LATE-SEASON INTERSPECIFIC COMPETITION IN DRYLAND TARO (*COLOCASIA ESCULENTA* L. SCHOTT) SYSTEMS

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We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Agronomy and Soil Science.

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CHAPTER ONE

INTRODUCTION

Taro (*Colocasia esculenta* L. Schott) has the most widespread production of any root crop (Coursey, 1983). It is grown to some extent almost everywhere in the humid tropics. It is grown mainly for its edible corm, though in some regions the leaves are also eaten (Moy and Nip, 1983).

Taro is an important food crop for parts of Asia (de la Pena, 1978; Onwueme, 1978; Wang, 1983), the Pacific Region (de la Pena, 1978; Lambert et al., 1978; Onwueme, 1978; Wilson and Cable, 1984), and parts of the African Continent (Onwueme, 1978; Wang, 1983).

At present, the total acreage of world taro production is unclear, but it is grown both in commercial and subsistence agricultural settings (Wang, 1983).

Of interest in both commercial and subsistence taro systems is the impact of interspecific competition on the crop. Interspecific competition can be defined as the net negative effect plants have on each other when grown together as opposed to when growing alone. This thesis uses this definition as its working description of interspecific competition. Interspecific competition for light, water, soil nutrients, and space in taro systems can come from weed competition and competition from crops intercropped with taro.

TARO'S LIFE CYCLE AND COMPETITION

The life cycle characteristics of taro make it particularly prone to competition effects at certain phases of its growth cycle (Plucknett et al., 1967). Current literature on taro has two different growth stage models which are used to differentiate the phases in the taro growth cycle.

The first model describes plant growth in two phases: a "vegetative phase" and a "reproductive phase" (Onwueme, 1978; Ching, 1970). The "vegetative phase" is characterized by increasing leaf area, increasing mass of the plant, and increasing height. This phase ends when the plant reaches its peak above ground growth. The "reproductive phase" is characterized by the continued development in size and mass of the corm and a decline in above ground growth. This phase occurs after the above ground growth has reached its maximum.

The second model of taro development describes the growth cycle as three phases (Igbokwe, 1983; Plucknett, 1967; Sivan, 1984). In the first phase, the plant develops slowly, the leaf area of the canopy is small and the roots emerge. In the second phase, the plant rapidly accumulates biomass, mainly in the above ground tissues. This phase is characterized by a large leaf canopy and ends when the height of the plant begins to decline. The third phase is characterized by a decreasing leaf area, a decreasing above ground biomass, and rapid growth in below ground biomass, especially in the corm.

TARO COMPETITION STUDIES

The two primary directions past taro competition studies have taken are in evaluating the effect of weed competition on taro and the effect of intercrop competition on taro.

Taro Weed Studies

A constraint to taro production in both commercial and subsistence cropping systems is the competition weeds introduce to the system. Weeds may hinder the growth of taro by competing with it for soil nutrients, water, and sunlight, as well as attracting and harboring insect pests (Lambert et al., 1978). Weed control is a significant cost to the producer of taro. In a survey of commercial wetland taro farmers in Hawaii, it was found that fifteen percent or more of their total production costs went into weeding (Vieth et al., 1980). Weed problems affect taro cultivated in both dryland and wetland culture, however they can be much more troublesome in dryland conditions since the continuous flooding of wetland cultivation does not allow many weeds to grow (de la Pena, 1986). Weeds may also interfere with field operations, especially harvesting (de la Pena, 1986).

Weed Competition Studies in Taro

Onwueme (1978) found that taro is susceptible to weed competition in the first three or four months after planting, when the canopy is sparse. When the canopy closes, much of the weed problem is kept in check. Then, as the life cycle of the plant progresses, the leaves become smaller, and the canopy reopens. This decreased shade cover allows weeds to germinate and compete with the taro once again.

The effect of weed competition in both wetland and dryland cultivated taro is well documented for the first three to four months of its growing season (de la Pena, 1978; de la Pena, 1979; Gurnah, 1985; Onwueme, 1978; Rodriquez and Martell, 1988; Talatala et al., 1983, Talatala et al., 1985). This first period is considered the period in which taro is most sensitive to weed competition. These studies indicate that weed competition after this period does not appear to reduce crop yields significantly.

Plucknett et al. (1967) challenged these assertions. He found that weed control is a problem throughout the cropping season of dryland cultivated taro and in wetland cultivated taro as the crop matures. Gurnah (1985) reiterates this for dryland cultivated taro by acknowledging that taro is sensitive to competition from weeds through most of its life cycle; yet he considers the first three to four months as the most critical.

None of the studies mentioned have dealt with weed competition relative to the growth phases of taro. They have based their periods of evaluating weed competition effects on time after planting. There is no mention of the effect of taro leaf area index and taro growth phase on weed competition nor is there an indication of whether the plants were in the final growth phase during the competition period studied or at harvest. This final growth phase is the one described by Igbokwe (1983), Plucknett (1967), and Sivan (1984) in their three phase model of taro development.

Taro Intercropping Systems

Plucknett (1970) described taro intercropped with plantation crops of rubber, banana, cacao, and coconuts. These same types of situations are described by Onwueme (1978). Plucknett (1970) goes on to describe the situation in Egypt where taro is intercropped with radishes, cucumbers, beans, and turnips.

The effects of competition on taro in intercropping situations have been measured for a variety of crops. Sivan (1984) found that peanuts, corn, long beans, cowpeas, sweet potato, and okra significantly reduced the yields of intercropped taro. Mishra et al. (1985) determined that taro yields were significantly better under an intercropping system with wheat than in a sequential cropping system of wheat followed by taro. However, this effect was due to adverse weather conditions which occurred around the time of the sequential planting.

The current literature on taro is lacking information on the effects of interspecific competition on taro late in its growing season. There is a lack of information on how competition in this last growth phase affects taro yields and how it affects the growth and development of the crop. Current literature also lacks information on the competitive effect taro has on other species germinating late in its growing season.

THEORY OF THESIS

The description of taro development with three phases better illustrates the critical periods in which the effects of competition may be most pronounced. The first and last phases of the life cycle are periods where a smaller leaf canopy does not shade out competitors, allowing them the chance to grow. It is in these two phases that weed control may be critical and intercropping is feasible. The majority of the current literature on taro contains studies of competition in reference to months or days after planting and usually focused on the first growth phase, although no direct references to growth phase were made. There has not been a research effort which focused on interspecific competition effects in taro's final growth phase.

Since the majority of corm development occurs in phase three of taro growth, information on interspecific competition in this phase may be crucial to farmers. This information will enable farmers to evaluate whether to continue or discontinue weed control, based on the growth phase of their taro. This information can also be used to determine the feasibility of intercropping into a taro system that is in its final growth phase.

Since these knowledge gaps exist, a field experiment was conducted at the University of Hawaii. The experiment focused on the effects of interspecific competition during taro's final growth phase, in a dryland taro cropping system. The purpose of this experiment was to evaluate the importance of weed control in taro's final growth phase and to determine the feasibility of interplanting other crops late in the growing season of taro.

Maize (*Zea mays* L.) and rice (*Oryza sativa* L.) were selected to serve both as "pseudo-weeds" and intercrop components in the experiment. These competitors, planted late in the beginning of the final growth phase of taro , permitted the gathering of information on interspecific competition.

HYPOTHESIS

Taro yields are not affected by interspecific competition occurring in the crop's final phase of growth.

OBJECTIVES

(1) To assess the response of taro to interspecific competition in taro's final phase of growth.

(2) To assess the ability of taro to suppress other species that germinate during it final phase of growth.

(3) To collect a Minimum Data Set (Nix, 1983) on taro and its competitors late in its growing season to be used in the development of process level simulation models.

PLANTING MATERIAL EXPERIMENT

Vegetative propagation is the standard method of cultivation in taro production. Before a taro crop can be planted, planting materials must be harvested and prepared.

If a taro grower is delayed from planting their prepared planting material, they run the risk of their planting material spoiling in storage. To evaluate the effects of field storage time on taro planting material, a greenhouse experiment was conducted in addition to the field experiment. The experiment was used to not only gain insight into the field storage time question, but to allow the author a chance to experience a different type of experiment. The greenhouse experiment is presented in Chapter Five of this thesis.

CHAPTER TWO

MATERIALS AND METHODS

CHARACTERISTICS OF FIELD LOCATION

The experiment was conducted at the Waimanalo Research Station, Waimanalo, Hawaii, from 5 April 1991 to 10 January 1992. It was conducted on an area of 914 m^2. The soil was a Waialua, gravely clay variant (Vertic Haplustoll, very-fine Kaolinitic, isohyperthermic). The annual rainfall ranges from 635 mm to 1270 mm, most of which falls between November and April (Ikawa et al., 1985). The average maximum air temperature measured for the period of the experiment was 28.4 °C. The average minimum air temperature was 22 °C.

Prior to initiation of the experiment, soil samples were collected to a depth of 1.10 m. The soil pH in the field was 6.67. The KCL-extractable nitrate and ammonium were 3.06 mg kg^{-1} and 1.28 mg kg^{-1}, respectively. The extractable potassium was 0.41 mg kg^{-1}. Modified Truog extractable phosphorus was 226 mg kg^{-1}.

JOINT EFFORT

The field experiment was a cooperative effort by three agronomy graduate students (Falaniko Amosa, Nicholas Hahn, and myself). Each student had his own treatments randomized within the same experiment. In addition to my treatments, there were treatments evaluating the shade tolerance of taro and for determining the effects of drought stress on taro. A taro sole crop control plot was shared by each student. See Appendix I for a layout of the treatments in the field.

EXPERIMENTAL DESIGN

The over-all experimental design, including all treatments, was a split plot in time with main plots (10 total), arranged in a Randomized Complete Block Design with two replications. Each main plot was 36.8 m^2. The main plots were subdivided into subplots to which harvest treatments were randomly assigned. The growth analysis subplots measured 1.37 m^2 and the subplot size for the final yield harvest was 2.74 m^2.

TREATMENT DESIGN

The treatment design of the overall experiment was a partial factorial of management practices (shade treatments: 2 levels; water stress treatments: 2 levels; late-season competition: 2 levels) and time (10 destructive harvests).

Treatment layout: Taro/Competition Study

In the first five months of the experiment, the late season competition treatments containing taro were treated the same as the taro sole crop. After this period, they were treated differently based on their treatment layout.

Approximately five months into the experiment, as the above-ground growth began to decline indicating the crop had moved into phase three growth, the late-season competitors of rice and maize were planted in the taro plots. These crops were chosen because they have well established growth and development patterns and they helped facilitate the projects interest in intercropping. Results from the following five treatments are reported in this thesis:

(1) Taro Sole Crop Control: The layout of this treatment was 7 rows per plot, 7 m in length, with 23 plants per row, for a total of 161 taro plants per plot. The plant spacing was 0.30 m between plants within rows and 0.76 m between rows. The planting was in prepared furrows and the depth of planting was approximately 0.10 to 0.15 m. This treatment was weeded by hand throughout the experiment. These plots were planted on 8 April 1991.

(2) Rice Sole Crop Control: The layout of this treatment was 7 rows per plot, 7 m in length, with 1285 seeds planted in each row. The planting furrows were dug approximately 80 mm in depth and the seeds were hand planted. Percent germination was estimated to be 50% of the seeds planted. This estimate was obtained by counting the plants that emerged in the harvest subplots. The total number of plants in this treatment was estimated to be 4500 plants per plot. The plant spacing was 10 to 20 mm between plants within rows and 0.76 m between rows. This treatment was weeded by hand throughout the experiment. These plots were planted on 14 September 1991, 154 days after the planting of the taro.

(3) Maize Sole Crop Control: The layout of this treatment was 7 rows per plot, 7 m in length, with 45 plants each for a total of 315 plants per plot. The plants were in

hills of two plants each spaced 0.30 m between hills within rows and 0.76 m between rows. Seed holes were dug approximately 80 mm in depth and the seeds hand planted. No weed control was used in these plots to permit assessment of weed competition and to provide a biomass replacement to the maize intercrops which had a low percent germination. The weed species present, in order of predominance, were *Cenchrus echinatus* L., *Mimosa pudica* L., *Portulaca oleracea* L., *Ipomoea obscura* (L.) Ker, *Amaranthus spinosus* L., and *Taraxacum officinale* (L.) Weber. These plots were planted on 27 September 1991, 172 days after the planting of the taro.

(4) Taro/Rice System: The layout of this treatment was a combination of the taro sole crop treatment and the rice sole crop treatment. The taro was planted in 7 rows per plot, 7 m in length, with 23 plants each, for a total of 161 taro plants per plot. The plant spacing was 0.30 m between plants within rows and 0.76 m between rows. The rice was planted in 7 rows per plot, 7 m in length, with 1285 seeds planted in each row. Percent germination was estimated to be 28% of the seeds planted. This estimate was determined by counting the plants that emerged in the harvest subplots. The total number of rice plants in this treatment was estimated to be 2518 plants per plot. The plant spacing was 10 to 20 mm between plants within rows and 0.76 m between rows. The rice was planted between the rows of taro, with taro at a distance of 0.38 m on either side of the rice row. This treatment was

weeded by hand throughout the experiment. The taro was planted on 8 April 1991 and the rice was planted on 14 September 1991.

(5) Taro/Maize System: The layout of this treatment was a combination of the taro sole crop treatment and the maize sole crop treatment. The taro was planted in 7 rows per plot, 7 m in length, with 23 plants each, for a total of 161 taro plants per plot. The plant spacing was 0.30 m between plants within rows and 0.76 m between rows. The maize was planted in 7 rows per plot, 7 m in length, with 45 plants each. Percentage germination was estimated to be 15% of the seeds planted. This estimate was determined by counting the plants that emerged in the harvest subplots. The total number of plants in this treatment was about 48 plants per plot. The target plant spacing was 0.30 m between plants within rows and 0.76 m between rows. The actual spacing varied considerable due to the poor establishment of the maize seeds. Maize was planted between the rows of taro, with taro at a distance of 0.38 m on either side of the maize. For the reasons mentioned in the sole crop maize layout description, no weed control was used in these plots. The weed species present, in order of predominance, were *Cenchrus echinatus L., Mimosa pudica L., Portulaca oleracea L., Ipomoea obscura* (L.) Ker, *Amaranthus spinosus* L., and *Taraxacum officinale* Weber. The taro was planted on 8 April 1991 and the maize was planted on 27 September 1991.

