of the genetic inputs, expressed in terms of accumulated thermal time (°C), influence phasic development in aroids (Table 2). Maturity is not only influenced by genotype (P5) and temperature, but also by assimilate availability. All other growth durations are temperature driven.

Morphological Development

Morphological development represents the beginning and ending of plant organ development within the whole plant life cycle. The SUBSTOR-aroid model simulates the number of leaves, suckers, and cormels produced. The model also simulates growth of roots, leaves, petioles, corms, and cormels. The principal environmental factor affecting morphogenesis is temperature.

The model simulates formation of roots followed by leaves, petioles, and corms. Leaves and corms develop synchronously in aroids, and organ development is closely tied to leaf appearance. In taro, sucker formation begins in the rapid vegetative growth stage and only after the appearance of the sixth leaf. The establishment of leaf area is important because it is the site of biomass production through the conver-

Table 2. Genetic and species specific coefficients (°C) for phasic development in aroids.

Growth Stage	*Genetic Input*	*Taro Cultivars*		*Tanier Cultivars*	
		Lehua Maoli	*Bun Long*	*Kelly*	*Blanca*
Root formation	*P8**	35	35	250	250
First leaf emergence	*P9**	50	50	500	500
Establishment stage	*P1*	700	500	1500	1540
Rapid vegetative growth stage	*P3*	800	700	1200	1500
	P4	1000	700	400	900
Rapid corm and cormel growth to maturity stage	*P5*	1050	1500	600	1850

** Species-specific coefficient for crop establishment with "hulis" in taro and mini-setts in tanier.*

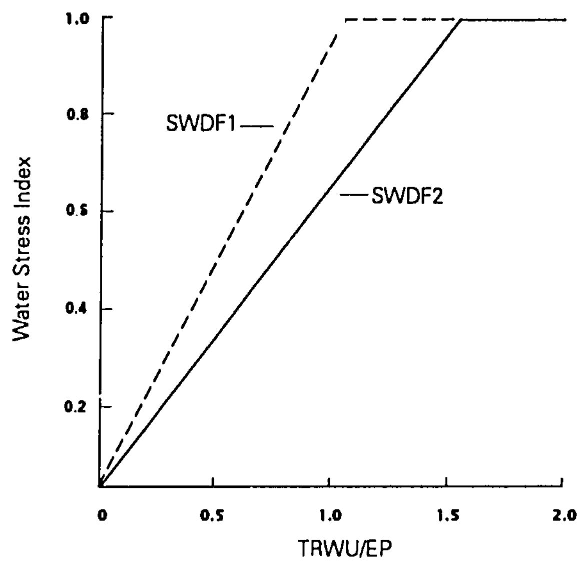


Figure 2. Water stress indices for reducing biomass accumulation (SWDF1) and leaf expansion (SWDF2).

sion of CO_2 and light energy to biomass. It is therefore imperative that the model predict leaf appearance reliably.

The leaf appearance rate in the SUBSTOR-aroid model is thermal time driven. It is also dependent on genotype. The phyllochron interval or the thermal time required for a single leaftip to appear is 150 °C for *Colocasia.* This was found to be the case with at least four taro cultivars: Lehua Maoli, Bun Long, Samoa Hybrid, and Tausala-ni-Samoa (Niue). In *Xanthosoma,* however, phyllochron interval is cultivar-specific ranging from 111 to 180 °C. The SUBSTOR-aroid model simulates a faster rate of leaf appearance when the plants are young. The phyllochron interval approach works well except under extreme water and nutrient stress. Light quality as is present under shading experiments or intercropped conditions may also influence leaf appearance rate. However, additional research is needed before the effect of stress and light level and quality on leaf appearance rate can be implemented in the model.

Crop Growth

The purpose of the growth submodel in SUBSTOR-aroid is fourfold: mass accumulation, expansion growth, assimilate partitioning, and senescence. The development of the growth routine has been a major challenge because the partitioning of assimilates is a dynamic process, requiring several feedback mechanisms.

Mass Accumulation

Potential biomass accumulation (PCARB in g plant $^{-1}$) is a linear function of intercepted photosynthetic active radiation (PAR). The constant for conversion is 2.15 g biomass per MJ of intercepted PAR. The value of PAR above the canopy is equal to 50% of the incoming solar radiation in MJ $m^{-2} d^{-1}$. The percentage of incoming PAR intercepted by the canopy is an exponential function of leaf area index (LAI) with extinction coefficient (KLITE) of 0.603. The KLITE value is affected by row spacing.

PCARB = 2.15 * PAR/PLANTS * [1-EXP(KLITE * LAI)] (2)

The actual rate of biomass production is usually less than the potential rate due to effects of nonoptimal temperature, water stress, or nutrient stress (not implemented in SUBSTOR-aroid v.1.0). The optimum daytime temperature for biomass accumulation is 26 °C. Water deficit stress (SWDF1) reduces dry matter production rates below the potential whenever crop extraction of soil water (TRWU) falls below the potential transpiration (EP) rate calculated for the crop (Fig. 2).

Expansion Growth

Plant leaf area has a crucial role in determining light interception and biomass accumulation. In the model, leaf expansion growth is reduced more than the rate of photosynthesis by environmental stress. This reduction in expansion growth without a concomitant decrease in photosynthesis could increase the specific leaf weight or increase the proportion of assimilate partitioned to the roots or corms. SUBSTOR-aroid simulates these plant responses by using separate water deficit functions for reducing leaf expansion growth (SWDF2) and mass accumulation (SWDF1) (Fig. 2). The rate of leaf expansion already decreases when the maximum possible root water absorption on a day (TRWU) is less than 1.5 times the potential transpiration (EP) while biomass accumulation is unaffected.

The total leaf area for any given day is a function of leaf expansion and the number of leaves growing. Leaf number as previously discussed is dependent on phyllochron interval, temperature, and also sucker formation.

Assimilate Partitioning

The partitioning of produced biomass between the roots, leaves, petiole, corm, suckers, and cormels is one of the major functions of the growth routine. In SUBSTOR-aroid, once the first leaf has appeared,

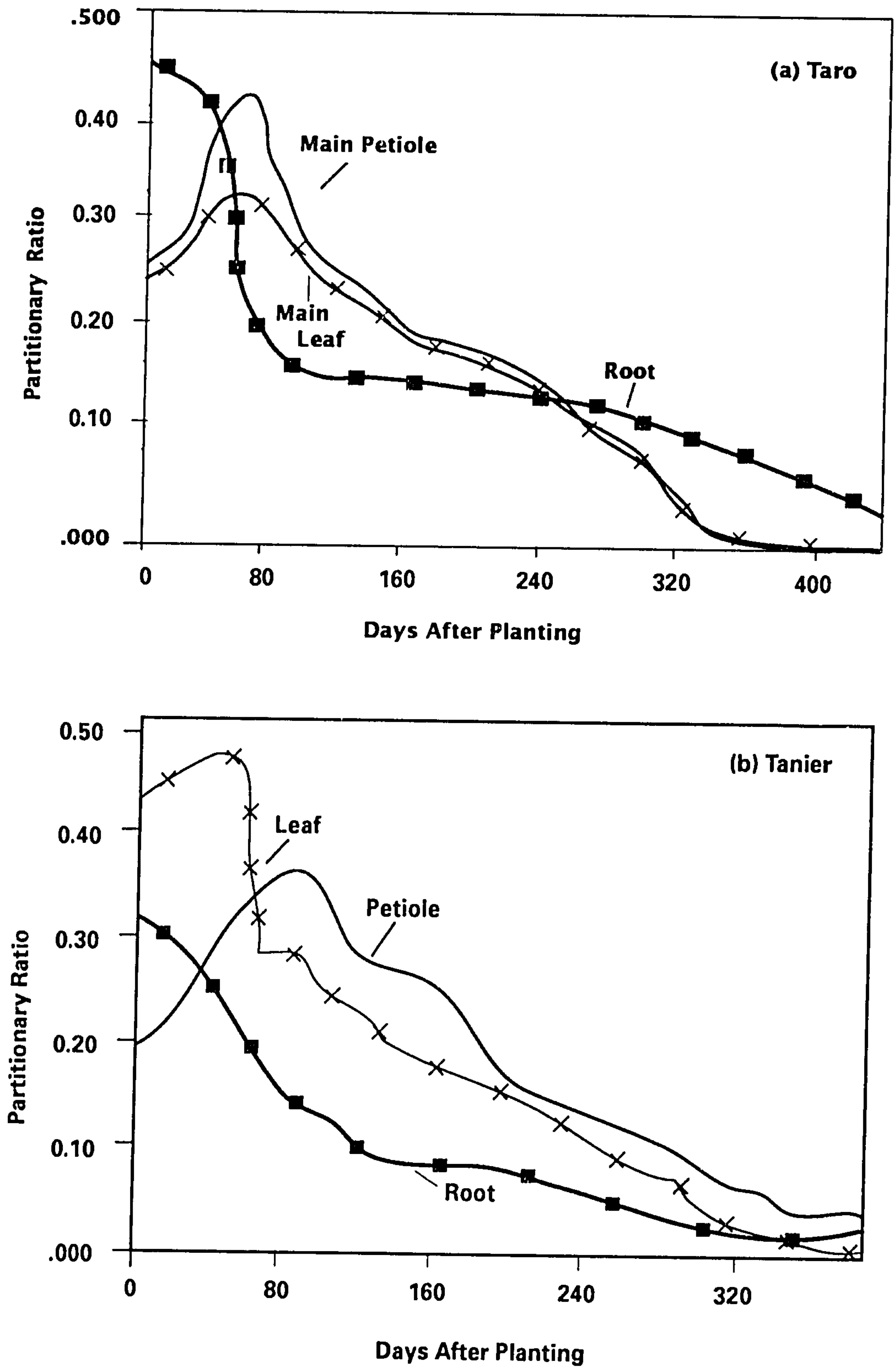


Figure 3. ***Predicted dry matter partitioning to main plant leaf, petiole, and root in (a) taro and (b) tanier under Hawaii and Puerto Rico conditions, respectively.***

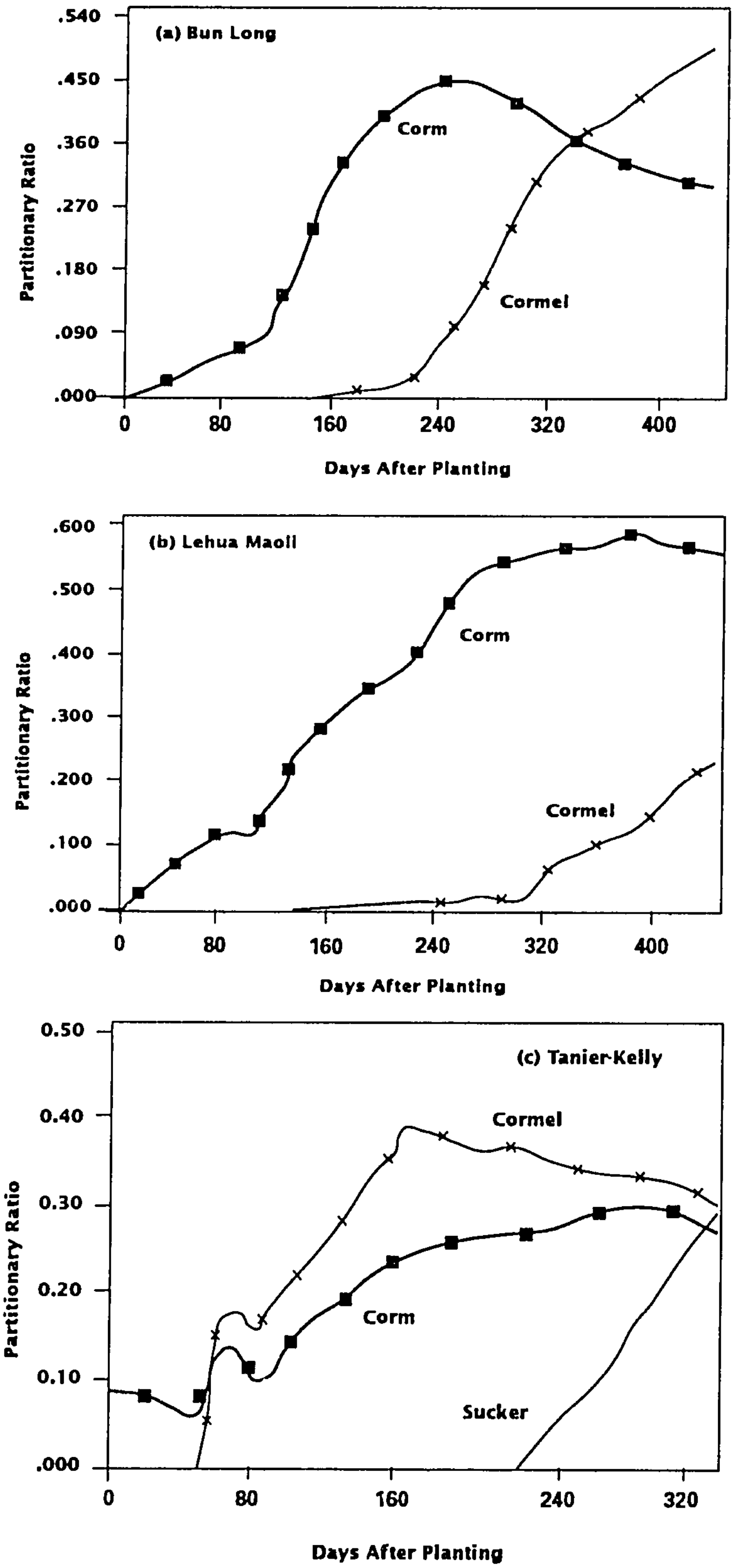


Figure 4. Predicted partitioning of assimilate to storage organs for taro cultivars (a) Bun Long and (b) Lehua Maoli in Hawaii, and (c) tanier cultivar, Kelly in Puerto Rico

assimilate is partitioned to roots, leaves, petioles, and corm. Assimilate partitioning is dynamic in nature with 90-100% of assimilates in the early stages of main plant growth going to roots, leaves, and petioles. In sharp contrast, this value drops to less than 10% late in the season (Fig. 3).

Partitioning of assimilates in SUBSTOR-aroid is not only dependent on growth stage but also influenced by genotype, as illustrated in Figure 4 for two taro cultivars. In the high tillering taro cultivar Bun Long, a greater proportion of the assimilates is channeled to the cormels. This trait is more desirable in tanier, where cormels form the marketable yield (Fig. 4). As realistically shown by the simulated result (Fig. 4c), sucker formation in tanier occurs quite late in the plant life cycle. Generally, the tanier crop is harvested once cormels begin to sprout and form suckers. SUBSTOR-aroid simulates sucker growth and development as a function of leaf appearance rate, assimilate availability, unfavorable temperatures, and water stress.

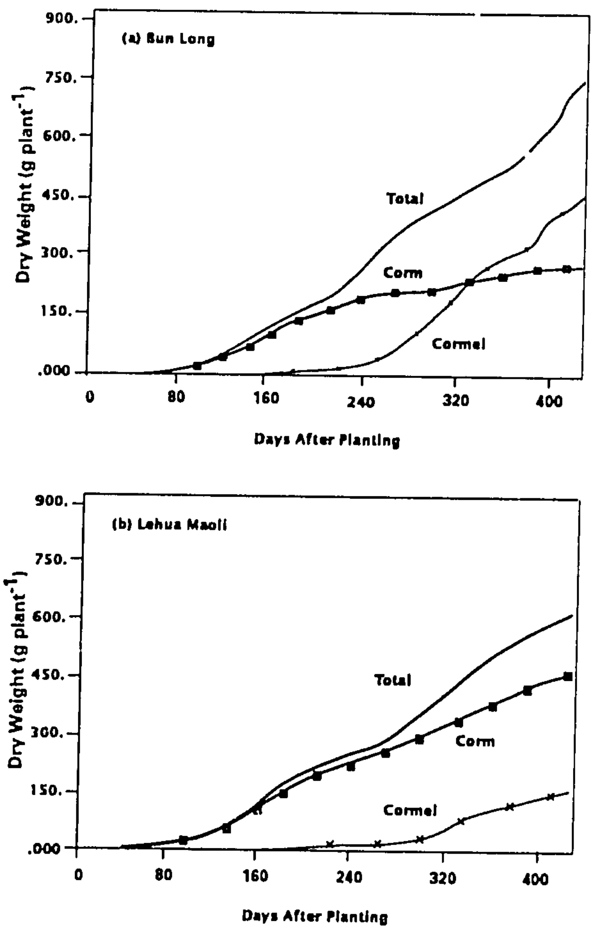


Figure 5. Simulated corm, cormel, and total storage organ (corm + cormel) growth.

Senescence

Senescence of leaves and petioles is dependent on growth stage, shading, cold temperatures (< 6°C) and water stress. As expected, the model predicts leaf and petiole senescence in the growth stage leading to maturity. A reliable prediction of senescence, particularly late in the season, is important because the declining LAI has significant impact on biomass production and corm yield.

Root Growth and Distribution

The proportion of assimilates partitioned to roots affects root density and the ability of the root system to supply the shoot with water and nutrients. The fraction partitioned to roots depends primarily on the growth stage of the plant and usually declines as the plant matures (Fig. 3). When water is limiting, the proportion of assimilate partitioned to roots increases.

SUBSTOR-aroid simulates distribution of roots in each layer as a function of rooting preference factor. The preference factor of a layer is reduced when the soil water content is below a threshold value. When a particular soil layer becomes dry, the model simulates a decrease in root growth in that layer. However, compensatory root growth occurs elsewhere in the profile where the water status is more favorable.

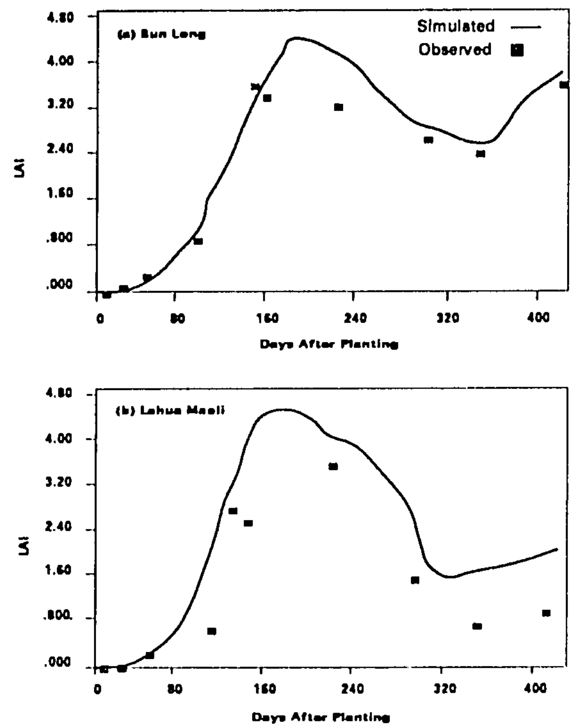
Simulated Results

The pattern of assimilate partitioning predicted by the model for the 1989-1990 taro experiment from Haleakala, Hawaii and 1989-1990 tanier experiment from Puerto Rico is shown in Figures 3 and 4. The predictions are similar to the patterns observed in the field.

The model was also able to depict the differences between the taro cultivars Bun Long and Lehua Maoli in terms of LAI and corm and cormel production. For Bun Long, the model predicted earlier cormel formation and total cormel production exceeding mother corm production, whereas for Lehua Maoli, the mother corm was the main yield component (Fig. 5). These simulated results are in accord with field observations.

Model Evaluation

It must be noted that the SUBSTOR-aroid model has not yet been tested against independent field data. Independent data sets from experiments that have not been used for developing the model are being compiled to validate the model. The results presented here are thus preliminary, and more rigorous testing of the model is warranted.