DATA COLLECTION TECHNIQUES

Sampling Design: Taro/Competition Study

DESTRUCTIVE SAMPLING

Taro: All taro plots contained 8 sub-plots from which destructive harvests were taken throughout the experiment. A schedule of these harvests is included in Appendix II. An outline of the total number of harvests is included in Appendix III. Harvest sub-plots were assigned randomly within each plot. The first six harvests and the eighth harvest covered an area of 1.37 m^2 and contained six taro plants. The seventh harvest was the final yield harvest covering an area 2.74 m^2 and contained 12 taro plants.

Rice: All rice plots contained 4 sub-plots from which destructive harvests were taken throughout the experiment. A schedule of these harvests is included in Appendix II. An outline of the total number of harvests is included in Appendix III. Sub-plots were assigned randomly within each plot. In the taro/rice intercrop plots, the rice sub-plots were randomly assigned to existing taro sub-plots. The rice harvests occurred in conjunction with the taro harvests. The first three sub-plots covered an area 1.37 m^2 and contained the total number of rice plants in that area. The fourth harvest was the final harvest covering an area 2.74 m^2 and contained the total number of rice plants in that area.

Maize: All maize plots contained 4 sub-plots from which destructive harvests were taken throughout the experiment. A schedule of these harvests is included in Appendix II. An outline of the total number of harvests is included in Appendix III. Sub-plots were assigned randomly within each plot. In the taro/maize intercrop plots, the maize sub-plots were randomly assigned to existing taro sub-plots. The maize harvests all occurred in conjunction with the taro harvests. The first three sub-plots covered an area 1.37 m^2 and contained the total number of maize plants and weeds in that area. The fourth harvest was the final harvest covering an area 2.37 m^2 and also contained the total number of maize plants and weeds in that area.

NON-DESTRUCTIVE SAMPLING

Taro: A sampling area of three plants was selected randomly from each taro plot. These three plants were measured weekly throughout the experiment. The measurements taken for each of the three plants were height, canopy width, vegetative stage (leaf number), and sucker number (axillary shoots). Vegetative stage was followed throughout the experiment by numbering the taro leaves, after emergence, with a felt-tip marker.

Rice: A sampling area of 0.68 m^2 was selected randomly within each plot containing rice treatments. Four plants in this area were measured weekly throughout the experiment. The measurements taken for each of the four plants were height, canopy width, vegetative stage (leaf number), reproductive stage, and tiller number. Vegetative stage was followed throughout the experiment by numbering the rice leaves, after emergence, with a felt-tip marker. The tillers around the marked primary shoot were counted at each measurement period.

Maize: A sampling area of 0.68 m^2 was selected randomly from each plot containing maize treatments. Four plants in this area were measured weekly throughout the experiment. The measurements taken for each of the four plants were height, canopy width, vegetative stage (leaf number), and reproductive stage. Vegetative stage was followed throughout the experiment by numbering the maize, leaves, after emergence with a felt-tip marker.

CULTIVARS USED AND PLANTING MATERIAL COLLECTION

Taro: Taro planting materials were harvested from a completed experiment at the Waimanalo Research Station. Two cultivars were harvested: the Hawaiian cv. *Lehua Maoli* and Bun-Long (commonly called Chinese Taro). The Bun-Long cultivar was used as the experimental plant receiving treatments. The *Lehua Maoli* cultivar was used for border rows around each plot. The planting materials came from both primary shoots and axillary shoots and had a variety of petiole girths and corm diameters. The planting materials were prepared by cutting off a portion of the corm and the petiole, and cutting off the leaf laminae. The planting materials consisted of from 40 to 80 mm of the upper portion of the corm or cormel and about 0.20 to 0.25 m of the lower part of the petiole. The planting material were stored in an open shed for three days before planting. This allowed the cut ends to develop a dry coat. This helped prevent problems due to rotting or fungal infection after planting.

Rice : cv. IR-36.

Maize : cv. Pioneer brand X304C

PRE-PLANTING AND POST PLANTING FIELD PREPARATION

The field was prepared by plowing and disk harrowing. Fertilizer was broadcast on the field at a rate of 179 kg N ha^{-1}, 77 kg P ha^{-1}, and 149 kg K ha^{-1} and rototill incorporated. Rough furrows were plowed into the field. A drip irrigation system was installed. Three weeks after planting, as the roots of the taro became established, urea was side-dressed at a rate of 46 kg N ha^{-1}.

Just prior to the planting of the competitors on 14 September 1991, the field was fertilized for the last time at a rate of 179 kg N ha^{-1}, 77 kg P ha^{-1}, and 149 kg K ha^{-1}. The fertilizer was broadcast but not incorporated, so as to avoid damage to the taro crop in the field.

MEASUREMENT OF FIELD VARIABLES

Field variables were collected in accordance with the International Benchmark Sites Network for Agrotechnology Transfer Minimum Data Set (MDS) requirements (Nix, 1983). Weather information for the Minimum Data Set was collected using a meteorological data logging system (LI-COR Inc., Lincoln, Nebraska, Model LI 1200S). This system included: a minimum data set recorder (LI-COR Inc., Lincoln, Nebraska, Model LI-1200); a pyranometer sensor which collected total daily solar radiation in M Joules m^{-2} (LI-COR Inc., Lincoln, Nebraska, Model LI-200SA); an air temperature sensor which recorded air temperature in degrees Celsius; a soil temperature sensor which recorded soil temperature in degrees Celsius at a depth of 0.30 m (LI-COR Inc., Lincoln, Nebraska, Model 1000-15); and a tipping bucket rain gauge which recorded total daily precipitation in millimeters (LI-COR Inc., Lincoln, Nebraska, Model 1000-20).

HARVEST PROCEDURES

Taro: Harvest procedures were suited for the collection of data described in IBSNAT Technical Report 1 (IBSNAT, 1988) as needed for the taro Minimum Data Set. Taro plants, from the designated sub-plots, were removed from the field, the leaf laminae removed, and the plants thoroughly washed of all soil. The roots were removed and discarded. The laminae area was measured with an area meter (LI-COR Inc., Lincoln, Nebraska, Model LI-3100) and then the laminae oven dried at 70°C for an average of one week. The remaining plant parts were separated into primary shoot petioles, axillary shoot petioles, corms and cormels. The corms and cormels were counted and weighed. The plant parts were then chopped into smaller pieces and oven dried at 70°C for an average of two weeks. Once dried, the plant parts were weighed.

Rice: Harvest procedures were suited for the collection of data described in IBSNAT Technical Report 1 (IBSNAT, 1988) as needed for the rice Minimum Data Set. Rice plants, from the designated sub-plots, were removed from the field, the leaves were removed and weighed. The leaf area of a sub-sample of the rice leaves was measured with an area meter (LI-COR Inc., Lincoln, Nebraska, Model LI-3100). After the measurement of leaf area, the sub-samples were weighed and all the leaf laminae were oven dried at 70°C for an average of one week. The roots were removed from the stem and discarded. The remaining plant parts were separated into stems and seeds. The plant parts were then chopped into smaller pieces and oven dried at 70°C for an average of two weeks. Once dried, the plant parts were weighed.

Maize: Harvest procedures were suited for the collection of data described in IBSNAT Technical Report 1 (IBSNAT, 1988) as needed for the maize Minimum Data Set. Maize plants, from the designated sub-plots, were removed from the field by cutting them off at ground level, leaving the roots in the ground. The leaves were removed and weighed. The leaf area of a sub-sample of the maize leaves was measured with an area meter (LI-COR Inc., Lincoln, Nebraska, Model LI-3100). After the measurement of leaf area, the sub-samples were weighed and then oven dried at 70°C for an average of one week. The remaining plant parts were separated into stems, ears, shucks and stems. Due to a lack of oven space, a sub-sample of stems was taken from the sole crop treatments and weighed. The plant parts were then chopped in to smaller pieces and oven dried at 70°C for an average of two weeks. Once dried, the plant parts were weighed. The seeds were separated from the cobs and weighted separately. The weeds in the maize plots were removed from the field by cutting them off at ground level. The weeds were then identified using a weed handbook (Haselwood and Motter, 1966). The weeds were oven dried together at 70°C for an average of two weeks. Once dried, the weeds were weighed.

ANALYSIS

Appendix IV contains the definitions of the basic data measured and the dependent variables derived from the measurements.

The dependent variables were statistically analyzed using the SAS (SAS Institute, Inc., 1988) statistics program. The level of significance selected was 0.05 for treatment effects. Logarithmic transformation was performed on all variables to reduce problems of non-homogeneous error variances.

Taro

A standard analysis of variance was performed for the logarithm of variables collected using a split-plot in time design (Steel and Torrie, 1960). These variables were: total corm fresh weight, total corm dry weight, leaf area index, total below ground biomass, total above ground biomass, total biomass, and harvest index for the combination of the seven harvests.

Rice

A standard analysis of variance was performed for the logarithm of total biomass and leaf area index using the split-plot in time design (Steel and Torrie, 1960) for the combination of four harvests.

In the split plot in time analysis, the error mean squares used to test the system effects (replicate-by-system interaction) had only one degree of freedom. Given the layout of the experiment (see Appendix I, replicates were not contiguous), it was considered likely that the replicate effect would be no greater than the replicate-by-system effect, therefore these terms were pooled if the test for equality failed at a probability level of 0.25. Likewise, if the replicate-by-time interaction was no larger than the replicate-by-system-by-time interaction ($p > 0.25$), these terms were also pooled.

Maize

A standard analysis of variance was performed for the logarithm of maize total biomass, weed total biomass, total biomass of maize biomass and weeds biomass, and leaf area index using the split-plot in time design (Steel and Torrie, 1960) for the combination of the four harvests. As with the rice, the error terms in the split-plot in time analysis were pooled when possible.

CHAPTER THREE

RESULTS

TARO

The hypothesis of this experiment, taro yields are not affected by interspecific competition occurring in the crop's final phase of growth, was not rejected based on what was found in this experiment. The split plot in time analysis revealed no treatment effects except for the main effect of time (Tables 1 to 7). The effect of time is illustrated for above ground biomass and below ground biomass in Fig. 1. It is also illustrated for corm fresh weight and corm dry weight in Fig.2 and leaf area index in Fig. 3.

Table 1. SAS output for logarithm of taro total above ground biomass ln (TTAGB), split plot in time analysis.

```
Analysis of Variance Procedure

Dependent Variable: LTTAGB
                                    Sum of            Mean
Source                  DF         Squares          Square   F Value     Pr > F

Model                   29     23.56166566      0.81247123      3.63     0.0110

Error                   12      2.68329569      0.22360797

Corrected Total         41     26.24496135

                  R-Square            C.V.        Root MSE            LTTAGB Mean

                  0.897760        8.482827       0.4728720             5.57446291


Source                  DF        Anova SS     Mean Square   F Value     Pr > F

REP                      1      1.28026547      1.28026547      5.73     0.0340
SYSTEM                   2      0.53542802      0.26771401      1.20     0.3357
REP*SYSTEM               2      1.28557929      0.64278965      2.87     0.0955
DAP                      6     16.94067065      2.82344511     12.63     0.0001
REP*DAP                  6      0.93569432      0.15594905      0.70     0.6571
SYSTEM*DAP              12      2.58402791      0.21533566      0.96     0.5255

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                  DF        Anova SS     Mean Square   F Value     Pr > F

REP                      1      1.28026547      1.28026547      1.99     0.2936

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                  DF        Anova SS     Mean Square   F Value     Pr > F

SYSTEM                   2      0.53542802      0.26771401      0.42     0.7060

Tests of Hypotheses using the Anova MS for REP*DAP as an error term

Source                  DF        Anova SS     Mean Square   F Value     Pr > F

DAP                      6     16.94067065      2.82344511     18.10     0.0013
```

Table 2. SAS output for logarithm of taro total below ground biomass ln (TTBGB), split plot in time analysis.

```
Analysis of Variance Procedure

Dependent Variable: LTTBGB
                                        Sum of               Mean
Source                    DF           Squares             Square  F Value     Pr > F

Model                     29       70.66406285         2.43669182    25.46     0.0001

Error                     12        1.14840991         0.09570083

Corrected Total           41       71.81247277

                    R-Square              C.V.           Root MSE          LTTBGB Mean

                    0.984008          4.739483          0.3093555           6.52719945


Source                    DF          Anova SS        Mean Square  F Value     Pr > F

REP                        1        0.00019095         0.00019095     0.00     0.9651
SYSTEM                     2        0.25117924         0.12558962     1.31     0.3052
REP*SYSTEM                 2        0.18157983         0.09078991     0.95     0.4145
DAP                        6       68.87200963        11.47866827   119.94     0.0001
REP*DAP                    6        0.55112205         0.09185367     0.96     0.4906
SYSTEM*DAP                12        0.80798116         0.06733176     0.70     0.7241

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                    DF          Anova SS        Mean Square  F Value     Pr > F

REP                        1        0.00019095         0.00019095     0.00     0.9676

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                    DF          Anova SS        Mean Square  F Value     Pr > F

SYSTEM                     2        0.25117924         0.12558962     1.38     0.4196

Tests of Hypotheses using the Anova MS for REP*DAP as an error term

Source                    DF          Anova SS        Mean Square  F Value     Pr > F

DAP                        6       68.87200963        11.47866827   124.97     0.0001
```