4.80

Figure 6. Comparison of simulated and observed LAI response for (a) Bun Long and (b) Lehua Maoli taro grown at Haleakala, Hawaii.

In Figures 6 and 7 the model's performance as compared with the 1989-1990 taro experiment conducted at the Haleakala site, is presented. Taro was planted on 19 April under ample nutrient and irrigated conditions.

The model simulated the changes in LAI during the growing cycle reliably for cultivars Bun Long and Lehua Maoli (Fig. 6). It simulated the increase in LAI late in the season due to rapid sucker growth. This effect was more pronounced in the high tillering cultivar Bun Long. SUBSTOR-aroid predicted similar trends, though not as accurately, for leaf weight and aboveground biomass. The total corm (corm + cormel) yield in general was overpredicted by the model (Fig. 7).

The above results indicate the need for further calibration and testing of the model. The field experiments also need to adhere to model requirements. For example, in the above simulations, the assumptions were 1) ample nutrients and micronutrients for nonlimiting growth, 2) absence of pests and diseases, and 3) adequate irrigation. In the field experiment, the latter assumption was not always met.

Sensitivity Analysis

The sensitivity of SUBSTOR-aroid to water stress was evaluated by conducting a "model" experiment under rainfed conditions using the field data from the 1989-1990 Haleakala experiment for the remaining model input. The results clearly show a sharp decline in LAI and, as expected, a reduction in total corm yield (Fig. 8).

Next, the model's sensitivity to environment was evaluated using the above data under original field conditions (irrigated April planting, etc.) but with daily weather data from Mayagüez, Puerto Rico. Under warmer Puerto Rican climatic conditions, the crop duration was shortened from 400 to 250 days and there was a corresponding decline in total corm yield from 65,000 to 29,000 kg ha^{-1}.

From sensitivity tests it is evident that the model's performance would be highly dependent on the quality of the weather, soil, and crop input data.

Knowledge Gaps

Only a few MDS experiments have been conducted with aroids. Many vital data for understanding crop growth and development have not been accurately determined and reported in the literature. All of this is not surprising, as taro and tanier are grown predominantly in the developing world and

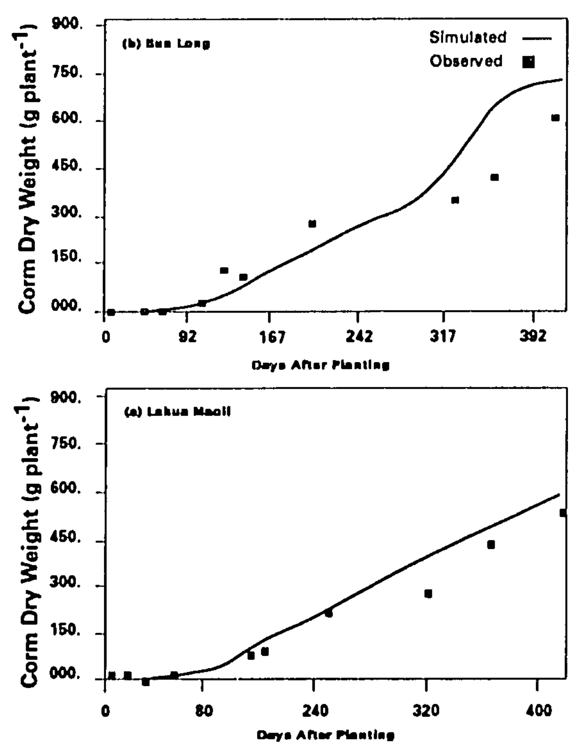


Figure 7. Comparison of simulated and observed total corm growth.

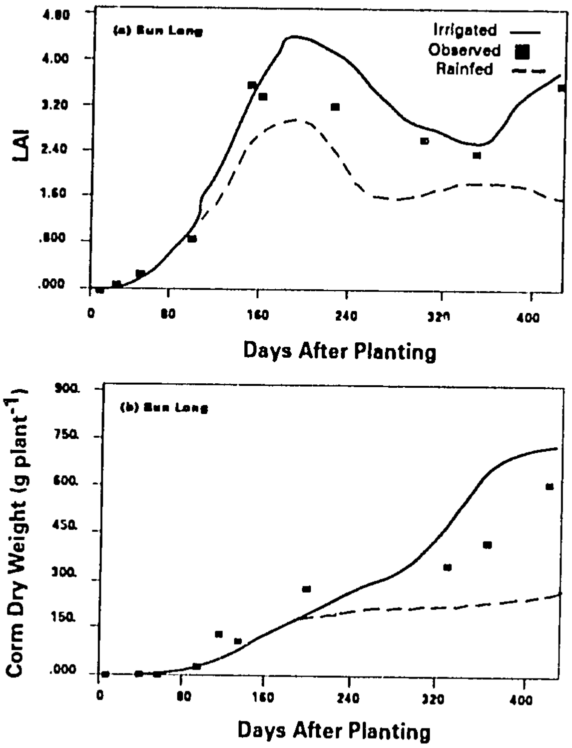


Figure 8. Simulated response of LAI and total corm growth to irrigation and rainfed treatements. Observed data is for irrigated treatments.

in general not as a high value commercial crop. Some data are available on taro and tanier with respect to plant competition for resources such as light, water, and nutrients. However, in none of these studies has a complete data set been collected to help comprehend physiological processes, the interactions within the soil-plant-atmosphere continuum, and the influence of cultural practices on plant growth. Raising the status of aroids from underexploited or famine crop to that of a major energy and food supply will require coordinated research among scientists of the developing world. Future experiments must be designed to collect the minimum data set (IBSNAT, 1988; Appendices A and B of this proceedings) enhance basic research, improve genetic resources, and facilitate model development and improvement.

A data base on varietal traits, cultural practices, and socioeconomic aspects is nonexistent. Yet farmers in developing countries have identified appropriate cultivars for upland versus lowland conditions in terms of starch quality and have developed unique cultural practices. The need for a scientific knowledge base for many of the underground storage organ crops (cassava, yams, sweet potato, taro, and tanier) is critical.

Further development, improvement, and validation of SUBSTOR-aroid are thus dependent on establishing a network of coordinated experimental trials and creating and improving the information base for aroids. Work is in progress to incorporate a nitrogen routine, and it is hoped that the IBSNAT Project in collaboration with international, regional, and national agricultural centers will take a lead role in enhancing research and development for aroids.

Conclusions

Although this is a first attempt to develop a model for a tropical root crop with a predominantly subsistence base, edible aroids, particularly taro and tanier, have considerable untapped potential as a food and energy source. SUBSTOR-aroid is a useful tool to describe the growth and development of aroids, because the model can realistically capture the differences between taro and tanier, as well as the effects of varieties, weather conditions, and irrigation regimes.

Once validated, the model could be used for identifying appropriate varieties, locations, soil types, and cultural practices for the production of edible aroids. The applications of SUBSTOR-aroid are broadened by its linkage to IBSNAT's DSSAT package. It is also anticipated that the use of the model would promote much-needed research on aroids.

Acknowledgement

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Appendices

Appendix A: Supplemental Aroid MDS Forms

The forms provided in Appendix A are supplementary to or replacement for the respective forms in Technical Report 1 (IBSNAT, 1988). These forms are specifically for aroids.

Appendix B: Aroid Observation Forms

These forms are for non-destructive samplings and observations.

Appendix C: Light Interpretation

Data form Appendices A and B are required, but light interception measurements are strictly optional.

Appendix D: List of Participants and Program

Form H

Supplemental Notes for Aroid Experimental Plots

Importance
These data are necessary for the nitrogen and water balance components of the crop models. The residue data also have an impact on the runoff curve number, the soil water content, soil evaporation, and bare soil albedo.

Plot Size
The size of a single plot will depend on:

a. number of intermediate biomass sampling (at least 9)
b. number of plants sampled (minimum of 6 plants/intermediate harvest)
c. planting density
d. sampling style.

Data Collection
The data collected comprises the minimum data set for soil (fully characterized pedon description, and initial values for soil water content, soil nitrate, and ammonium); weather (daily values for solar radiation, rainfall, and maximum and minimum air temperature), and management data (fertilizer, planting date, variety etc.).

Note 1
In "Amt. of weed/crop residue incorporated during land preparation," report weed/crop residues cut close to the ground and taken away from the experimental plot as 0 (zero).

Note 2
If weed/crop residue is a treatment factor in the experiment, then residue for each treatment should be identified in Forms F-1 and F-2 and reported in Form N.

Note 3
If weed/Crop residue is incorporated, report the amount of weed/crop residue on this form and report it on a dry-weight basis. The recommended procedure for estimating the dry-weight amount of weed/crop residue can be found in Technical Report 2 (p. 8).

Note 4
Identify the type of residue incorporated, visually estimate, and report the percentage(s) of each type on this form under the section "Type of Residue."

Note 5
If residue is burned and incorporated, then determine the amount of the residue before burning.

Note 6
In general, information on "Slope and slope length" are required to alert modelers to the site's susceptibility to soil erosion. If the topography of the site is level and no erosion is expected, then the value entered for "Slope" would be 0 (zero), and the value for slope length would be the width of the experiment.

If large unprotected blocks or plots are used, however, the slope can be determined as an angle or percentage by an Abney level or clinometer.

"Slope length" is the distance from the nearest break in slope above the experiment to the nearest break in slope, or concentration of runoff into an outlet or channel, below the experiment.

Note 7

"Aspect" is the orientation of the slope in respect to magnetic north. Use the designations N, NE, E, SE, S, SW, W, NW. For example, if the site is on an east-facing slope then aspect is west relative to magnetic north, and a "W" should be recorded for "aspect." However, if the slope is 0 (zero), then the aspect is 0 (zero).

Note 8

"Depth of soil drain" is the vertical distance from the soil surface to either a buried tile (pipe) drainage system or the water table.

Note 9

If a particular plot(s) differs with respect to any of the data listed in this form, then that information should be noted in "Specific Comments." Other factors which may limit crop performance in the plots should also be noted in this space. These might include the presence of plow pans, gravel layers, poor drainage, crusting problems, or any number of other problems which may be important in interpreting experimental results.