Table 3. SAS output for logarithm of taro corm fresh weight ln (TCFW), split plot in time analysis.

```
Analysis of Variance Procedure

Dependent Variable: LTCFW
                                      Sum of          Mean
Source                   DF          Squares        Square   F Value     Pr > F

Model                    29      48.96918224    1.68859249     13.69     0.0001

Error                    12       1.48038264    0.12336522

Corrected Total          41      50.44956487

                   R-Square             C.V.      Root MSE          LTCFW Mean

                   0.970656         4.653448     0.3512339          7.54781872


Source                   DF         Anova SS   Mean Square   F Value     Pr > F

REP                       1       0.10049228    0.10049228      0.81     0.3845
SYSTEM                    2       0.22568595    0.11284298      0.91     0.4268
REP*SYSTEM                2       0.68428281    0.34214141      2.77     0.1023
DAP                       6      46.29603393    7.71600565     62.55     0.0001
REP*DAP                   6       0.46265207    0.07710868      0.63     0.7079
SYSTEM*DAP               12       1.20003520    0.10000293      0.81     0.6390

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                   DF         Anova SS   Mean Square   F Value     Pr > F

REP                       1       0.10049228    0.10049228      0.29     0.6422

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                   DF         Anova SS   Mean Square   F Value     Pr > F

SYSTEM                    2       0.22568595    0.11284298      0.33     0.7520

Tests of Hypotheses using the Anova MS for REP*DAP as an error term

Source                   DF         Anova SS   Mean Square   F Value     Pr > F

DAP                       6      46.29603393    7.71600565    100.07     0.0001
```

Table 4. SAS output for logarithm of taro corm dry weight ln (TCW), split plot in time analysis.

```
Analysis of Variance Procedure

Dependent Variable: LTCW
                                      Sum of            Mean
Source                   DF          Squares          Square  F Value     Pr > F

Model                    29      62.61599282      2.15917217    17.91     0.0001

Error                    12       1.44687412      0.12057284

Corrected Total          41      64.06286694

                   R-Square             C.V.        Root MSE           LTCW Mean

                   0.977415         5.612208       0.3472360          6.18715470


Source                   DF         Anova SS     Mean Square  F Value     Pr > F

REP                       1       0.00005231      0.00005231     0.00     0.9837
SYSTEM                    2       0.19849927      0.09924964     0.82     0.4624
REP*SYSTEM                2       0.22675706      0.11337853     0.94     0.4175
DAP                       6      60.74169366     10.12361561    83.96     0.0001
REP*DAP                   6       0.48814398      0.08135733     0.67     0.6729
SYSTEM*DAP               12       0.96084653      0.08007054     0.66     0.7555

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                   DF         Anova SS     Mean Square  F Value     Pr > F

REP                       1       0.00005231      0.00005231     0.00     0.9848

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                   DF         Anova SS     Mean Square  F Value     Pr > F

SYSTEM                    2       0.19849927      0.09924964     0.88     0.5332

Tests of Hypotheses using the Anova MS for REP*DAP as an error term

Source                   DF         Anova SS     Mean Square  F Value     Pr > F

DAP                       6      60.74169366     10.12361561   124.43     0.0001
```

Table 5. SAS output for logarithm of taro leaf area index ln (TLAI), split plot in time analysis.

```
Analysis of Variance Procedure

Dependent Variable: LTLAI
                                       Sum of              Mean
Source                    DF          Squares            Square   F Value     Pr > F

Model                     29      13.08579233        0.45123422      2.13     0.0839

Error                     12       2.54560690        0.21213391

Corrected Total           41      15.63139923

                    R-Square             C.V.          Root MSE             LTLAI Mean

                    0.837148         65.68792         0.4605800             0.70116391


Source                    DF         Anova SS       Mean Square   F Value     Pr > F

REP                        1       0.72628700        0.72628700      3.42     0.0890
SYSTEM                     2       0.47387255        0.23693628      1.12     0.3591
REP*SYSTEM                 2       0.52391671        0.26195836      1.23     0.3253
DAP                        6       8.83266139        1.47211023      6.94     0.0023
REP*DAP                    6       0.33516245        0.05586041      0.26     0.9438
SYSTEM*DAP                12       2.19389222        0.18282435      0.86     0.5995

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                    DF         Anova SS       Mean Square   F Value     Pr > F

REP                        1       0.72628700        0.72628700      2.77     0.2378

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                    DF         Anova SS       Mean Square   F Value     Pr > F

SYSTEM                     2       0.47387255        0.23693628      0.90     0.5251

Tests of Hypotheses using the Anova MS for REP*DAP as an error term

Source                    DF         Anova SS       Mean Square   F Value     Pr > F

DAP                        6       8.83266139        1.47211023     26.35     0.0005
```

Table 6. SAS output for logarithm of taro harvest index ln (THI), split plot in time analysis.

```
Analysis of Variance Procedure

Dependent Variable: LTHI
                                      Sum of           Mean
Source                  DF           Squares         Square  F Value     Pr > F

Model                   29        6.59440017     0.22739311     3.70     0.0102

Error                   12        0.73774066     0.06147839

Corrected Total         41        7.33214084

                  R-Square              C.V.       Root MSE           LTHI Mean

                  0.899383         -29.82140      0.2479484         -0.83144432


Source                  DF          Anova SS    Mean Square  F Value     Pr > F

REP                      1        0.18532451     0.18532451     3.01     0.1081
SYSTEM                   2        0.04306011     0.02153006     0.35     0.7115
REP*SYSTEM               2        0.04526718     0.02263359     0.37     0.6996
DAP                      6        5.67525575     0.94587596    15.39     0.0001
REP*DAP                  6        0.33054025     0.05509004     0.90     0.5279
SYSTEM*DAP              12        0.31495236     0.02624603     0.43     0.9227

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                  DF          Anova SS    Mean Square  F Value     Pr > F

REP                      1        0.18532451     0.18532451     8.19     0.1035

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                  DF          Anova SS    Mean Square  F Value     Pr > F

SYSTEM                   2        0.04306011     0.02153006     0.95     0.5125

Tests of Hypotheses using the Anova MS for REP*DAP as an error term

Source                  DF          Anova SS    Mean Square  F Value     Pr > F

DAP                      6        5.67525575     0.94587596    17.17     0.0015
```

Table 7. SAS output for logarithm of taro total biomass ln (TTB), split plot in time analysis.

```
Analysis of Variance Procedure

Dependent Variable: LTTB
                                      Sum of            Mean
Source                    DF         Squares          Square   F Value     Pr > F

Model                     29     36.23123278      1.24935285     12.88     0.0001

Error                     12      1.16402740      0.09700228

Corrected Total           41     37.39526017

                    R-Square            C.V.        Root MSE              LTTB Mean

                    0.968872        4.437522       0.3114519             7.01859902


Source                    DF        Anova SS     Mean Square   F Value     Pr > F

REP                        1      0.19160414      0.19160414      1.98     0.1852
SYSTEM                     2      0.31524202      0.15762101      1.62     0.2374
REP*SYSTEM                 2      0.47366634      0.23683317      2.44     0.1289
DAP                        6     33.20670595      5.53445099     57.05     0.0001
REP*DAP                    6      0.87360639      0.14560107      1.50     0.2583
SYSTEM*DAP                12      1.17040794      0.09753400      1.01     0.4963

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                    DF        Anova SS     Mean Square   F Value     Pr > F

REP                        1      0.19160414      0.19160414      0.81     0.4633

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                    DF        Anova SS     Mean Square   F Value     Pr > F

SYSTEM                     2      0.31524202      0.15762101      0.67     0.6004

Tests of Hypotheses using the Anova MS for REP*DAP as an error term

Source                    DF        Anova SS     Mean Square   F Value     Pr > F

DAP                        6     33.20670595      5.53445099     38.01     0.0002
```

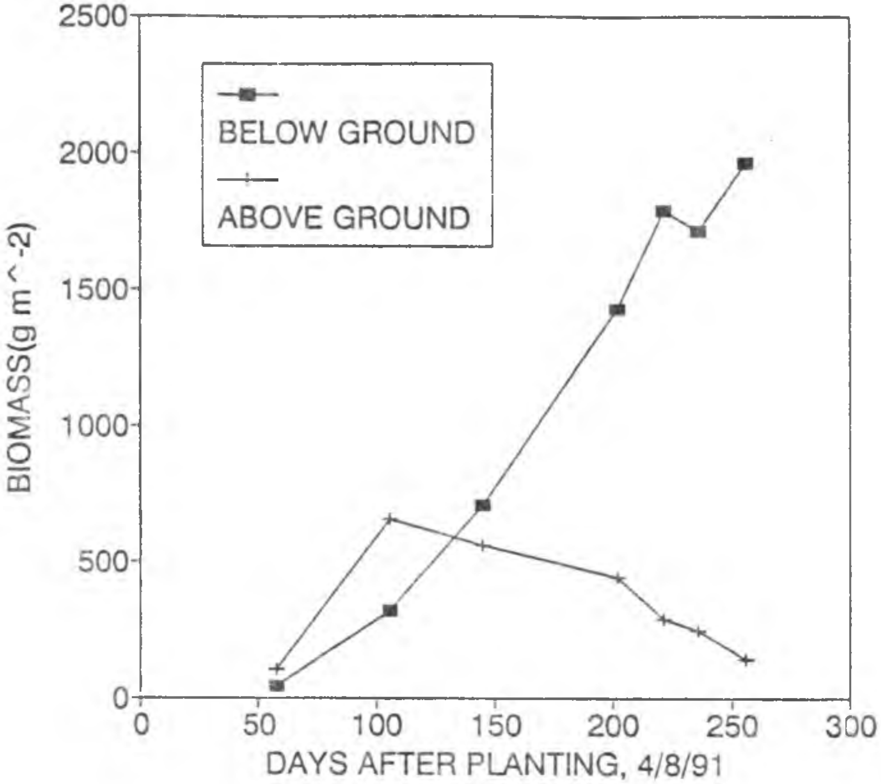


Fig. 1. Taro above ground biomass (leaf laminae and leaf petioles) and taro below ground biomass (corms and cormels) in taro treatments (averaged from Taro Sole Crop, Taro/Rice System, and Taro/Maize/Weed System) at seven harvest dates.

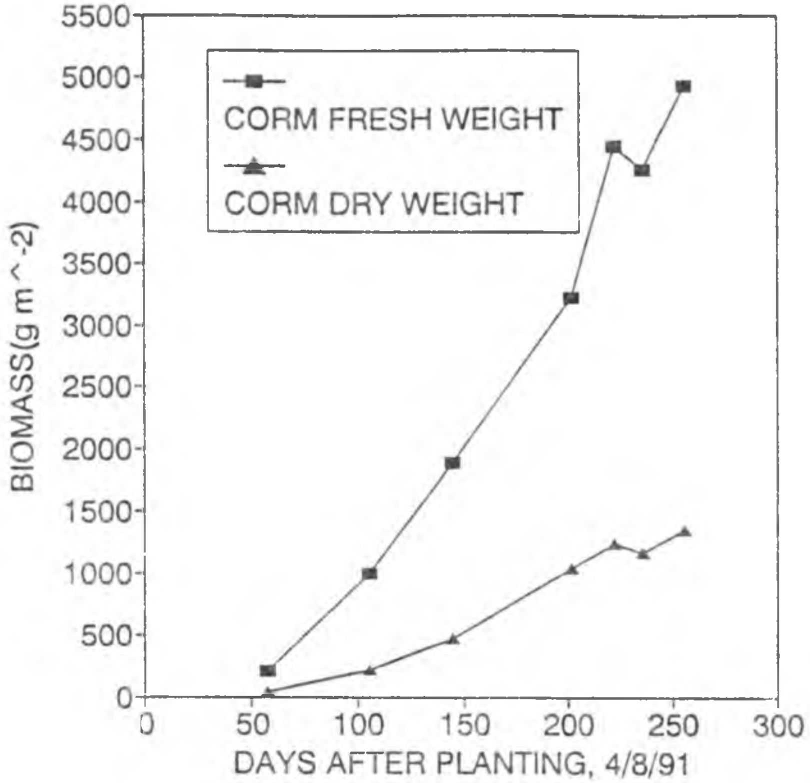


Fig. 2. Taro corm fresh weight and taro corm dry weight in taro treatments (averaged from Taro Sole Crop, Taro/Rice System, and Taro/Maize/Weed System) at seven harvest dates.

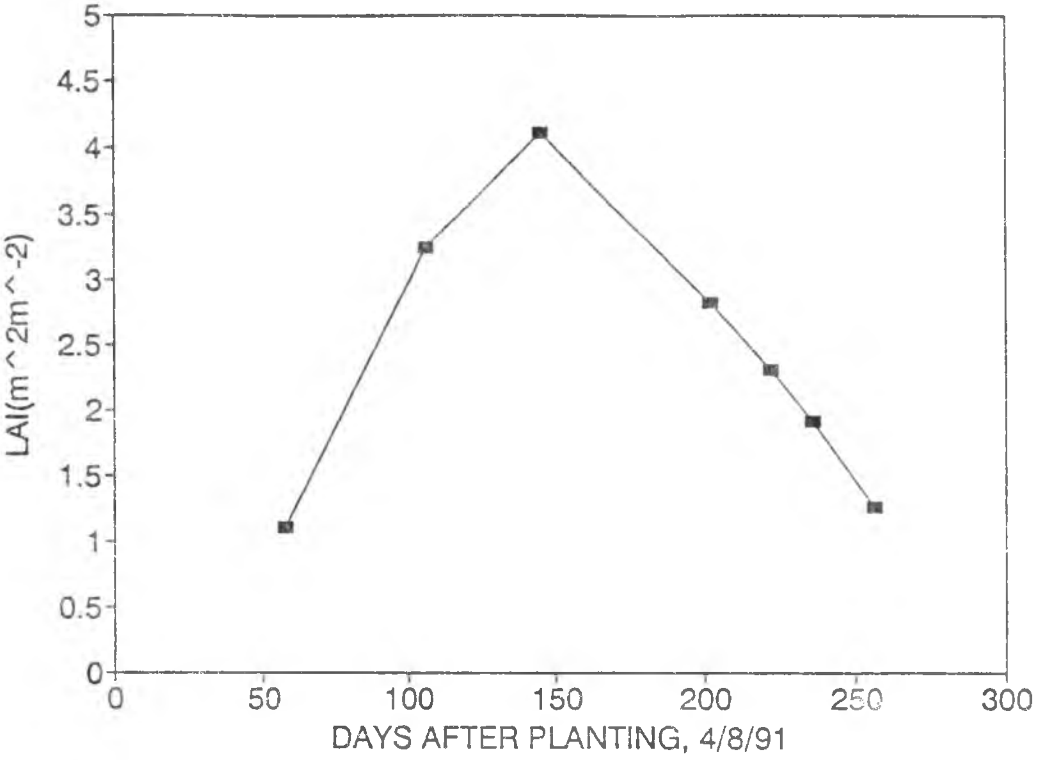


Fig. 3. Leaf Area Index (LAI) for taro measured in taro treatments (averaged from Taro Sole Crop, Taro/Rice System, and Taro/Maize/Weed System) at seven harvest dates.