Form I
Supplemental Notes for Aroid Soil Fertility Measurements

Importance
Accurate measurement of pH and nitrogen components of the soil at the time of planting are necessary to run the nitrogen subroutine of the crop models. Root distribution by soil layer is also affected by chemical constraints.

Note 1
Conduct preplant soil sampling for fertility measurements at least 30 days prior to planting and record the results of the soil analyses on Form I-1. Make two subsamples from each soil layer (except andepts) for field-moist (1/3) and air-dried samples (2/3). The larger subsample (2/3) should be dried immediately at 50-60°C to prevent mineralization and degradation of soil proteins. A single sample for soils classified as andepts is adequate. DO NOT DRY ANDEPTS. Store the field-moist subsamples in air-tight containers and analyze as soon as possible for NH_4^+ and NO_3^- N (see Technical Report 2).

Note 2
Sample the soil in the following increments: 0-5, 5-15, 15-30 cm, etc. Depth of sampling should be 25 cm beyond the rooting depth. Determine pH, NH_4^+, NO_3^-, and PO_4^{3-} (for procedure refer to Technical Report 2). Sample by individual plot, by grouping plots receiving the same treatment, or, if the experimental area is homogeneous, by the entire experimental area, using a single composite sample which represents the entire area. If fertilizer will be incorporated, the maximum sampling depth should correspond to the depth of fertilizer incorporation.

Note 3
When a single composite sample, representing the entire experiment area is used, then a "99" should be recorded for "Plot(s)."

Note 4
If soil fertility measurements are taken at times other than at preplant, then Form I-2 should be used. Sampling should be done in the way described in Notes 2 and 3 above.

Note 5
See Technical Report 2 (p. 40) for recommended procedures and methodologies for obtaining soil fertility measurements.

FORM L
Cultivar

Importance
The data supplied on Form L will assist in assigning cultivar-specific coefficients used in most crop growth models and in interpreting a cultivar's response to various stresses.

Note 1
A cultivar name is defined as the cultivated variety name. If a cultivar has other or equivalent names, then these should be given under "Other Name." For example, if a collaborator is using the taro variety named 'Lehua Maoli' then 'Lehua Maoli' should be entered under "Cultivar Name." If this variety is also known by another name in the collaborator's country, then write this name under "Other Name."

Note 2
If a cultivar name or other name is longer than 10 characters, then give the full name in the "Comments" section. When further explanation about the cultivar is necessary for identification, this information should be noted in the "Comments" section.

Note 3
If cultivars are a treatment factor, then all cultivars used must be named under "Cultivar Name."

Note 4
Enter "Type" indicate cultivar characteristics such as, open-pollinated, hybrid, inbred, maturity group, photoperiod sensitivity, short-season, long-season, determinate, indeterminate, spring wheat, winter wheat, dwarf, semidwarf, tall, bush, climbing, etc. When the "Type" description exceeds 10 characters, use the "Comments" section to note background and special characteristics of the cultivar(s).

Note 5
"Seed Weight" is dried seed weight. Oven dry seed at 70°C until constant weight.

For root crops, seed weight is the average dry weight of at least 10 seed pieces or tubers (selected at random).

Note 6
"Seed Age" refers to the time from harvest to planting and gives an indication of the viability of the seed. For aroids this is the interval that elapses from harvest until planting seed buds, mini-sett or "huli," and includes the dormancy period plus any other period in storage.

Note 7
"Stump Diameter" is MDS-required data for aroids only. To measure, take a random sample of seed material at planting time and measure the diameter of at least 12 "hulis" at the point where the petiole meets the corm. Calculate mean diameter (See Figure A4).

Note 8
Taro descriptor sheet (Figure L1) would provide plant breeders additional information not available in Form L.

FORM L
Cultivar

* Cultivar Name	Other Names	Type	Seed Weight/ # seeds (g)	Seed Age (days)	Stump Diameter (cm)
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COMMENTS:

Taro Variety Characterization

Acc. No.______________ Variety Name______________ Origin______________

Growth Habit: erect/spreading stolons/rhizomes/runners/suckers

Plant Size (maximum): dwarf<50 cm medium 50-100 cm tall>100 cm

Leaves: hastate/peltate/sagittate; clockwise/counterclockwise

Leaf shape: hastate/ovate/sagittate/other ______________

Lami.ıa: droopy/erect/cup shaped. Margin: entire/undulated

Margin color: ______________ Lamina appendages: absent/present

Leaf color: ______________ Leaf surface: non-glossy/glossy (shiny)

Leaf variegaticn: absent/present, color ______________

Pike shape & color ______________ Sap color ______________

Vein pattern: V/I/Y/other Vein color ______________

Petiole color: top ______________ middle ______________ base ______________

Petiole basal ring color: ______________

Petiole stripes: absent/present, color ______________

Leaf sheath: open/closed Leaf sheath color ______________

Inflorescence: flowering/non-flowering No. leaf axis: ______________

Male: enclosed/exposed Spathe shape: hooded/keeled/flat

Spathe color: upper part ______________ lower part ______________

Feduncle color: ______________ Flag leaf color: ______________

Fruit color: unripe ______________ ripe ______________

Corm shape: ______________ Corm flesh color ______________

Fiber color: ______________ Skin color ______________

Culture: upland/lowland/both ______________ Pests and Diseases: ______________

Main Uses: table/poi/chip/luau/vegetable/flour/dessert/other

Miscellaneous: ______________

____

Form L1. Taro descriptor sheet

Form M
Supplemental Note Sheet for Aroid Planting

Importance
Seed depth data affects the size of the corm.

"Hulis" for taro do not show a tendency for dormancy. In contrast, "hulis" and corms from recently harvested *Xanthosoma*, and eddoe (*C. esculenta* (L.) Schott var. globulifera) show dormancy like behavior. The exact nature of this dormancy has not been investigated.

Planting density
A planting density of 1.0 m by 0.6 m or 0.6 m by 0.6 m is recommended. Use of an alternative planting density as an additional treatment is optional.

Biomass Sampling
The experimental plot size should be large enough to accommodate at least nine intermediate samplings and one final harvest is possible. For intermediate samples, six plants per plot will be harvested per sampling date. Preliminary intervals for sampling dates are every six weeks. For the final harvest at least 12 plants per plot will be sampled.

Planting Material
Planting sett "huli" consists of cuttings from the upper tip of the corm (including at least 2 cm of corm) together with the bottom 15 to 25 cm of the petiole. If the "huli"s are of nonuniform size (determined by weight or diameter of the "huli"), then separate according to size into as many groups as the number of replicates. In either case weight the planting setts, and determine weight of planting sett. Also take a subsample (10 "hulis") from each category, and obtain fresh weight and dry weight for petiole, corm, and stump per "huli". If buds are used as planting material determine age and biomass of seedlings at transplanting time.

Note 1
Unless row spacing, plant population, and seed depth are defined as treatment factors in the experiment, the crop models assume uniform row spacing, plant population, and seed depth. If uniformity is not maintained, then simulation results may not compare well with actual experimental results.

Note 2
For "Method of Planting" record a "1" for direct planting of "hulis" in the field, a "2" for direct planting of mini-sett or bud in the field, or a "3" for transplanting a seedling plant with roots, leaf, and petiole.

Note 3
"Row Spacing" is the distance between rows. "Plant Pop." is the plant count per square meter.

Note 4
The seed size (weight or diameter of stalk) has to be as uniform as possible. If differences exist, then steps should be take to block these out. For example, for an experiment with three replications, the non-uniform seed material should be separated into three classes of similar size. Each replicate would then be planted with seeds of similar size.

Note 5
The dry weight of seed material must be known at planting. In addition, it would be useful to have the dry weights of petiole and corm and their nutrient status N and P content at planting (see Form S).

Note 6

"Age of Seedling" is 0 except for transplanting seedlings where the age is time interval between planting in the seedbed or nursery and the field. Please note the difference in Form L Note 6 "Seed Age."

Note 7

On the facing page of Form K (p.32, Technical Report 1, IBSNAT, 1988) is a list of field implements and their codes. However, many field implements listed by one name in this appendix may have a different name in other countries. If your implement is not listed and if you are uncertain as to which field implement to select, then enter a "99" in the "Imp. Code" column and sketch and/or describe the implement in the "Comments Section" in this Appendix.

FORM M
Planting

Method of Planting: __________ Age of Seedling: __________ Imp. Code: __________

Date dd/mm/yy	*Plot(s)	*Cultivar	*Row Spacing (cm)	*Plant Pop. (pl./m²)	*Seed Depth (cm)	*Total Dry wt. (g/m²)	*Corm Dry wt. (g/m²)	*Petiole Dry wt. (g/m²)
--/--/--	-- -- --	-- -- -- --	---.-	---.-	---.-	---.-	---.-	---.-
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COMMENTS:

FORM R-1, & R-2
Introduction

Importance
The data supplied on Forms R-1, and R-2 are used in model testing and validation. Use Form R-1 to record the dates at which the growth stages are attained. Record harvest measurements for the specified V stage on Form R-2. The data supplied on Form R-2 will be used for model validation by comparing these measured responses with simulated ones.

Read these notes before using Forms R-1 and R-2

Note 1
Forms R-1 and R-2 should be completed together. Several of the dates required for Form R-1 are also the required biomass sampling dates for Form R-2.