RICE

Rice's growth rate in the taro/rice plot was reduced relative to the growth of the rice in the sole crop rice plots. This reduction is presented statistically for the variables total biomass (Table 8) and LAI (Table 9) and graphically for total biomass (Fig. 4), plant height (Fig. 5) and leaf number (Fig. 6). The development rate of the rice was accelerated in the taro/rice plots compared to the development rate of the rice in the rice sole crop plots. This acceleration is illustrated by the timing of seed production in the plants (Table 10).

Leaf area index was nineteen times greater in the sole crop then in the taro/rice system (Table 11). The vegetative phase of the intercrop was fourteen days shorter than the sole crop. The panicle emerged in the intercropped rice sixty-eight days after planting. In the sole crop rice the panicle emerged eighty- two days after planting.

Table 8. SAS output for logarithm of Rice Total Biomass (ln(RTB)), split plot in time with pooled error term analysis.

```
                        Analysis of Variance Procedure

Dependent Variable: LRTB
                                     Sum of          Mean
Source                   DF         Squares        Square    F Value      Pr > F

Model                     9     57.83014502    6.42557167      19.28      0.0009

Error                     6      1.99947193    0.33324532

Corrected Total          15     59.82961695

                   R-Square            C.V.      Root MSE              LRTB Mean

                   0.966581        18.57135      0.577274             3.10841120


Source                   DF        Anova SS   Mean Square    F Value      Pr > F

SYSTEM                    1     50.49542662   50.49542662     151.53      0.0001
REP(SYSTEM)               2      0.90337367    0.45168683       1.36      0.3268
DAP                       3      6.18952706    2.06317569       6.19      0.0288
SYSTEM*DAP                3      0.24181766    0.08060589       0.24      0.8643

Tests of Hypotheses using the Anova MS for REP(SYSTEM) as an error term

Source                   DF        Anova SS   Mean Square    F Value      Pr > F

SYSTEM                    1     50.49542662   50.49542662     111.79      0.0088
```

Table 9. SAS output for logarithm of Rice Leaf Area Index (ln(RLAI)), split plot in time pooled error term analysis.

```
                        Analysis of Variance Procedure

Dependent Variable: LRLAI
                                         Sum of            Mean
Source                     DF           Squares          Square   F Value     Pr > F

Model                       9       40.05288589      4.45032065     10.06     0.0055

Error                       6        2.65462319      0.44243720

Corrected Total            15       42.70750908

                     R-Square              C.V.        Root MSE           LRLAI Mean

                     0.937842         -47.51041        0.665160           -1.4000290


Source                     DF          Anova SS     Mean Square   F Value     Pr > F

REP                         1        1.37158366      1.37158366      3.10     0.1288
SYSTEM                      1       35.02426932     35.02426932     79.16     0.0001
REP*SYSTEM                  1        0.09235760      0.09235760      0.21     0.6638
DAP                         3        3.45726282      1.15242094      2.60     0.1469
SYSTEM*DAP                  3        0.10741249      0.03580416      0.08     0.9680

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                     DF          Anova SS     Mean Square   F Value     Pr > F

SYSTEM                      1       35.02426932     35.02426932    379.22     0.0327
```

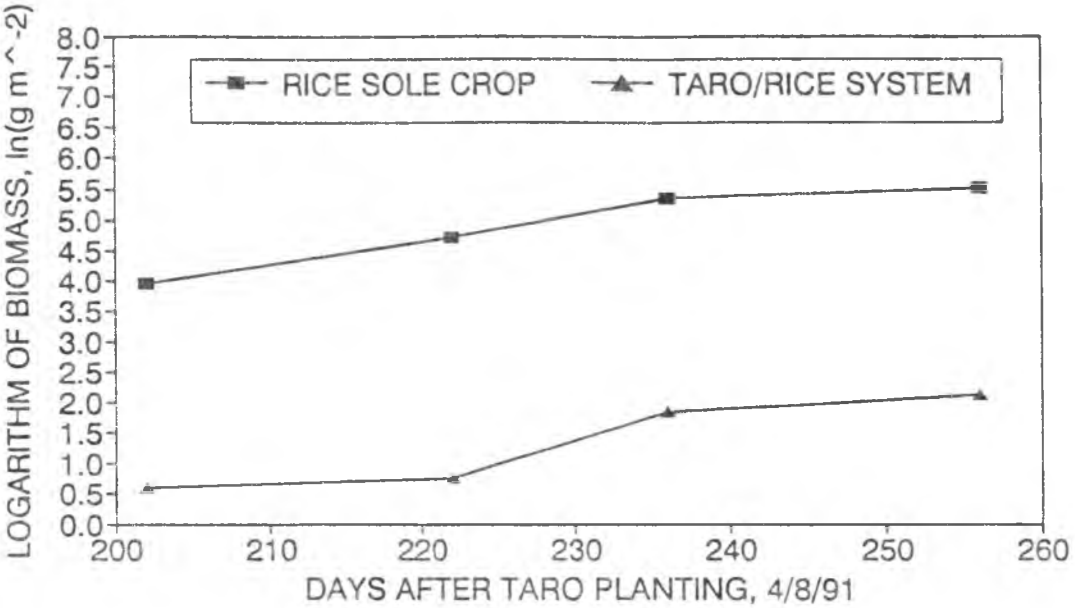


Fig. 4. Rice total biomass measured at four harvest dates. Rice was planted at 159 DAP Taro. System-by-DAP interaction was no larger than experimental error.

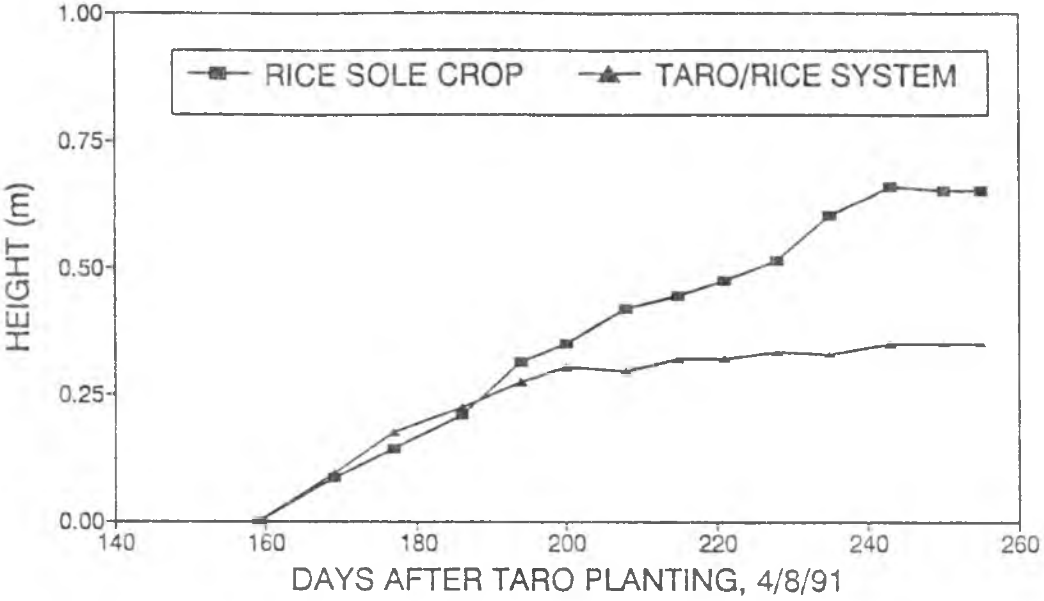


Fig. 5. Treatment means for rice plant height. Rice was planted 159 DAP Taro.

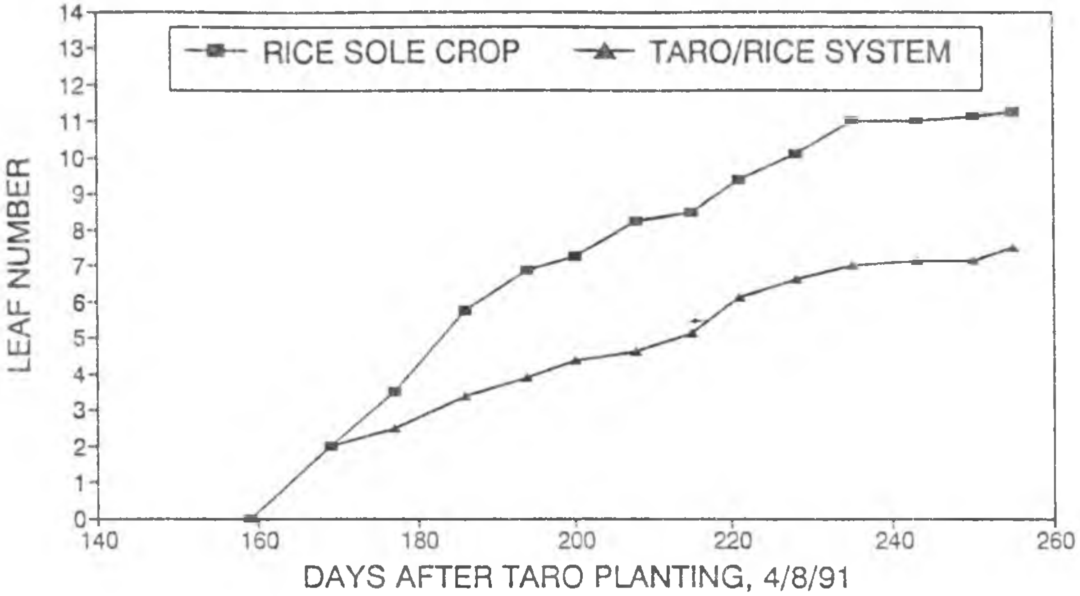


Fig. 6. Treatment means for rice leaf number. Rice was planted at 159 DAP Taro.

TABLE 10. Treatment means for rice seed dry weight as measured at the last two harvests.

Harvest Date (DAP Rice)	Taro/Rice Systems	Rice Sole Crop
	---------------g m^{-2}-------------	
76	0.1825	0.0000
95	0.8775	51.2975

TABLE 11. Effect of system on rice Leaf Area Index (LAI)

	Taro/Rice System	Rice Sole Crop
	---------------m^2 g^{-1}-------------	
Mean Value	0.0685	1.3161

MAIZE/WEEDS

The growth rate of the maize in the taro/maize/weeds plots was reduced relative to the growth rate of the maize in the sole crop plots. This reduction is presented statistically for the variables maize total biomass (Table 12) and maize leaf area index (Table 13) and graphically for maize total biomass (Fig. 7), maize leaf area index (Fig. 8), plant height (Fig.9), and leaf number (Fig. 10). The weed growth in the taro/maize/weed plots was reduced relative to the weed growth in the maize/weed plots. This is presented statistically for weed total biomass (Table 14) and graphically for weed total biomass (Fig. 11). The overall reduction of growth rate for both the maize and the weeds in the taro/maize/weed plots is presented statistically for the variable maize weed total biomass (Table 15) and graphically for maize weed total biomass (Fig.12). Figure number nine especially illustrates the difference between the maize in the taro plots and the maize in the sole crop plots, the maize plants in the intercrop system were spindly and short in size compared to those in the sole crop plots, which were robust and tall.

There was also an effect of system on seed production (Table 16). The vegetative phase of the intercropped maize was longer than the vegetative phase in the sole crop. Tassel emergence occurred in the sole crop maize seven days before the intercropped maize.