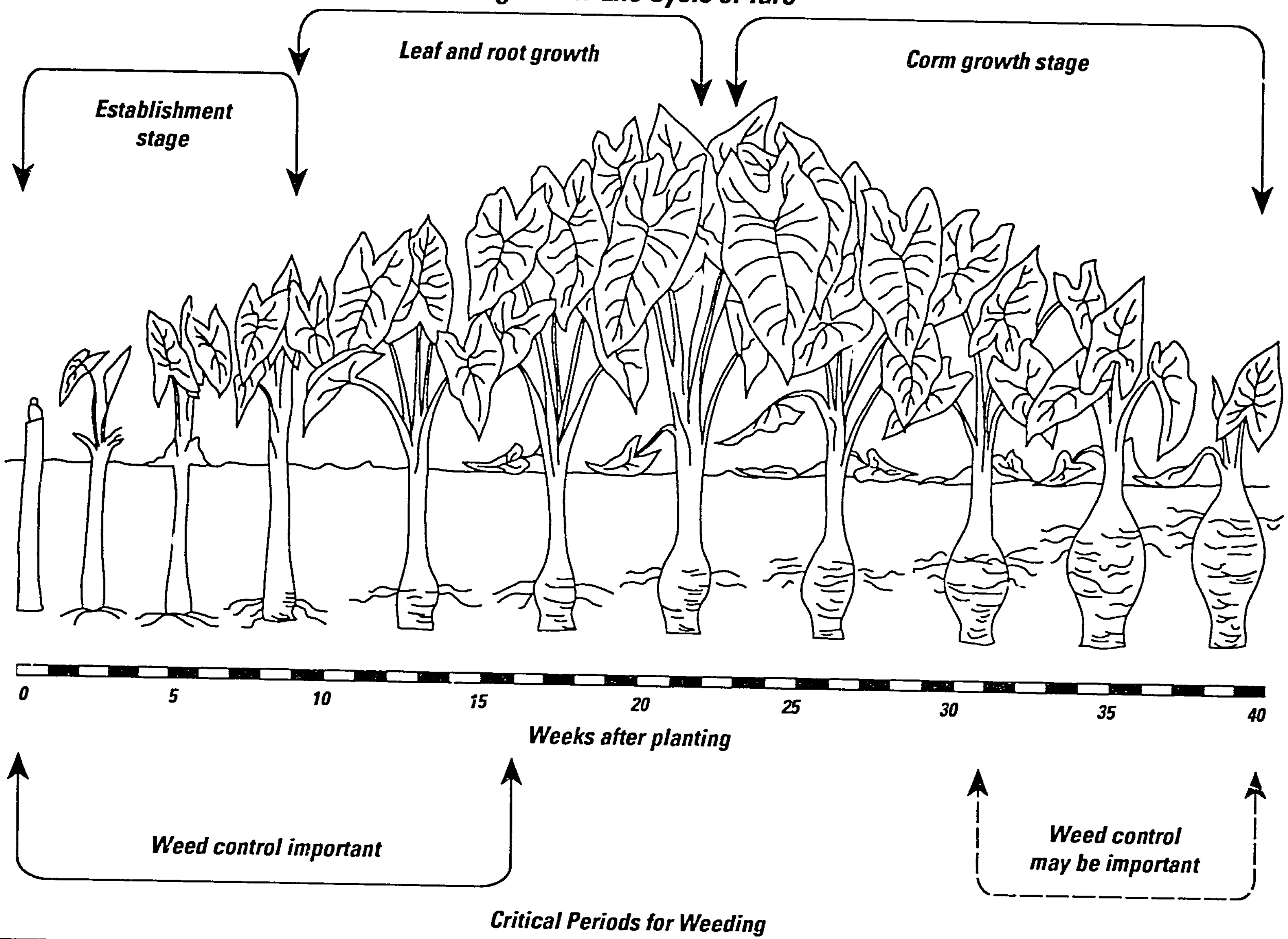
Note 2
The crop V stage for which dates must be recorded are given below, followed by a brief description of each stage.

Aroid (*Colocasia esculenta* and *Xanthosoma*)
Growth Stage Codes

Code	Growth Stage
V1	50% of plants having produced 1 fully opened leaf
V2	50% of plants having produced 2 fully opened leaves since emergence
V3	50% of plants having produced 3 fully opened leaves since emergence
V(N)	50% of plants having produced N fully opened
C	50% of plants have at least one cormel (belowground)
S	50% of plants having suckers aboveground
R1	Plants are flowering.

Note 3
As Shown in Figure A1, the V stages can be used to designate different stages of crop growth in aroids.

Figure A1. Life Cycle of Taro



Form R-2
Supplemental Notes for Aroid

Root Sampling
Determine root weight of two plants (out of six, the middle two plants) for the first five harvests and at the final harvest. Take the middle two plants from each row (Figure A2). Get the roots from the area covered by these two plants i.e., 1/2-distance between rows on either side of the target plants (0) and 1/2-distance within row.

Leaf Area Measurement
At each harvest determine leaf area, leaf fresh weight, dry weight, and number of leaves for six plants per plot. At every alternate harvest also determine AA[1], AB measurement and the area of each individual leaf (Figure A3).

Partitioning
At each harvest, determine the number of suckers and separate suckers and main plants.

For the main plant, at each harvest, separate leaf blade, petiole, stump, corm and roots (Figure A4). Take the fresh weight for individual parts separated and their dry weights. If there is too much sample for drying then take subsamples for leaf blades, petioles, corms, and roots, and determine their fresh and dry weights. For the stump, dry the whole sample (no subsampling), separate petiole and corm after drying, and then determine dry weight.

For the suckers, follow as for main stem except do not separate stump.

TARO Biomass Harvest: Form R-2

Date: ____________ **Site:** ____________ **Growth Stage:** ____________

main stem:

plot no.	trt. no.	Dry Weight (g m⁻²) root	corm	petiole	leaves	inflorescence	leaf area $cm^2\ m^{-2}$	No. of suckers

suckers:

plot no.	trt. no.	Dry Weight (g m⁻²) root	cormel	petiole	leaves	inflorescence	leaf area $cm^2\ m^{-2}$	No. of cormels

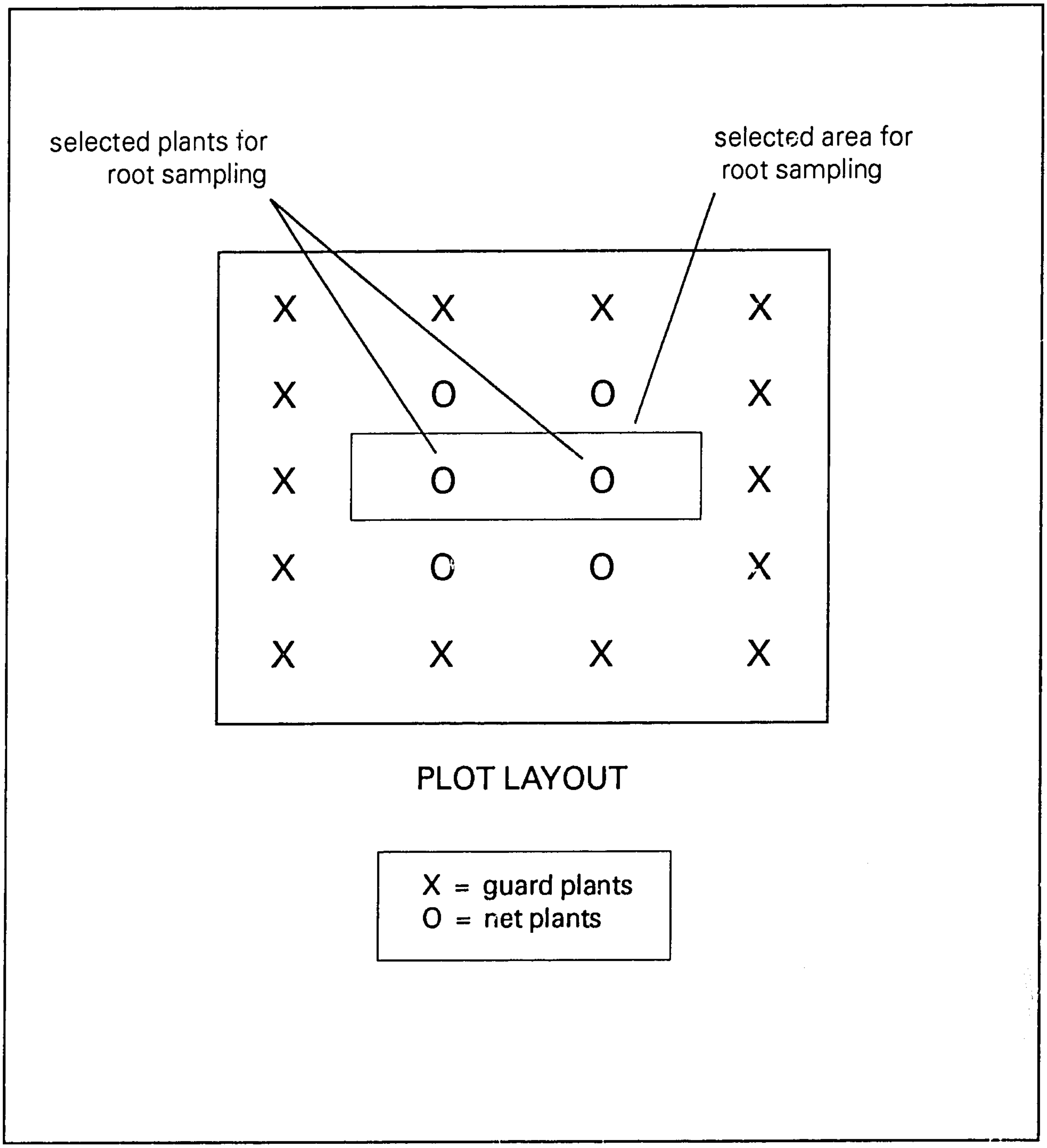


Figure A2. Root sampling area layout.

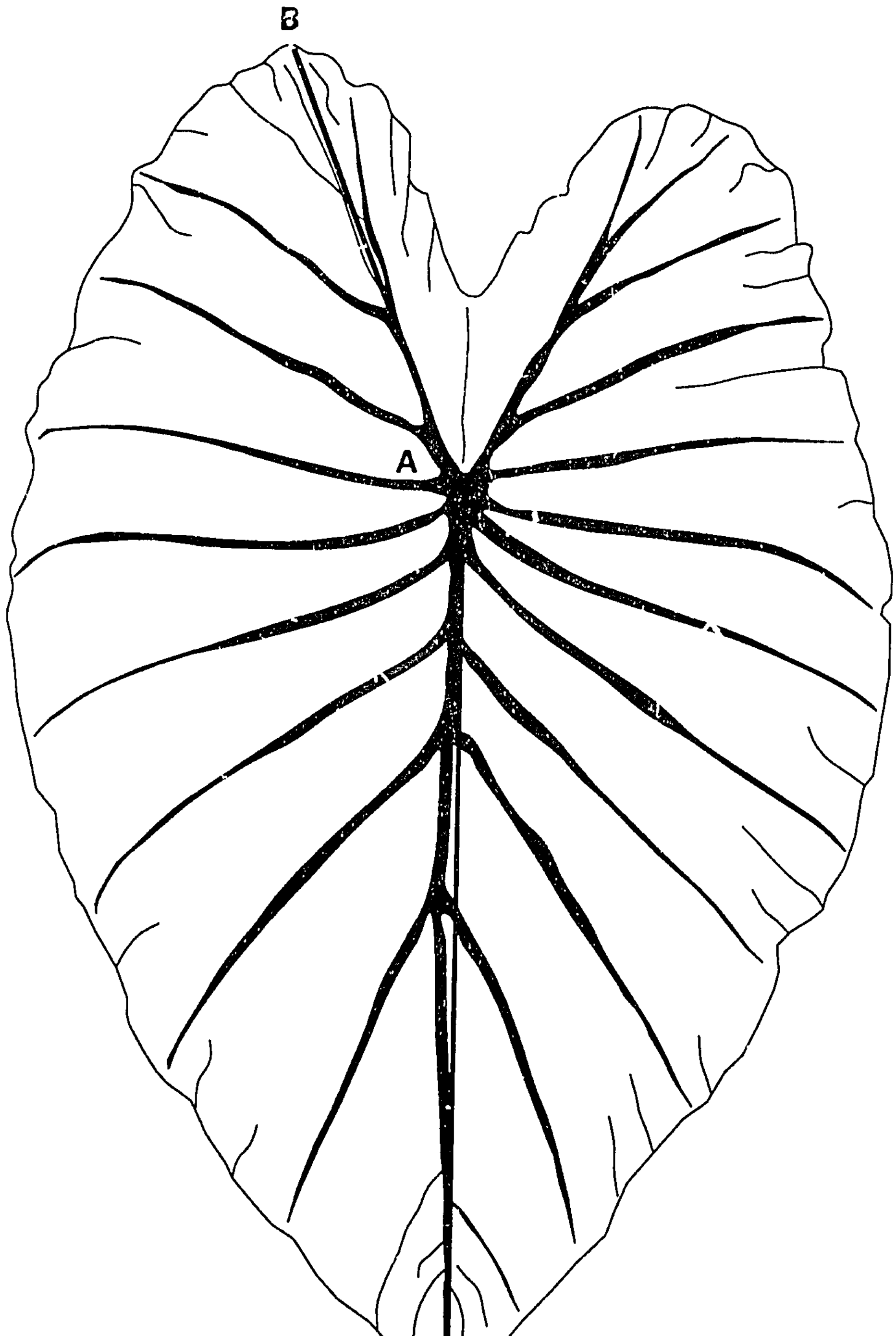


Figure A3. Leaf area estimation.

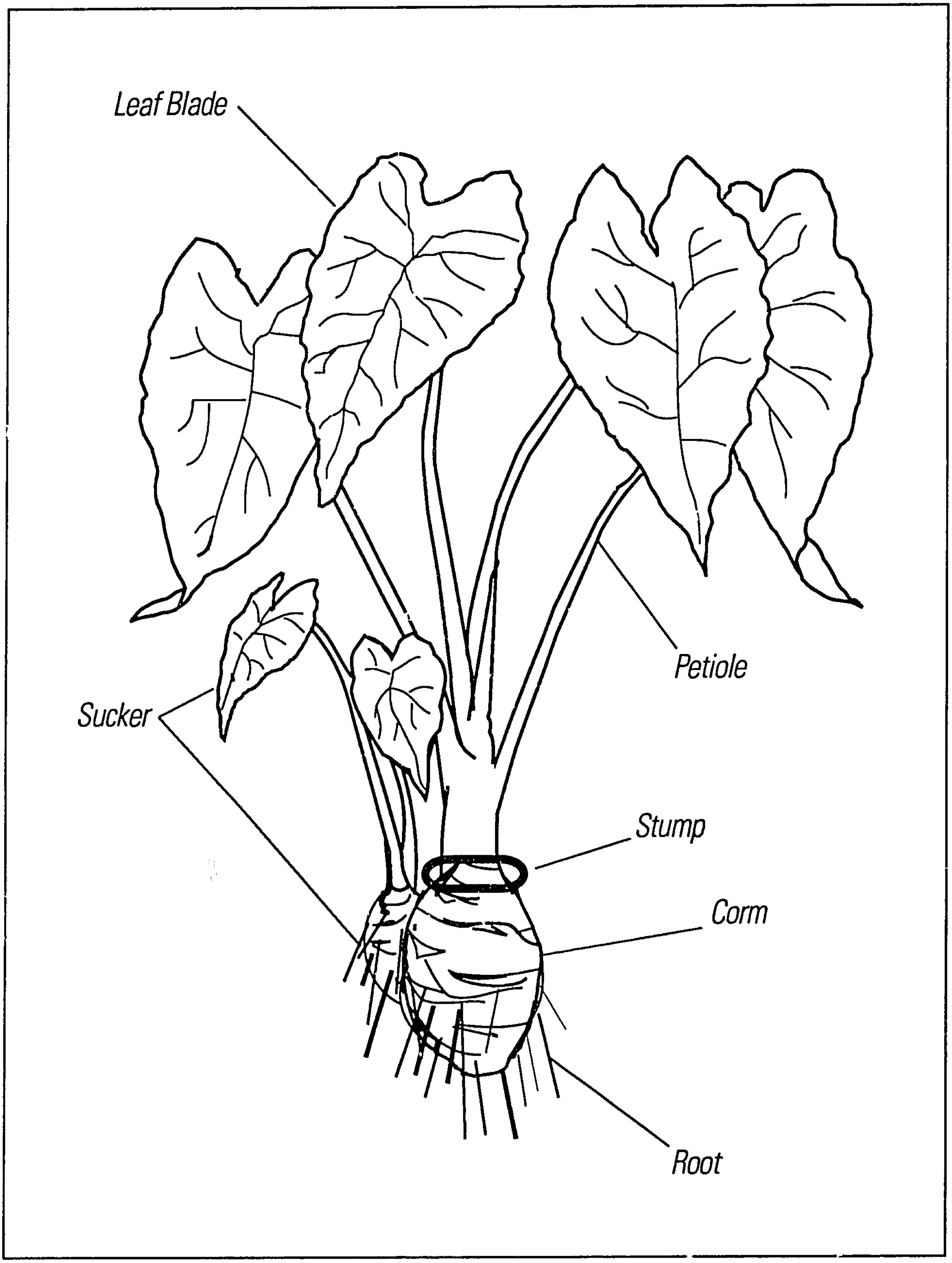


Figure A4. Plant components for partitioning.

FORM R-2 (Raw Data)

Supplemental Notes for Aroids
Growth Analysis, Harvest, and Final Yield Components

Harvest Data

Highly significant and positive correlations have been consistently reported between LAI and corm yields in *Xanthosoma* and *Colocasia* (Enyi, 1977). Thus for each sampling and final harvest the following measurements per plot are essential:

1. Date of sampling
2. Growth Stage (leaf number at harvest)
3. Site
4. Plot number
5. Number of plants harvested
6. Leaf area (cm^2) for main plant also referred to a mother plant
7. Leaf dry weight for main plant
8. Petiole dry weight for main plant
9. Corm dry weight (main plant)
10. Root dry weight (for main plant + suckers)
11. Number of suckers (cormels)
12. Plant height (cm)
13. Leaf area (cm^2 for suckers)
14. Leaf dry weight for suckers
15. Petiole dry weight for suckers
16. Cormel dry weight (suckers)

Use Form R-2(Raw Data) for steps 1-12. Use a separate copy of Form R-2 (Raw Data) for recording data pertinent to suckers (13-16).

Note 1

Form R-2(Raw Data) is a supplemental (optional) form designed to help in completing Form R-2.

Note 2

To obtain plant height measurement stand facing parallel to the row direction. Select a line-of sight in a horizontal plane that passes over 95% of the plants in their free standing position (do not manually extend the top leaf). Use a measuring tape or a meter stick to measure the vertical distance from the soil surface to that line. Record the number in centimeters as the plant height.

TARO Biomass: Field Form R-2 (Raw Data)

Date of harvest: ______________ **Harvest number:** ______________ **Site:** ______________

plot no.	no of plants	STUMP (g)				LEAF AREA	HEIGHT
		Total		Corm	Petiole	($cm^2\ m^{-2}$)	(cm)
		tare	fresh	dry	dry		

plot no.	PETIOLE (g)						CORM (g)					
	TOTAL			SUBSAMPLE			TOTAL			SUBSAMPLE		
	tare	fresh	dry	tare	fresh	dry	tare	fresh	dry	tare	fresh	dry

plot no.	ROOT (g)						LEAVES (g)					
	TOTAL			SUBSAMPLE			TOTAL			SUBSAMPLE		
	tare	fresh	dry	tare	fresh	dry	tare	fresh	dry	tare	fresh	dry

Aroid
Observation Forms

Observation Data

To fully understand development and growth in aroids, Forms 1-6 must be filled in as accurately as possible. The above observations will not require destructive sampling. The leaf angle measurement (Form 5) is a one time measurement conducted when leaf number 5 is fully open. Hence leaf angles for at least five leaves may be determined. In some cases you may get only three measurements (e.g., the first two leaves may have senesced by the time the fifth leaf opened). Additional leaf angle measurement during the season is optional.

Form 4 allows for continuous measurement of leaf area. At least weekly measurement is suggested.