Table 12. SAS output for logarithm of Maize Total Biomass (ln(MTB)), split plot in time with pooled error term analysis.

```
                        Analysis of Variance Procedure

Dependent Variable: LMTB
                                     Sum of            Mean
Source                   DF         Squares          Square    F Value      Pr > F

Model                     9     99.63634773     11.07070530     127.64      0.0001

Error                     6      0.52038847      0.08673141

Corrected Total          15    100.15673621

                   R-Square            C.V.        Root MSE                LMTB Mean

                   0.994804        8.059959        0.294502               3.65388930


Source                   DF        Anova SS     Mean Square    F Value      Pr > F

SYSTEM                    1     86.96700923     86.96700923    1002.72      0.0001
REP(SYSTEM)               2      2.74221367      1.37110684      15.81      0.0041
DAP                       3      8.18912971      2.72970990      31.47      0.0005
SYSTEM*DAP                3      1.73799512      0.57933171       6.68      0.0243

Tests of Hypotheses using the Anova MS for REP(SYSTEM) as an error term

Source                   DF        Anova SS     Mean Square    F Value      Pr > F

SYSTEM                    1     86.96700923     86.96700923      63.43      0.0154
```

Table 13. SAS output for logarithm of Maize Leaf Area Index (ln(MLAI)), split plot in time pooled error term analysis.

```
                 Analysis of Variance Procedure

Dependent Variable: LMLAI
                                       Sum of          Mean
Source                       DF       Squares        Square    F Value      Pr > F

Model                         9   74.60111931    8.28901326      66.17      0.0001

Error                         6    0.75159253    0.12526542

Corrected Total              15   75.35271184

                       R-Square          C.V.      Root MSE             LMLAI Mean
                       0.990026     -53.65119      0.353929             -.65968450


Source                       DF      Anova SS   Mean Square    F Value      Pr > F

SYSTEM                        1   63.21945511   63.21945511     504.68      0.0001
REP(SYSTEM)                   2    1.19774152    0.59887076       4.78      0.0573
DAP                           3    4.77024419    1.59008140      12.69      0.0052
SYSTEM*DAP                    3    5.41367848    1.80455949      14.41      0.0038

Tests of Hypotheses using the Anova MS for REP(SYSTEM) as an error term

Source                       DF      Anova SS   Mean Square    F Value      Pr > F

SYSTEM                        1   63.21945511   63.21945511     105.56      0.0093
```

Table 14. SAS output for logarithm of Weeds in Maize Plot (ln(WEEDS)), split plot in time pooled error term analysis.

```
                        Analysis of Variance Procedure

Dependent Variable: LWEEDS
                                      Sum of            Mean
Source                  DF           Squares          Square   F Value      Pr > F

Model                    9       115.4343779      12.8260420      3.66      0.0640

Error                    6        21.0099165       3.5016527

Corrected Total         15       136.4442944

                  R-Square              C.V.        Root MSE           LWEEDS Mean

                  0.846018          75.65274        1.871270            2.47349976


Source                  DF          Anova SS     Mean Square   F Value      Pr > F

REP                      1        2.55454897      2.55454897      0.73      0.4258
SYSTEM                   1       66.65299159     66.65299159     19.03      0.0048
REP*SYSTEM               1        0.27719497      0.27719497      0.08      0.7879
DAP                      3       23.63419789      7.87806596      2.25      0.1830
SYSTEM*DAP               3       22.31544451      7.43848150      2.12      0.1985

Tests of Hypotheses using the Anova MS for REP*SYSTEM as an error term

Source                  DF          Anova SS     Mean Square   F Value      Pr > F

SYSTEM                   1       66.65299159     66.65299159    240.46      0.0410
```

Table 15. SAS output for logarithm of Maize Weed Biomass (ln(MWB)), split plot in time pooled error term analysis.

```
                       General Linear Models Procedure

Dependent Variable: LMWB
                                   Sum of           Mean
Source                  DF        Squares         Square    F Value      Pr > F

Model                   12    89.05104461     7.42092038      92.19      0.0016

Error                    3     0.24149377     0.08049792

Corrected Total         15    89.29253838

                  R-Square           C.V.       Root MSE              LMWB Mean
                  0.997295       6.928518       0.283722             4.09498173


Source                  DF      Type I SS    Mean Square    F Value      Pr > F

SYSTEM                   1    75.44174048    75.44174048     937.19      0.0001
REP(SYSTEM)              2     1.44334839     0.72167420       8.97      0.0543
DAP                      3     8.87529013     2.95843004      36.75      0.0073
REP*DAP                  3     0.64763500     0.21587833       2.68      0.2197
SYSTEM*DAP               3     2.64303061     0.88101020      10.94      0.0401
Tests of Hypotheses using the Type III MS for REP*DAP as an error term

Source                  DF    Type III SS    Mean Square    F Value      Pr > F

DAP                      3    8.87529013     2.95843004      13.70      0.0295
```

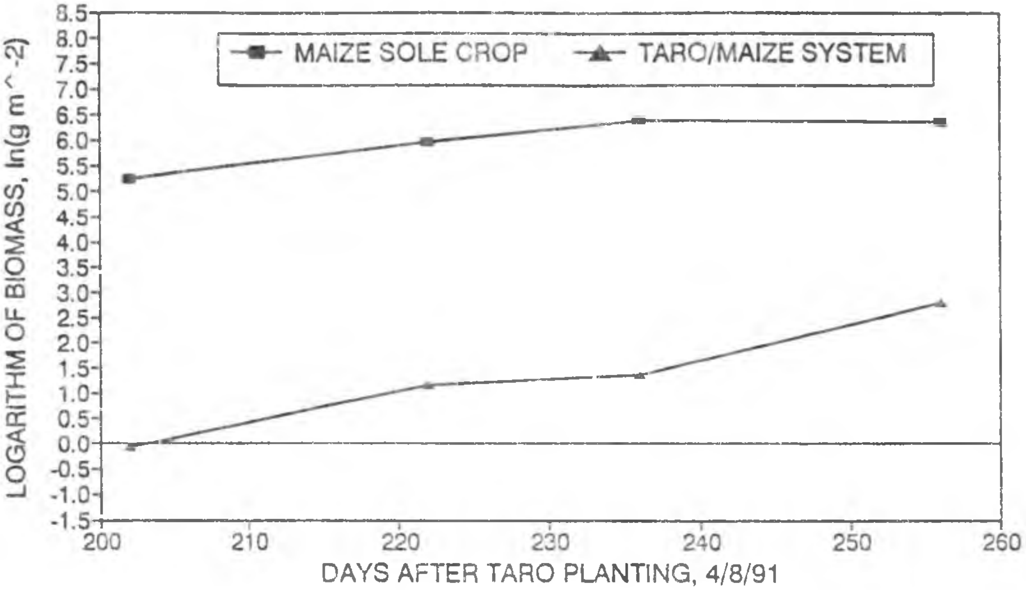


Fig. 7. Maize biomass measured at four harvest dates. Maize was planted at 172 DAP Taro.

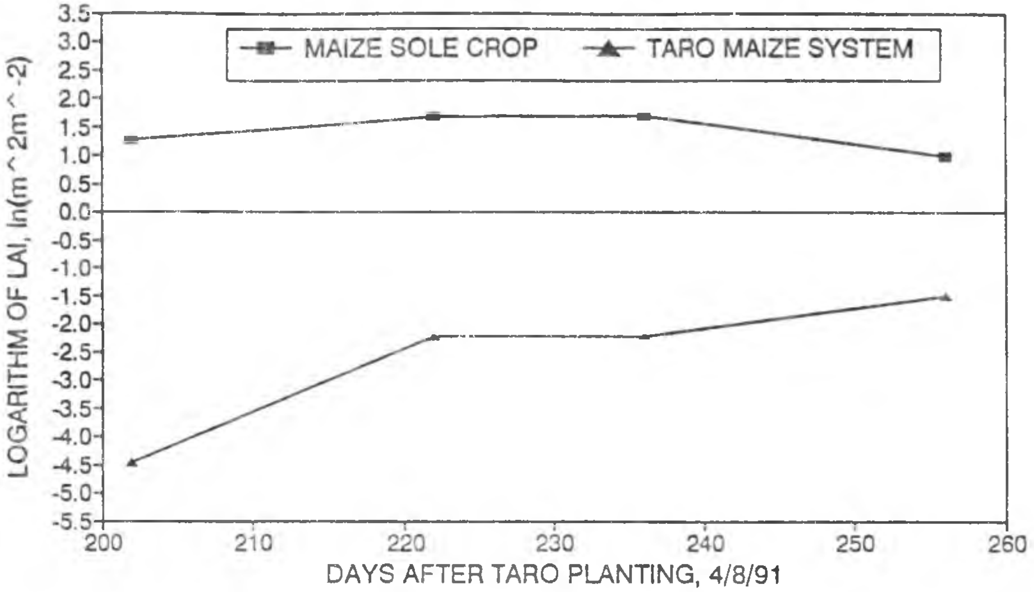


Fig. 8. Leaf Area Index (LAI) measured at four harvest dates for maize. Maize was planted at 172 DAP Taro.

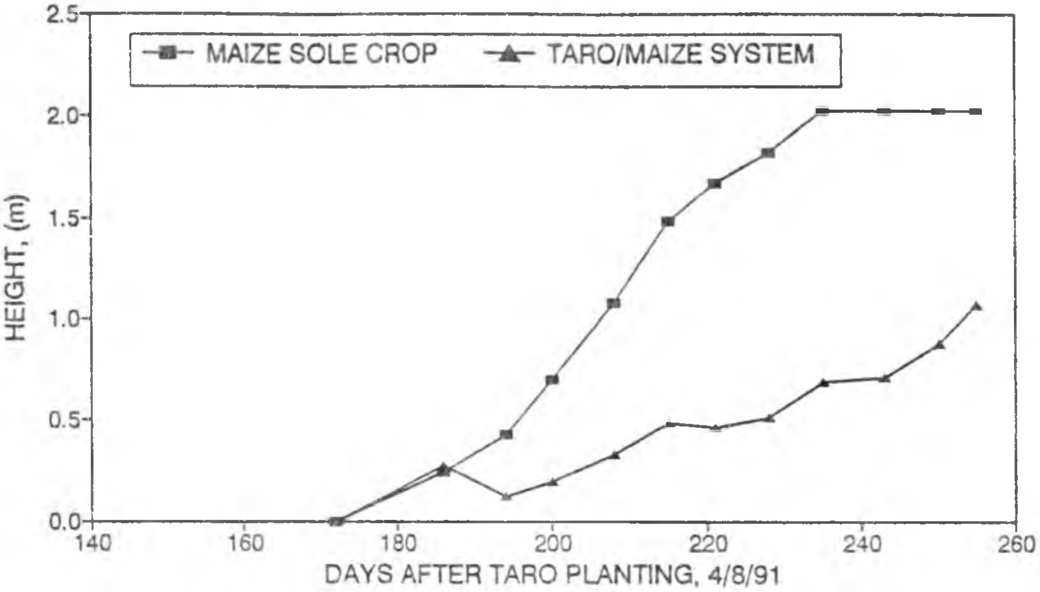


Fig. 9. Treatment means for maize plant height. Maize was planted at 172 DAP Taro.

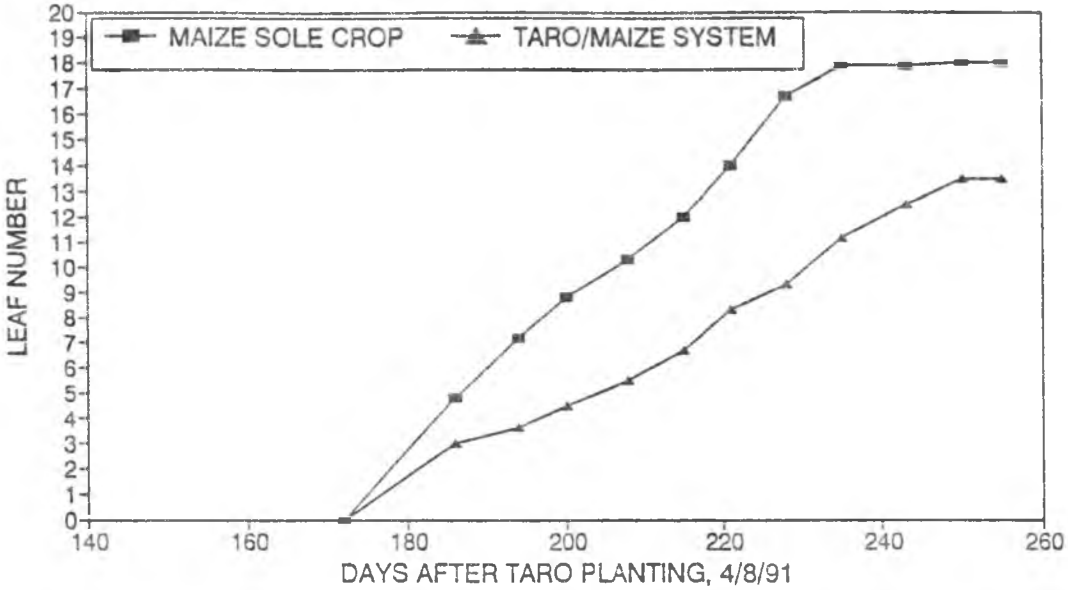


Fig. 10. Treatment means for maize leaf number. Maize was planted at 172 DAP Taro.

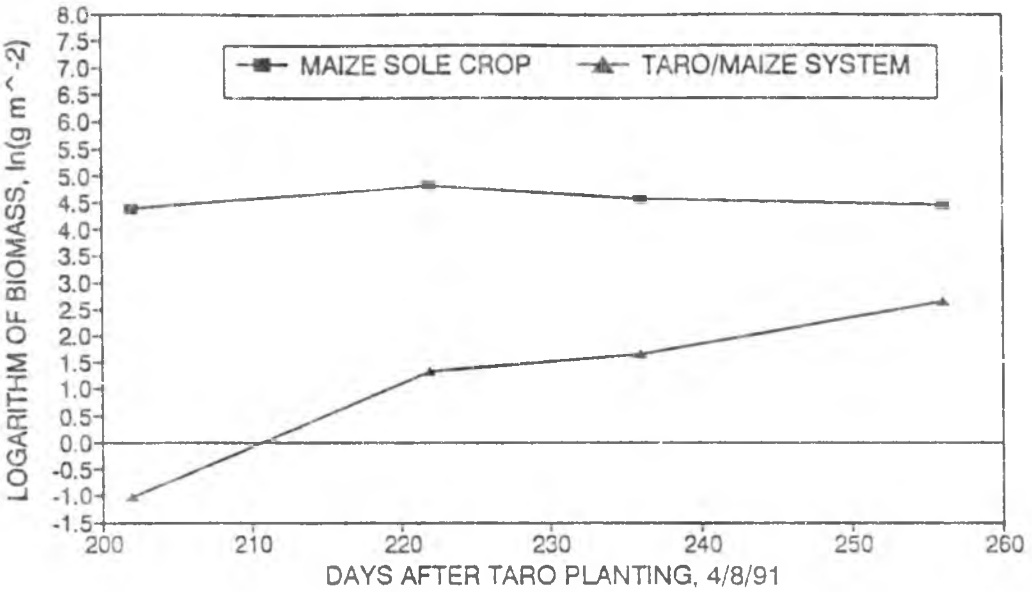


Fig. 11. Weed biomass in maize plots measured at four harvest dates. Weeds were allowed to grow in maize sole crop plots and taro/maize/weed system plots after the maize was planted at 172 DAP Taro. System-by-DAP interaction was no larger than experimental error.