For a crop model to simulate LAI and leaf number, the time it takes for a single leaf to appear must be known. Leaf appearance rate is generally dependent on temperature and variety under optimum conditions.

Forms 1- 6 are for filing *observation* data carried out with non-destructive sampling.

FORM 1

Leaf tip (unopened) appearance data.

FORM 2

Leaf opening date (fully opened).

FORM 3

Numbers of active leaves—those leaves that are fully open but less than 50% yellow.

FORM 4

Leaf length measurement AA' (cm) and AB (cm) (see Fig. A3). The values obtained would be used to determine leaf area by non-destructive method.

FORM 5

Leaf angle measurements for first five leaves when fully open (Fig. B1). Results will give some measure of photosynthesis "efficiency" and generate a "genetic coefficient" for different cultivars.

FORM 6

Number of visible (aboveground) suckers.

To generate data for Forms 1-6 select at least six plants/plot. The forms are designed to handle additional plants/plots if desired.

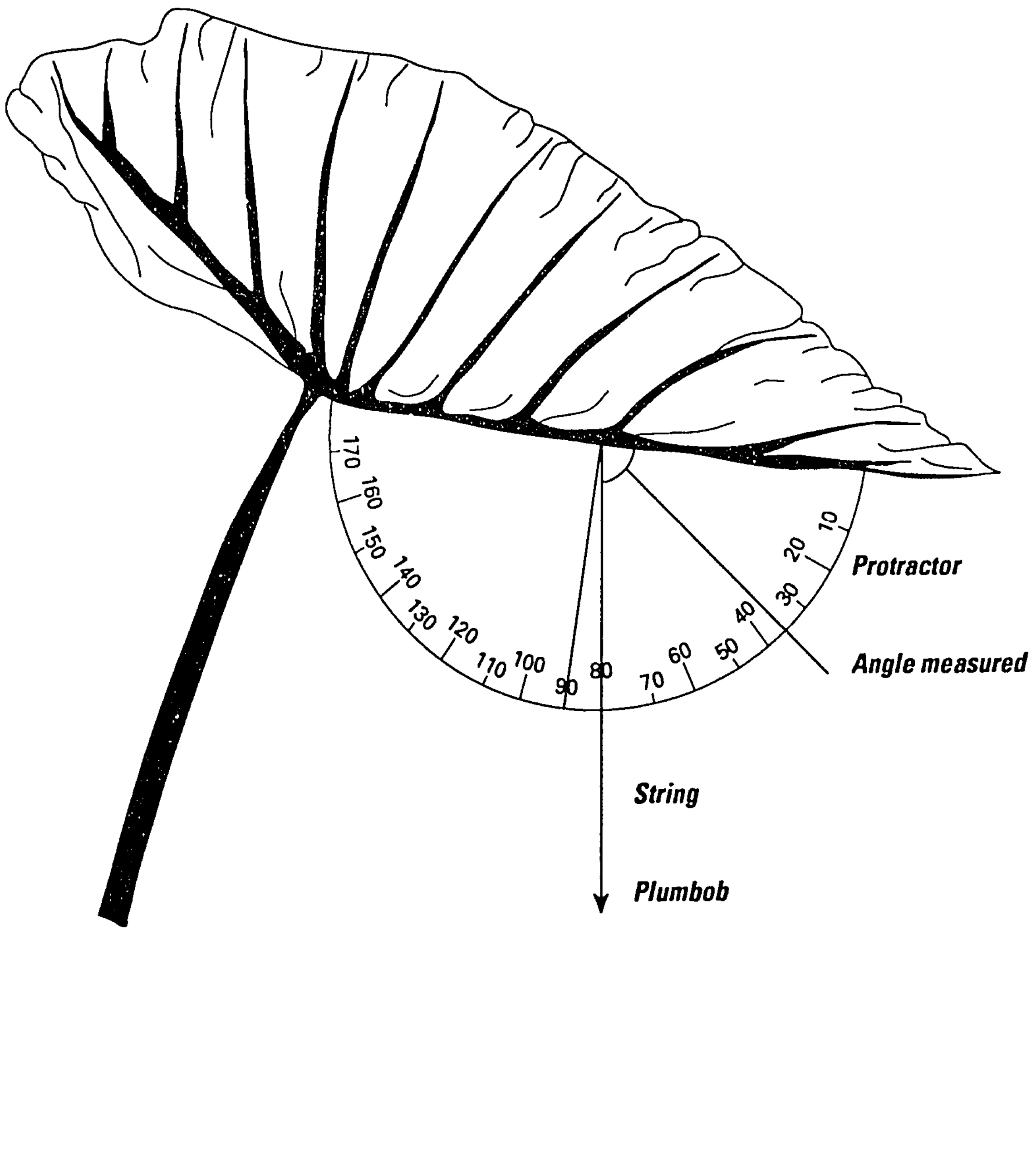


Figure B1. Leaf of taro showing the method of leaf angle measurements.

Light Interception

It is worthwhile to determine light interception in observation plots because leaf area is measured continuously. The best time to measure light interception is between 10:00 a.m. and 2:00 p.m or when the sun is directly overhead. When measuring light interception avoid casting any shadows. In the morning (10:00 a.m. — 12:00 p.m.) stand on the west side of the plant. In the afternoon (12:00 p.m. — 2:00 p.m.) stand on the east side of the plant.

Take 3 or 4 measurements per plot. All measurements must be done in one hour.

The measurements should be continued at 14-day intervals until full canopy or maximum LAI is reached.

A. Within Canopy Measurements

Determine light interception at three positions: (1) place the line-sensor at the base of selected plant, (2) 1/4 the within row distance from the selected plant, and (3) 1/2 way between two plants within the row (Figure C1).

The above diagram represents the positions of the sensor perpendicular to the rows. This will only apply when the sensor length is equal to the row spacing. If the sensor length is twice the row spacing, one measurement represents 3 rows of plants.

When the light-sensor is not the same length as the row spacing (normal case) then place the sensor diagonally at each of the three positions described above. The angle (a) between the sensor and the row must be 30° or more (Figure C2).

B. Above Canopy Measurement

Take two measurements above the canopy with the sensor before taking any measurements within the canopy (Section A above) and after all measurements have been taken within the canopy.

C. Reflectance Measurement

Determine light reflected from the canopy by inverting the sensor above the canopy (position 3).

D. Leaf Area Measurement

Measure leaf area (non-destructive) for each plot when light interception is determined (Figure A4).

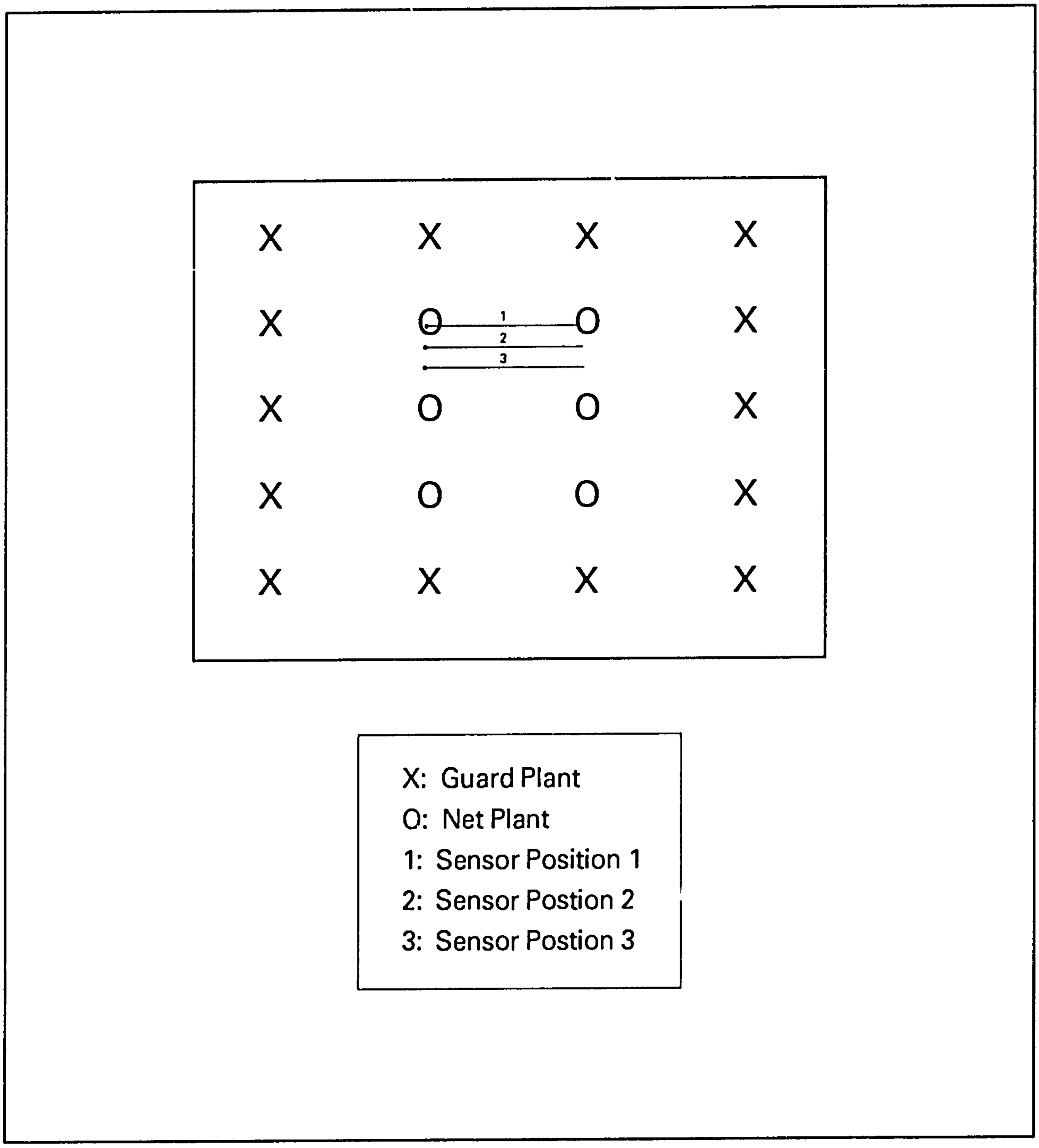


Figure C1. ***Diagrammatic representation of light interception measurement for aroid crop where row spacing is the same as the length of the sensor.***