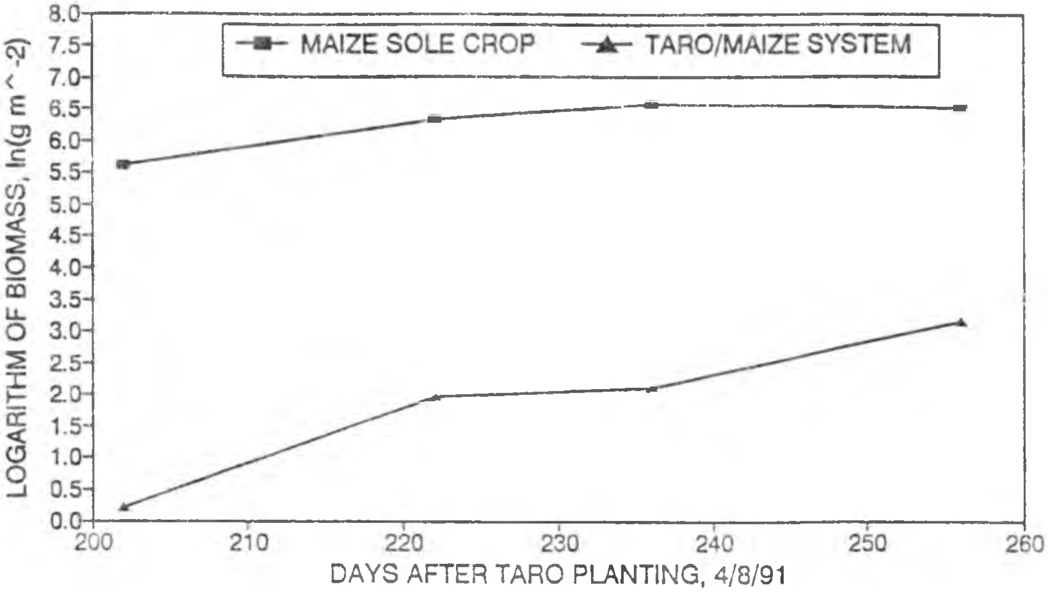


Fig. 12. Total biomass of taro competitors (maize biomass + weed biomass) in maize plots measured at four harvest dates. Weeds were allowed to grow in maize sole crop plots and taro/maize/weed system plots after the maize was planted at 172 DAP Taro.

Table 16. Treatment means for maize seed weight measured at final harvest.

Harvest Date (DAP Maize)	Taro/Maize System	Maize Sole Crop
	$g\ m^{-2}$	$g\ m^{-2}$
81	0.1825	46.3450

CHAPTER FOUR

DISCUSSION

TARO

The yields from all three systems exceeded yields typically found in the Hawaiian Islands. An average of the final yields from all taro treatments revealed that the yields from this experiment were 49350 kg ha^{-1}. This is quite high compared to the yields of a Hawaiian taro farm on Kauai, which has good agronomic practices, which had average recorded yields of 31000 kg ha^{-1} (Wang, 1983).

The results of this study support the experimental findings of Gurnah (1985), Rodriguez and Martell (1988), and Talatala et al. (1983). In their studies of weed effects on taro, they determined that plants germinating late in the cropping period of taro had no effect on final yields of taro. Furthermore this study seems to show that taro's competitive ability is high in its final growth phase and it has the ability to suppress its competitors, in this case rice and maize. The main factor which appeared to enable taro to have competitive dominance over the other plants was the shade the taro canopy imposed.

As mentioned in the introduction, when taro moves towards maturity its leaves become smaller and its canopy diminishes. The impression of the author, from a review of current literature, was that this occurs rapidly, thus allowing weeds or intercrops a chance to grow under the canopy of maturing taro. What actually happened in the field was the canopy cover diminished rather slowly. The taro leaf area index at the final harvest averaged 1.257 for the taro plots and the plant heights were still over a meter (Fig. 13). Using light interception calculations from the crop simulation model SUBSTOR-Aroid, the amount of light predicted to be reaching the cereal crop component at final harvest was fifty-three percent. This amount, even at the final harvest, may still have severely restricted the growth of either the intercropped maize or the weeds. This illustrates that the canopy of the taro was still fairly large until right near the end of the taro's growth cycle, when it then rapidly began to decline. The author observed in the field that the canopy decline correlated with the senescence of the primary shoot. If interspecific competition was to restrict taro growth, it would presumably occur during this rapid decline period, but the restriction, if any, would be slight since at this point the taro is nearing harvest. There would be little time for weeds or other crops to become established and begin to influence taro yields. The weeds would also not have the growing time to become a burden to the harvest procedures of the farmer.

The weed control in the six months prior to the planting of the rice and maize may have also significantly reduced the weed problems late in the taro's growing season. The weeding

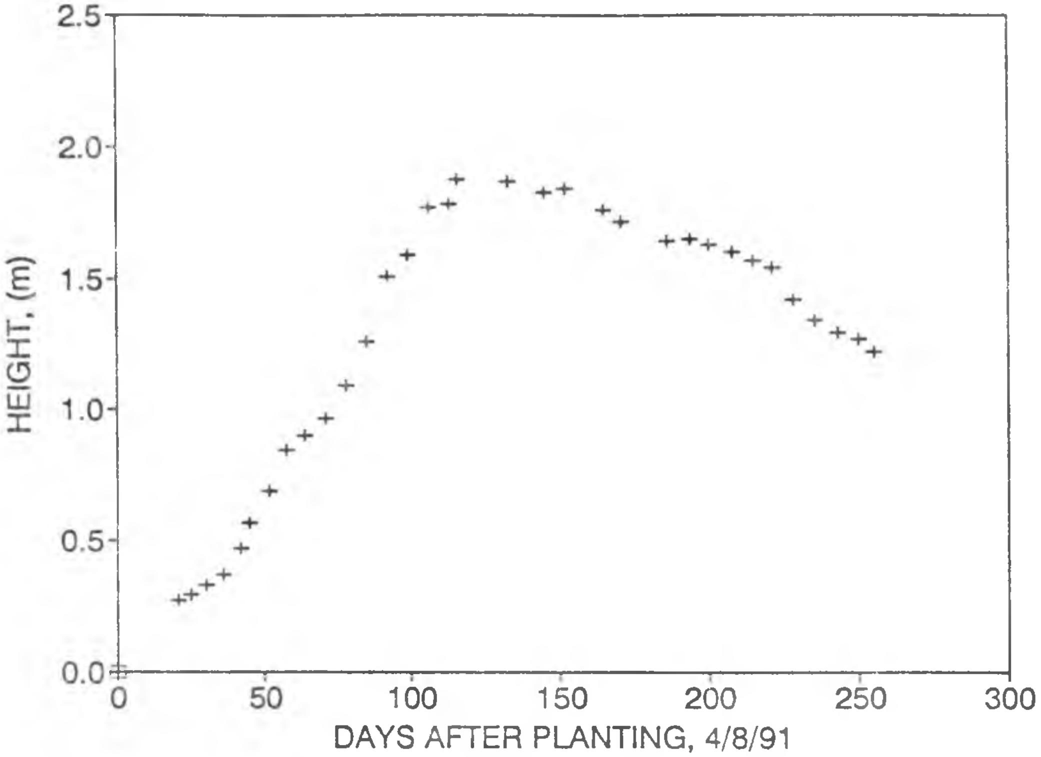


Fig. 13. Taro plant height as observed in Taro/Rice System, Taro/Maize/Weed System, and Taro Sole Crop. Rice was planted at 159 DAP and maize was planted at 172 DAP Taro.

in the initial period of the growing season, reduced the weeds ability to become established, produce seeds, and propagate. So when the weeding was stopped, the weeds were unable to rapidly make a comeback, due to not only a low number of seeds, but the taro's dense canopy shading out growth. To summarize, this study found that weed control late in the growing season of a dryland taro system should not be a priority in farm operations, since weeds germinating in this period did not influence the growth and development of the taro.

As for the strategy of intercropping late in the growing season of taro, it could be possible since the late-season intercrop components would not affect the yields of the taro. But the yields of the late-season intercrop components, as discussed further in the next section, would almost certainly be low. Planting the intercrops could also pose a problem. Disturbing the soil this late in the taro growing season may damage the corms. This damage to the corm could not only lower the taro's appearance quality, but provide a point of entry for many pests and diseases into the corm. Another consideration is that the harvest procedures for taro could easily damage an intercrop planted within the taro late in its growing season. An option that may make intercropping feasible this late in the taro's growing season is a lower taro planting density and a wider plant spacing of the taro.

RICE

Rice was severely shaded by the taro, hindering the light interception ability of the rice, which may explain its low growth and biomass production rates. What is unclear is if the shade effect was also responsible for the quick maturity of the intercrop. It's possible the low photosynthetic ability of the plant, which may have caused the plant to reach a very minimal height and have a short stem, is the reason behind the short vegetative period. The panicle in the intercrop only had a very short stem to move up in its progression toward flowering, thus allowing these plants to flower more quickly.

The quality of light in the intercrop, due to the taro canopy, would not have been the same as the daylight hitting the sole crop rice. Light transmitted through the taro in the intercrop is enriched in far-red light relative to red light (Salisbury and Ross, 1978). This change in quality of light may have brought about the change in development in the intercropped rice.

Rice is a photoperiod sensitive crop (Vergara and Chang, 1976) and thus may be effected by a change in light quality. This fact may potentially be disregarded though, since most improved rice cultivars are bred to be photoperiod insensitive and the cultivar used for this experiment is an improved cultivar. This cultivar has been bred to mature early and be resistant to major insects and diseases (IRRI, 1976).

The high shade suggests less sunlight under the canopy which would cause cooler temperatures. Cooler temperatures delay flowering in both photoperiod sensitive and photoperiod insensitive varsities of rice (Vergara and Chang, 1976) and a delay in flowering did not occur in the intercropped rice. That a delay of flowering did not occur appears to rule out temperature as an explanation of rice flowering.

The conclusion drawn from the field experiment is that rice's ability to compete with taro in the taro/rice system is very low.

MAIZE

As with rice, the main competition effect on the maize by the taro seemed to be the shading on the crop caused by the taro canopy. Rain runoff from the taro canopy during heavy rain caused the intercrop maize plants to lodge whereas the sole crop maize plants continued to stand erect. This lodging early in the intercropped maize's growth cycle may have also further caused the plants growth to be erratic.

Again, the quality of light the maize was intercepting under the taro canopy may have influenced the lower leaf numbers of the intercrop compared to the sole crop. Though, regardless of the light quality effect, the low leaf numbers were no surprise since the stress imposed by the taro canopy shade on the maize intercrop may have decreased the photosynthetic effectiveness of the maize and thus reduced its ability to grow and develop.

The greater amount of far-red light reaching the soil through the taro canopy may also have contributed to the low weed population in the intercrops. This light quality factor may have inhibited germination of light-requiring weed seeds (Salisbury and Ross, 1978).

The conclusion drawn from these findings is that the ability of maize and weeds to germinate and grow in a phase three taro canopy is very low.

RESEARCH CONTRIBUTION

The taro results seem to match results and conclusions found in other experiments. Yet past experiments were done very differently and this makes a comparison of results difficult. It is nearly impossible to explain the results of this experiment with past research, since experiments of this type are not described in the current literature.

There is no real foundation of knowledge on how crops such as rice and maize deal with stress imposed on them by other crops. There is also little information on the competitive ability of the taro or on the change in taro's competitive ability with growth phase. These are areas that require further research if we are to gain a better understanding of plant growth and development in intercropping and weed systems.

Lastly, a database on not only taro growth and development but also the intercropped maize and rice was gathered. This database can be used in the testing of intercrop and weed/crop model simulations.

As modern agronomists move into the world of crop modeling, databases on how plants react in situations such as in this experiment are needed, since the present literature does not have this information. Without this information, modeling plant growth and development is very risky. This lack of information increases the risk that inaccurate crop simulation models are being considered valid for estimating situations in the field of agronomy.

CHAPTER FIVE

THE EFFECT OF FIELD STORAGE TIME ON TARO PLANTING MATERIAL.

INTRODUCTION

Before a crop of taro can be planted, planting materials must be harvested and prepared. The preparation consists of cutting off the leaf laminae, the upper portion of the leaf petiole, and the lower portion of the corm or cormel. These planting pieces, called *hulis* in the Hawaiian Islands, can come from both the primary shoot (above the corm) and the axillary shoots (above the cormels). Once the preparation is complete, *hulis* are often left to dry in the field for up to three days. This allows the *hulis* to develop a dry protective coat around the cut corm or cormel, reducing the risk of fungal infection or rotting after planting. A storage method documented for tropical Africa is the storing of taro planting material covered with palm leaves in a shaded place (Horton, 1983).

If taro farmers are unable to plant, due to bad weather or lack of labor, they run the risk of their *hulis* spoiling. The spoiling risk is also encountered when shipping *hulis* from one location to another, a practice done by both farmers and agricultural researchers. The farmer or researcher realizes their *hulis* can spoil because they rot or become infested with insects. The hulis can also exhaust their food reserve, which they consume to survive the storage time. Because a risk exists, farmers and researchers need a valid estimate of how long their *hulis* can be stored before they begin to spoil. They also need some estimate as to what survival rate to expect, based on the amount of time their *hulis* have spent in storage.

A delay in time before planting was looked into by Pardales and Dalion (1986) in their research in rapid vegetative propagation of taro. They studied the effect of length of storage, prior to planting, on the sprouting of single-node rhizome cuttings. These cuttings were stored at room temperature for two, four, six and eight days. They found storage time had no effect on the cuttings. The research question they answered will aid work with tissue culture, but storage of single node rhizome cuttings is a very different situation from the storage of *hulis*. In a research report by Ezumah and Plucknett (1981), the storage question is discussed, but the report only states that no information is available on the subject. At the Second Annual Symposium on Tropical Root and Tuber Crops, Leon (1970) stressed the need for research into the storage and shipping of taro planting materials. He emphasized this would facilitate better research on the crop.

To gain insight into the question of how long taro *hulis* can be stored in the field, a pot experiment was conducted.

HYPOTHESIS

Taro *hulis* can be stored in the field for up to two weeks with no effect on plant survival.

OBJECTIVES

(1) To determine if taro *hulis* can be stored in the field up to two weeks with no effect on plant growth and development.

(2) If there is an effect on *hulis* caused by storage time, determine how it affects plant survival.

MATERIALS AND METHODS

An experiment evaluating the survival of taro stored as *hulis* in the field for three different time intervals was conducted from 7 November 1991 to 15 December 1991. The first phase of the experiment, field storage, was conducted at the Waimanalo Research Station. The second phase, the greenhouse experiment, was conducted at the U.H. Department of Agronomy and Soil Science Mauka Campus greenhouse.

Experimental Design

The experimental design was a completely randomized design with two replicates for the first two observation times before planting and four replicates for the final harvest after planting.

Treatment Design

The treatment design of the experiment was a complete factorial of: (1) *hulis* source (primary or axillary),

(2) field storage time (14, 7, and 3 days), and (3) harvest time (at *huli* preparation, at planting, and at final harvest).

Pre-Storage Field Harvest and Planting Material Preparation

The *hulis* for the experiment were collected and stored at the Waimanalo Research Station. They were collected from a nursery planted in October 1990. The cultivar of taro harvested for the experiment was Bun-Long. The storage time intervals were three, seven, and fourteen days.

The *hulis* were prepared as follows: Fourteen days before planting, eight primary shoots and eight axillary shoots were harvested. These plants were of the same above-ground visible corm or cormel diameter and the same visible leaf stage. The plants were harvested and the corm or cormel cut so the upper 20 mm of corm or cormel remained. The leaf laminae and a portion of the petiole were cut off, leaving 0.15 m length of petiole attached to the corm or cormel. The corm or cormel diameters were measured to determine if the cut basal diameters were the same as the others in their group. *Hulis* from primary shoots and axillary shoots were collected in separate groups. The target basal diameter was 80 mm for primary shoot *hulis* and 70 mm for the axillary shoot *hulis*. A deviation of plus-or-minus 2.5 mm was allowed. The harvested and prepared *hulis* were weighed and left in the field under the cover of an open wooden box. The box was one of many left in the field waiting to be buried for another experiment. The box covered the planting material, keeping out rain and sunlight, but still allowed ventilation. The same procedures were followed seven days from planting and three days from planting. Four *hulis* for each storage time were not stored. Following preparation and weighing, two primary shoot and two axillary shoot planting materials were picked at random and dissected. The interior leaf numbers were counted and the dissected *hulis* were oven dried.

A black felt tip marker was used to write an identification number on the cut petiole and corm or cormel of each *huli*. A total of thirty-six *hulis* were stored in the field.

On 21 November 1991, all the *hulis* were collected from storage and weighed. Four *hulis*, two from each plant group, were again picked at random from each storage treatment and dissected. Once again the interior leaf numbers were counted. The dissected parts were then oven dried. It was assumed the interior leaf numbers for the *hulis* dissected and the *hulis* being planted were the same. This is based on work by Ghani (1984), on the morphological and anatomical changes of taro. These dissections were used to determine the leaf number of the taro before planting.

Pot Experiment

The *hulis* were planted on 21 November 1991 in pots with an inside diameter of 0.25 m and a depth of 0.25 m. The pots were filled with Supersoil brand (Rod McLellan Co., So. San Francisco, Calif.) potting soil. This potting soil was mixed with fertilizer at a rate of 179 kg N ha^{-1}, 77 kg P ha^{-1}, and 149 kg K ha^{-1}.

Measurements of vegetative-stage, greenhouse temperature, soil temperature, and solar radiation were collected throughout the experiment. The last three measurements were accomplished using micro-logger equipment (Campbell Scientific Inc., Logan, UT, model 21X) run manually. The data was collected manually because the reliability of the data collection system at planting was unknown. During the experiment it was determined the data collection system of the micro-logger was, in fact, not working. The mean air temperature in the greenhouse for the duration of the experiment, manually measured daily at various times, was 30.5 °C. The mean soil temperature in the pots, also manually measured daily at various times, was 30.7 °C. Each pot was watered with 0.24 L every three days.

No growth measurements were taken in the first week of the experiment, as no above ground growth was visible. In the three weeks that followed, daily observations were taken. The positions of the pots on the green house bench were shifted every week, so as to avoid experimental error based on bench position.

Harvest

On 19 December 1991, final growth measurements and observations were taken and all plants harvested. The soil was removed from the harvested plants and the roots separated from the corms or cormels and weighed. The petioles were separated from the corm or cormel, leaving the apical portions attached to the petioles. The petioles were then dissected and the interior leaf numbers counted. Leaf area was measured with an area meter (LI-COR Inc., Lincoln, Nebraska, Model LI-3100) for the leaf laminae. The plant parts were then separated into petioles, leaf laminae, and corm or cormel for oven drying. All plant parts were oven dried at 70°C. After a weeks time the plants were removed from the oven and weighed.

The weights of the *hulis* at field preparation (pre-storage) were compared to the weights of the *hulis* at the end of the storage period, just prior to planting in the green house. The difference in these weights were used to determine if biomass reduction occurred during storage time. A comparison was also done between pre-plant, post-storage *hulis* and the final harvest plants. This comparison was used to determine if biomass accumulation occurred in the green house grown plants.

ANALYSIS

The data collected were statistically analyzed using the SAS (SAS Institute, Inc., 1988) statistics program to determine if there were treatment effects. Standard F-tests were conducted on the data as well as Least Significant Difference (LSD) tests on the means of the data. The level of significance for the means comparison was 0.05.

RESULTS

Plant Growth

LEAF AREA

There was a treatment effect on leaf area (Table 17) with primary shoot *hulis* stored two weeks and one week giving the highest leaf area values (Tables 18 and 19).

SPECIFIC LEAF AREA

There was no treatment effect on specific leaf area (Table 17).

PLANT GROWTH

There was a treatment effect on plant growth (biomass accumulation) (Table 20) with the two weeks and one week storage treatments achieving the highest amount of biomass accumulation (Table 21).

STORAGE LOSS

There was a treatment effect on storage loss (biomass reduction) (Table 20) with the two weeks storage time treatments experiencing the greatest reduction in biomass (Table 21). The three day storage time treatments experienced the least reduction in biomass (Table 21).

PARTITIONING

There was a treatment effect on final corm weight (Table 22) with primary shoots having the highest weights (Table 23). The same effects were found for petioles (Tables 22 and 23) and leaf weights (Table 22 and Table 23). The greatest leaf weights were found in the one week storage treatments (Table 24).

Plant Development

There was no difference in leaf number between plants of all treatments. All plants achieved relatively the same leaf number, two leaves, during the pot experiment duration.

Plant Survival

None of the storage treatments affected survival of the planting material. Only three plants of the twenty four total plants were unable to recover from the storage time. The plants that did not survive the storage time were a primary shoot two week storage time *huli*, an axillary shoot two week storage time *huli*, and a primary shoot three day storage time *huli*.

The fact that the majority of the plants survived the storage period supports accepting the experiment's hypothesis that taro planting material can be stored in the field for up to two weeks with no effect on plant survival.

Table 17. The analysis of variance for leaf area and specific leaf area from the final harvest of taro planting material storage experiment.

Source	df	Leaf area	Specific leaf area
		F statistic	
Treatments	5	3.63^*	0.87^{ns}
Hulis source	(1)	6.74^*	0.39^{ns}
Storage time	(2)	3.57^*	1.73^{ns}
Source X time	(2)	2.14^{ns}	0.24^{ns}
C. V. (%)		62.4	69.1

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

^{ns} Non-significant.

Table 18. Sample leaf area and specific leaf area means† for taro planting material sources.

Source	Leaf area	Specific leaf area
	cm^2	cm^2/g
Primary shoot	164.92^a	283.63^a
Axillary shoot	82.92^b	338.50^a

†Values followed by the same letter are not significantly different at the 0.05 probability level.

Table 19. Sample leaf area and specific leaf area means† for storage time in taro planting material experiment.

Source	Leaf area	Specific leaf area
	cm^2	cm^2/g
Two week	107.87^{ba}	240.3^{a}
One week	181.75^{a}	267.4^{a}
Three days	82.12^{b}	425.5^{a}

†Values followed by the same letter are not significantly different at the 0.05 probability level.

Table 20. The analysis of variance for Plant Growth and Storage Loss in taro planting material experiment.

Source	df	Plant Growth	Storage Loss
		F statistic	
Treatments	5	2.42^{ns}	20.17^{**}
Hulis source	(1)	0.04^{ns}	0.59^{ns}
Storage time	(2)	5.33^{*}	49.26^{**}
Source X time	(2)	0.70^{ns}	0.87^{ns}

* ** Significant at the 0.05 and 0.01 probability levels, respectively.
^{ns} Non-significant.

Table 21. Plant Growth and Storage Loss means† for storage time in taro planting material experiment.

Source	Plant Growth	Storage Loss
	g	g
Two weeks	13.46^{a}	18.03^{a}
One week	7.85^{ba}	9.63^{b}
Three days	1.70^{b}	5.94^{c}

†Values followed by the same letter are not significantly different at the 0.05 probability level.

Table 22. The analysis of variance for partitioned plant parts dry weights at final harvest of taro planting material experiment.

Source	df	Corm	Root	Petiole	Leaf
			F statistic		
Treatments	5	1.47^{ns}	2.01^{ns}	1.22^{ns}	5.42^{**}
Hulis source	(1)	6.49^{*}	4.12^{ns}	5.48^{*}	6.48^{*}
Storage time	(2)	0.31^{ns}	1.67^{ns}	0.07^{ns}	6.93^{**}
Source X time	(2)	0.13^{ns}	1.29^{ns}	0.24^{ns}	3.37^{ns}
C. V. (%)		48.6	85.9	39.2	65.4

* **: Significant at the 0.05 and 0.01 probability levels, respectively.
^{ns}: Non-significant.

Table 23. Partition plant part weights means† at final harvest for planting material source.

Source	Corm	Root	Petiole	Leaf
	g	g	g	g
Primary shoot	32.13^{a}	6.13^{a}	3.09^{a}	0.59^{a}
Axillary shoot	19.16^{b}	2.91^{a}	2.12^{b}	0.29^{b}

†Values followed by the same letter are not significantly different at the 0.05 probability level.

Table 24. Partitioned plant part weights means† at final harvest for storage time.

Source	Corm	Root	Petiole	Leaf
	g	g	g	g
Two weeks	28.43^{a}	6.08^{a}	2.63^{a}	0.38^{b}
One week	23.88^{a}	4.89^{a}	2.69^{a}	0.74^{a}
Three days	24.64^{a}	2.59^{a}	2.50^{a}	0.21^{b}

†Values followed by the same letter are not significantly different at the 0.05 probability level.

DISCUSSION

I found myself in a difficult situation in evaluating the results. There is no documentation to guide me in the interpretation of the effects found in this study, as there are no experiments of this kind in the literature. Nor have any distinct principles ever been presented on the growth and development of newly planted taro *hulis*. With this in mind, I set out to interpret the findings by theorizing how things occurred based on the results.

Another problem I found regarded the experimental design. If I had used many more plants, thus allowing daily harvests of the experiment, interpretation may have been easier. A closer evaluation of what was occurring while the plants were stored and while growing could have produced a more detailed picture of the growth of the plants.

Plant Growth

LEAF AREA

The high values for leaf area in primary shoot *hulis* were expected because the primary shoot planting *hulis* were larger than the axillary shoot *hulis*. The large leaf areas in the two week and one week treatment plants may have been due to the amount of stress put on the plant in these longer storage periods. This stress came in the form of the consumption and depletion of the food reserves in the planting material. This same stress may force the plant to put all its growth activity into developing large leaves, improving the photosynthetic ability of the plant and thus restoring its consumed food reserves.

PLANT GROWTH AND STORAGE LOSS

The effects of biomass reduction, being greatest in the two week and one week storage time treatments, were expected, because the plants consumed biomass (food reserves) to survive storage and the storage time was longest in the these treatments. Because biomass reduction occurred to such a great extent in the two week and one week storage time treatments, it is no surprise the highest biomass accumulation after planting also occurred in these treatments. As with the discussion of the high measured leaf areas, this could have been a reaction to the deficiency of food reserves, the reverse of this is the three days storage treatments, these plants did not have such a deficiency of dry matter to replace and thus did not begin to as quickly accumulate dry matter after planting.

Another explanation could be that taro *hulis* experience a rapid drop in biomass soon after preparation, regardless of whether they are in storage or planted. This seems to follow the findings of Sivan (1976) in his unpublished thesis on dry matter accumulation in three cultivars of taro. He found in his experiment that taro always experienced a drop in biomass during the first two weeks after planting. After this period, net biomass accumulation started. If this is true for stored *hulis* as well, the two week storage time treatments would have been ready to accumulate biomass quicker than the three day storage time treatments. The three day storage time treatments would have to go through this two week reduction period before accumulation could begin.