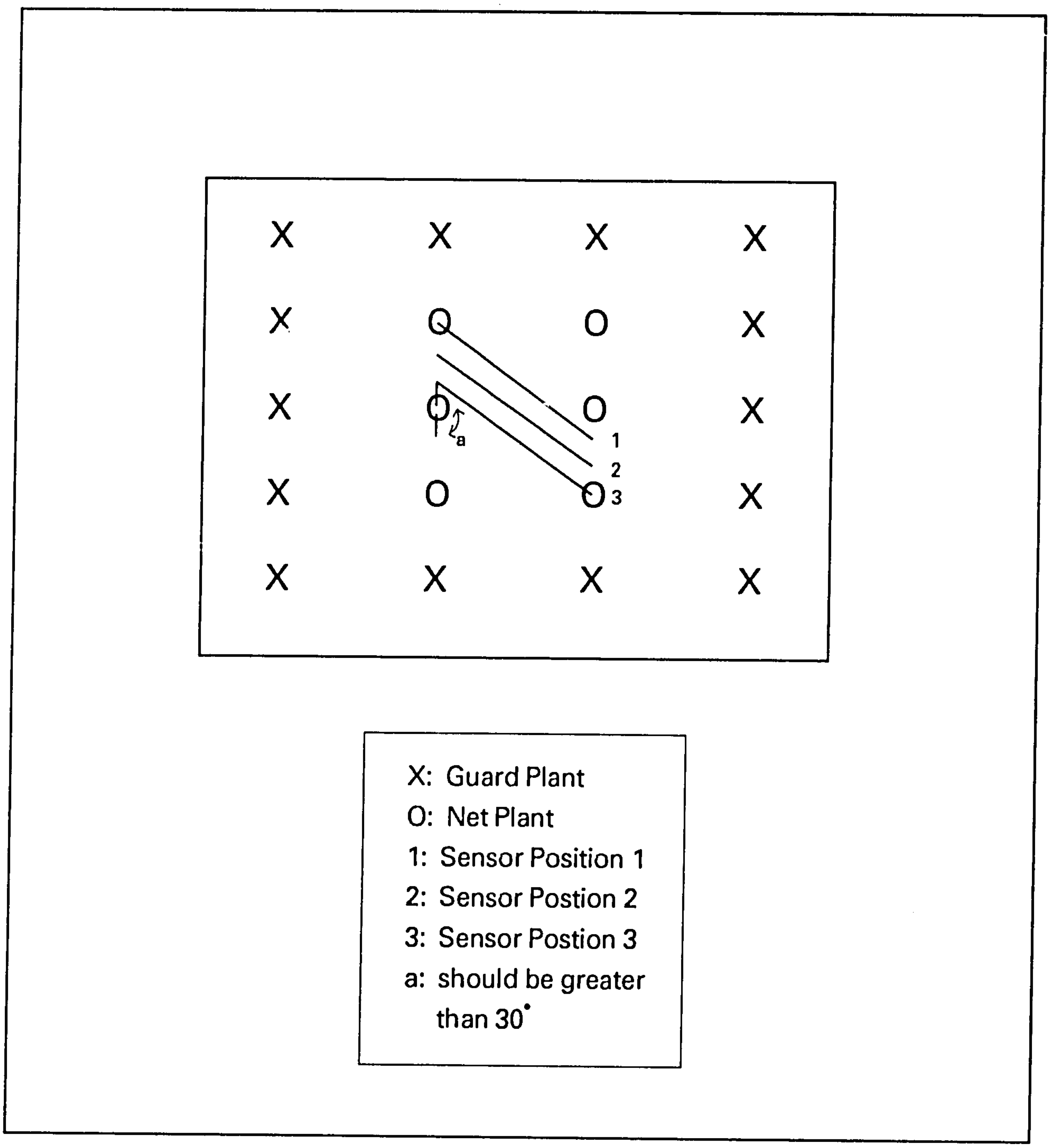


Figure C2. Diagrammatic representation of light interception measurement for aroid crop where row spacing is not the same as the length of the sensor.

Leaf-Tip Appearance Date

Plot No.: ______________ **Site:** __________________

Dates (dd/mm/yr)

Use this column for leaf count only

Leaf No. / **Plant No.**	**1**	**2**	**3**	**4**	**5**	**6**	___	___	___

FORM - 1

Leaf Opening Date

Plot No.: ______________

Site: ______________

Dates

Plant No.

Use this column for leaf count only

Leaf No.	1	2	3	4	5	6	___	___	___	___	___	___	___	___	___	___	___	___

Number of Active Leaves

Plot No.: ______________ **Site.** __________________

Plant No.

Date	1	2	3	4	5	6	___	___	___	___	___	___	___	___	___	___	___	___

FORM - 3

Plot No.: ____________

Leaf Length and Width (cm) AA'/AB

Site: ____________

Date: ____________

Leaf No.	Segment	Plant No. 1	2	3	4	5	6	___	___
	AA'								
	AB								
	AA'								
	AB								
	AA'								
	AB								
	AA'								
	AB								
	AA'								
	AB								
	AA'								
	AB								
	AA'								
	AB								
	AA'								
	AB								
	AA'								
	AB								

Leaf Angle: First 5 Active Leaves

Plot No.: ______________ **Site:** ______________

Date	Leaf No.	Plant No. 1	2	3	4	5	6	___	___	___	___	___	___	___	___	___	___	___	___

Number of Suckers

Plot No.: ____________ **Site:** ____________

Plant No.

Date	1	2	3	4	5	6	___	___	___	___	___	___	___	___	___	___	___	___

FORM - 6

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Workshop on Taro and Tanier Modeling Program

August 8, 1991 - Thursday
Registration held at Sherman 103

8:00 to 9:00 Registration of Participants
Introduction of Participants

Welcoming Remarks:
Ray Smith, Acting Director
Hawaii Institute of Tropical Agriculture & Human Resources
University of Hawaii

Samir A. El-Swaify, Chairman
Department of Agronomy & Soil Science
University of Hawaii

Linda Hamilton, Manager
South Pacific Regional Agricultural Development Project (SPRAD)

Workshop Charge:
Goro Uehara, Principal Investigator
IBSNAT Project

10:00 Break

10:30 **Joe T. Ritchie, Michigan State University**
Overview of IBSNAT Crop Models

12:00 Lunch

Session: Aroid Improvements
Chairman: James Silva

1:15 Param Sivan, University of the South Pacific
Taro Breeding in the South Pacific

2:00 Ramon de la Pena, University of Hawaii, Kauai Branch Station
The University of Hawaii Taro Germplasm Nursery and Breeding Program

2:45 Luis Sanabria, Universidad de Costa Rica
Micropropagation of Virus Free Edible Aroids

3:15 Break

3:30 L. Anthony Hunt, University of Guelph
Genetic Coefficients for Root Crops

4:15 to 4:30 Discussion

August 9 - Friday
Session held at Kuykendall 207

Session: Resource Management
Chairman: Param Sivan

8:00 James Silva, University of Hawaii
Response of Chinese Taro to Nitrogen Fertilization and Plant Population

8:30 Sanan Ratananukul, Sisaket Horticultural Research Center
Taro Production in Thailand

9:00 Susan Miyasaka, University of Hawaii, Hawaii Branch Station
Evaluation of Taro Germplasm for Tolerance to Acid Soils

9:30 to 10:00 Discussion

10:00 Break

Session: Resource Limitations
Chairman: Ricardo Goenaga

10:15 Victor Snyder, University of Puerto Rico
Soil Moisture Related Stresses Affecting Aroid Development

10:45 David Penn, University of Hawaii, Department of Geography
Modeling Water Requirements for Wetland Taro Cultivation in Hawaii

11:15 Robert Caldwell, University of Hawaii
Simulation of Aroid in Multiple Cropping Systems

12:00 to 12:15 Discussion

12:15 Lunch

Session: Aroid Model Development
Chairman: Robert Caldwell

1:30 Hemant Prasad, SPRAD
Effect of Photoperiod and Temperature on Growth and Development of Taro

2:15 Ricardo Goenaga, Tropical Agriculture Research Station
Accumulation and Partition of Dry Matter in Tanier

3:00 Break

3:15 Upendra Singh, International Fertilizer Development Center
Modeling Growth and Development of Taro and Tanier

4:00 Break

4:15 to 4:30 Discussion

August 10 - Saturday
Session held at Krauss Hall 118

8:00 to 1:00 Input of Experimental Data with DSSAT

August 11 - Sunday
Free Day

August 12 - Monday
Hotel Pick up
All Day Field trip to Waimanalo Research Station

- Description of field trials (Caldwell, Amosa, Prasad)
- Field data collection procedures
- Minimum data set for aroids
- Visit commerical taro farms

August 13 - Tuesday
Session held at Kuykendall 207

8:00 DSSAT Application
Agatha Tang, Daniel Imamura, Horatio Chan and Upendra Singh
Data Base Management System, Crop Models and Strategy Evaluation

10:00 Break

10:15 Upendra Singh, Hemant Prasad and Ricardo Goenaga
Demonstration of SUBSTOR-aroid

12: 00 Lunch

1:15	Upendra Singh, International Fertilizer Development Center Hands-on exercise on SUBSTOR-aroid
3:00	Break
3:15	Robert Caldwell, University of Hawaii CropSys Demonstration

August 14 · Wednesday
Session held at Kuykendall 207

8:00	Chairman: Hemant Prasad, SPRAD Improvement to SUBSTOR Taro and Tanier Models Identifying key limitations
9:30	Chairman: Param Sivan, University of the South Pacific Establishiment of Tropical Root Crop Network for Future Modeling Experiments • Types of Experiments • Data Requirements • Sharing of germplasm, information, etc.
11:45	Goro Uehara Closing Remarks