PARTITIONING

The treatment effect of primary shoots having the highest corm, petiole, and leaf dry weights was predictable since the dry weights of these parts were higher for primary shoots at field harvest (pre-storage). Their increased growth could be due to the larger size of the primary shoot *hulis* and the larger growth capacity which could come with the greater biomass associated with larger planting materials.

Plant Development

There was no influence of storage on the vegetative stage the plants were able to achieve, but an interesting event occurred during leaf emergence. In all the plants the first leaf to emerge was dead. It's possible that as the petiole of the plant dried up, during storage time, it killed the first leaf just under the petiole sheath. So when this first leaf emerged, it emerged dead.

SUMMARY

Based on this work, a farmer or researcher who is delayed from planting and must store their taro *hulis*, can be assured a good survival rate of their crop even if the storage time is two weeks.

CHAPTER SIX

SUMMARY

SUMMARY: FIELD EXPERIMENT

Taro's competitive ability is high compared to the competitive ability of plants germinating late in the taro's growing season.

RECOMMENDATIONS: FIELD EXPERIMENT

1. Minimal or no weed control may be necessary late in the growing season of taro.
2. Intercropping may be feasible, but not recommended, late in the growing season of taro. It is not recommended due to the low yields that would almost certainly come from the late-season intercrop component. Also, the planting procedures of the intercrop components may damage the taro crop and the harvest procedures could damage the intercrop component, if it was harvested after the taro.

SUMMARY: POT EXPERIMENT

Taro planting material may be stored in the field for up to two weeks with no effect on plant survival.

RECOMMENDATIONS: POT EXPERIMENT

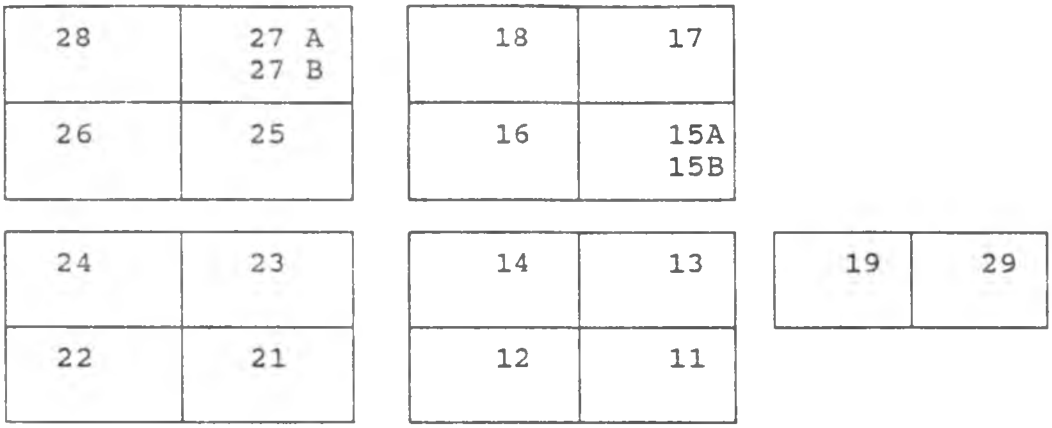
If a farmer or researcher is delayed from planting and must store their planting material, they may be assured a good survival rate of their crop, even if storage time is two weeks.

CONCLUSION

This thesis began with the assertion that taro is the most widely cultivated root crop in the humid tropics. This being true, why is it taro has received a relatively minimal research effort by agronomists and other associated researchers? The answer to this question could lie in the world economic view of taro. It is not typically considered a cash crop but a subsistence crop. The subsistence systems of taro production have been well tested through centuries of trial and error. So present taro production systems may be adequate. It is very possible, if taro production systems become more economically based, the same production principles of the subsistence system could be utilized. But it is also possible that to obtain the high yields and quality standards necessary for the crop to evolve into a cash crop, research in improving its production is needed.

This thesis attempted to answer some basic questions about taro production. The field experiment tested hypotheses about interspecific competition in the last phase of taro growth and generated a Minimum Data Set for the testing of simulation models. The pot experiment was a detailed look at a specific production problem, that being the storing of taro planting material. As with past research on taro, this work is only a beginning. More in-depth research needs to be pursued if a greater understanding of taro's growth and development is to be achieved. This detailed research will not only add to our understanding of taro production principles, but may enhance the use and transfer of knowledge of principles developed by past taro researchers.

APPENDIX I



PLOT NUMBER	TREATMENT	STUDENT RESPONSIBLE
11	Taro/Rice System (Late-Planted Maize)	L. Poland
12	Low Shade:Taro/Maize Intercrop	F. Amosa
13	High Shade:Taro/Maize Intercrop	F. Amosa
14	Taro/Maize System (Late-Planted Maize)	L. Poland
15A	Maize Sole Crop	F. Amosa, N. Hahn
15B	Maize Sole Crop (Late-Planted Maize)	L. Poland
16	Water stress:Taro/Maize Intercrop	N. Hahn
17	Water stress:Taro Sole Crop	N. Hahn
18	Taro Sole Crop	All
19	Rice Sole Crop (Late-Planted Rice)	L. Poland
21	Taro/Maize System (Late-Planted Maize)	L. Poland
22	Low shade:Taro/Maize Intercrop	F. Amosa
23	Taro Sole Crop	All
24	High Shade:Taro/Maize Intercrop	F. Amosa
25	Taro/Rice System (Late Planted Rice)	L. Poland
26	Water stress:Taro/Maize Intercrop	N. Hahn
27A	Maize Sole Crop	F. Amosa, N. Hahn
27B	Rice Sole Crop (Late Planted Rice)	L. Poland
28	Water stress:Taro Sole Crop	N. Hahn
29	Late Planted Maize Sole Crop	L. Poland

Fig.AI.1 Layout of treatments in Taro field experiment.

APPENDIX II

Table AII.1 Harvest Schedule for taro field experiment.

Date	Plot Number
5/3/91	12,13,15A,22,24,27A
6/5/91	ALL PLOTS, EXCEPT 15B,19,27B,29
7/9/91	12,13,15A,22,24,27A
7/23/91	ALL PLOTS, EXCEPT 15B,19,27B,29
8/7/91	15A, 27A
8/21/91	12,13,22,24
8/31/91	11,14,16,17,18,21,23,25,26,28
10/26/91	ALL PLOTS, EXCEPT 15A AND 27A
11/15/92	11,12,13,14,15B,18,19,21,22,23,24,25,27B,29
11/29/91	11,14,15B,18,19,21,23,25,27B,29
12/18/91	ALL PLOTS, EXCEPT 15A AND 27A
1/10/92	11,14,21,25

APPENDIX III

Table AIII.1. Number of harvests done on a per plot basis.

Plot	Harvest Number
11	8
12	8
13	8
14	8
15A	5
15B	4
16	5
17	5
18	8
19	4
21	8
22	8
23	8
24	8
25	8
26	5
27A	5
27B	4
28	5
29	4

APPENDIX IV

Table AIV.1. Dependent Variable Design: Basic data definitions for taro.

Name/Description	Variable	Units	Formula
(Unless specified otherwise all weights are on a dry weight basis)			
Petiole Subsample Fresh Weight	TPFSS	g	
Leaf Subsample Fresh Weight	TLFSS	g	
Corm Subsample Fresh Weight	TCFSS	g	
Cormel Subsample Fresh Weight	TCLFSS	g	
Petiole Subsample Weight	TPSS	g	
Leaf Subsample Weight	TLSS	g	
Corm Subsample Weight	TCSS	g	
Cormel Subsample Weight	TCLSS	g	
Petiole Total Fresh Weight	TPTFW	g	
Leaf Total Fresh Weight	TLTFW	g	
Corm Total Fresh Weight	TCTFW	g	
Cormel Total Fresh Weight	TCLTFW	g	

Table AIV.1. Dependent Variable Design: Basic data definitions for taro. (Continued)

Name/Description	Variable	Units	Formula
(Unless specified otherwise all weights are on a dry weight basis)			
Area Harvested	AH	m^2	treatment design designated harvest area
Plant Population density	TPPD	plants m^{-2}	# plants harvested/AH
Corm Number	TCN	plants m^{-2}	# corms harvested /AH
Cormel Number	TCLN	plants m^{-2}	#cormels harvested/AH
Leaf Area	TLA	cm^2	measured leaf area
Leaf Number	TL		measured v-stage

Table AIV.2. Dependent Variable Design: Taro variables statistically analyzed.

Name/Description	Variable	Units	Formula
(Unless specified otherwise all weights are on a dry weight basis)			
Corm Fresh Weight	TCFW	$g\ m^{-2}$	Fresh weight of corm harvested/AH
Cormel Fresh Weight	TCLFW	$g\ m^{-2}$	Fresh weight of cormels harvested/AH
Corm Weight	TCW	$g\ m^{-2}$	((TCSS/TCFSS) *(TCTFW))/AH
Cormel Weight	TCLW	$g\ m^{-2}$	((TCLSS/TCLFSS) *TCLTFW))/AH
Corm Fresh Weight/ Dry Weight Ratio	TFWDWR		(TCFW/TCW)
Leaf Weight	TLW	$g\ m^{-2}$	((TLSS/TLFSS) *(TLTFW)/AH
Petiole Weight	TPW	$g\ m^{-2}$	((TPSS/TPFSS) *(TPTFW))/AH
Leaf Area Index	TLAI	$m^2 m^{-2}$	$(TLA/AH)*(m^2/10000cm^2)$
Specific Leaf Area	TSL	$m^2\ g^{-1}$	(TLAI / TLW)
Total Biomass	TTB	$g\ m^{-2}$	TCW+TCLW+TLW+TPW
Total Above Ground Biomass	TTAGB	$g\ m^{-2}$	TLW+TPW
Total Below Ground Biomass	TTBGB	$g\ m^{-2}$	TCW+TCLW
Leaf Weight Ratio	TLWR		TLW / TTB
Harvest Index	THI		TCW / TTB

Table AIV.3. Dependent Variable Design: Basic data definitions for maize.

Name/Description	Variable	Units	Formula
(Unless specified otherwise all weights are on a dry weight basis)			
Stem Subsample Fresh Weight	MSMFSS	g	
Leaf Subsample Fresh Weight	MLFSS	g	
Stem Subsample Weight	MSMSS	g	
Leaf Subsample Weight	MLSS	g	
Stem Total Fresh Weight	MSMTFW	g	
Leaf Total Fresh Weight	MLTFW	g	
Seed and Cob Total Fresh Weight	MSCTFW	g	
Shuck Total Fresh Weight	MSTFW	g	
Area Harvested	AH	m^2	Treatment design designated harvest area
Plant Population Density	MPPD	plants m^{-2}	# plants harvested/AH
Weed Biomass	WEEDS	g m^{-2}	weed weight harvested/AH
Leaf Area	MLA	cm^2	measured leaf area
Leaf Number	ML		#measured v-stage

Table AIV.4. Dependent Variable Design: Maize variables statistically analyzed.

Name/Description	Variable	Units	Formula
(Unless specified otherwise all weights are on a dry weight basis)			
Seed and Cob and Fresh Weight	MSCF	$g\ m^{-2}$	Fresh weight of seeds Cobs harvested/AH
Ear Number	MEN	$g\ m^{-2}$	# Ears harvested/AH
Seed Weight	MSW	$g\ m^{-2}$	Seed weight/AH
Leaf Weight	MLW	$g\ m^{-2}$	((MLSS/MLFSS) *MLTFW)/AH
Stem Weight	MSMW	$g\ m^{-2}$	((MSMSS/MSMFSS) *MSMTFW)/AH
Cob and Shuck Weight	MCSW	$g\ m^{-2}$	cob weight+shuck weight/AH
Leaf Area Index	MLAI	$m^2 m^{-2}$	$(MLA/AH)*(m^2/10000cm^2)$
Specific Leaf Area	MSLA	$m^2\ g^{-1}$	(MLAI / MLW)
Total Biomass	MTB	$g\ m^{-2}$	MSW+MLW+MSMW+MCSW
Weed Biomass	WEEDS	$g\ m^{-2}$	WEEDS/AH
Leaf Weight Ratio	MLWR		MLW / MTB
Harvest Index	MHI		MSW / MTB
Maize Weed Biomass	MWB		MTB + WEEDS

Table AIV.5. Dependent Variable Design: Basic data definitions for rice.

Name/Description	Variable	Units	Formula
(Unless specified otherwise all weights are on a dry weight basis)			
Stem Subsample Fresh Weight	RSMFSS	g	
Leaf Subsample Fresh Weight	RLFSS	g	
Stem Subsample Weight	RSMSS	g	
Leaf Subsample Weight	RLSS	g	
Stem Total Fresh Weight	RSMTFW	g	
Leaf Total Fresh Weight	RLTFW	g	
Seed Total Fresh Weight	RSTFW	g	
Area Harvested	AH	m^2	Treatment design designated harvest area
Plant Population Density	RPPD	plants m^{-2}	# plants harvested/AH
Leaf Area	RLA	cm^2	measured leaf area
Leaf Number	RL#		measured v-stage

Table AIV.6. Dependent Variable Design: Rice variables statistically analyzed.

Name/Description	Variable	Units	Formula
(Unless specified otherwise all weights are on a dry weight basis)			
Seed Fresh Weight	RSFW	g m^{-2}	Fresh weight of seeds/AH
Seed Weight	RSW	g m^{-2}	seed weight / AH
Leaf Weight	RLW	g m^{-2}	((RLSS/RLFSS) *RLTFW)/AH
Stem Weight	RSMW	g m^{-2}	((RSMSS/RSMFSS) *RSMTFW)/AH
Leaf Area Index	RLAI	m^2m^{-2}	(RLA/AH) *(m^2/10000 cm^2)
Specific Leaf Area	RSLA	m^2 g^{-1}	(RLAI / RLW)
Total Biomass	RTB	g m^{-2}	RSW+RLW+RSMW
Leaf Weight Ratio	RLWR		RLW / RTB
Harvest Index	RHI		RSW / RTB

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