THE EFFECT OF WATERING REGIMES ON THE GROWTH AND DEVELOPMENT OF *ALPINIA PURPURATA* (VIEILL.) K. SCHUM. INFLORESCENCES

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By

Dave S. Inouye

Thesis Committee:

Richard Criley, Chairperson
Elizabeth Graser
Kent Kobayashi

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 Horticulture.

THESIS COMMITTEE

Richard A. Criley
Chairperson

Elizabeth A. Graser

Kent D. Kobayashi

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Abstract

The objective of this research was to determine the water requirement of *Alpinia purpurata* (red ginger) to produce high quality inflorescences. A farm using overhead irrigation with impact sprinklers at 4.3 mm per hour for one hour three times per week proved superior to the drip-irrigated three cultivars of *Alpinia purpurata*, red ginger, 'Eileen McDonald', and Ginoza No.___, were grown under different irrigation levels at the Waimanalo Research Station located in Waimanalo, Hawaii from August 1991 to May 1993. Five drip-irrigation treatments corresponded to replacement of 0.33 to 1.67 of pan evaporation.

Weekly samples of the shoots were monitored to determine the stages of growth and development of the plant. The stages of inflorescence development in chronological order were: inflorescence initiation, appearance of color at the shoot tip, swelling of the inflorescence, appearance of the inflorescence, and harvest of the shoot. The influence of water application rates was monitored by stomatal conductance, relative water content, total leaf area per shoot, inflorescence diameter and length, shoot diameter and length, number of expanded leaves, and number of inflorescences per clump. Seasonal trends were compared with environmental data collected by a weather station. The components of the soil water balance were determined.

The stages of inflorescence development were not affected by water application rates but were affected by the cultivars and seasonality. The average durations (weeks) for the appearance of color at the shoot tip, swelling of the inflorescence, appearance of the inflorescence, and harvest of the shoot were 20.8, 21.5, 23.2, and 26.4 respectively. The Ginoza cultivar took significantly longer from shoot emergence to all four stages compared to the other two cultivars. The Ginoza cultivar also produced the longest shoots, most number of expanded leaves, and shorter inflorescences than 'Eileen McDonald'. Shoots which emerged at the start of increasing temperatures and solar radiation (March and April) averaged shorter times to the four stages compared to shoots which emerged at the start of decreasing temperature and solar radiation (November).

The highest irrigation treatment produced higher quality inflorescences, but all treatments appeared to experience frequent water stress due to deep drainage.

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Chapter 1

Introduction

Water is vital for plant growth and production; however, only approximately 1% of the water entering the plant is actually involved in metabolic activities such as photosynthesis, hydration, maintaining plant turgor, and plant cell transport. The rest of the water passes through the plant and is vaporized into the air. Therefore, estimating the evapotranspiration (ET) of the plant is essential to water management (Rosenberg, 1983).

Water availability is the most critical factor for plant growth and reproduction. Crop yield increases as the soil moisture availability increases during the course of a growing season (Dale & Shaw, 1965). Knowing when to schedule irrigations involves accurate estimation of ET and from these estimates, determine the soil water supply. The soil water content can be determined periodically by volumetric soil water content sampling.

The amount of yield reduction due to water stress depends at which growth stage it occurs. In general, yields are affected most severely when water stress occurs after the vegetative growth stage (Howell & Hiller, 1975). Because *Alpinia purpurata* is a perennial, soil moisture must be available year-round to produce inflorescences year-round.

How much water does *Alpinia purpurata* need to produce high quality inflorescences?

This was the question that started my research. The focus of this project was to determine the effects of water application rates on *Alpinia purpurata* inflorescences, and whether these effects among the water application rates were important.

Why is the amount of water supplied to *Alpinia purpurata* important to the grower?

Water conservation is a worldwide concern. As competition for water resources increases, prices for municipal water are also increasing, forcing irrigators to become more efficient in applying water thereby reducing costs, to seek alternative sources of water, or to grow plants that require less water.

Alpinia purpurata does not handle water stress well because its large thin leaves turn brown when stressed or when the shoot is harvested. It thrives in areas of high rainfall, near a water source, and in flood plains where silt deposits occur. Therefore, production of high quality inflorescences require irrigation, and the grower needs to decide the type of irrigation system to use and the amount of water to apply. When the water source significantly increases the cost of production or when the water source is limited, efficient water applications maintain adequate moisture in the plant root zone by using the least amount of water and lowering cost.

Objectives

The objectives of the research were:

1. To determine the vegetative and inflorescence development for the water application rates.
2. To determine the influence of water application rates on inflorescence yield.
3. To determine the influence of water application rates on inflorescence quality.
4. To determine the influence of water application rates by various measures of plant water status, water stress, and growth.
5. To compare evapotranspiration of *Alpinia purpurata* in small weighing lysimeters with pan evaporation.
6. To explain the plant responses to the range of water application rates in terms of water availability in the water balance.

   There are three subobjectives which include:

   1) To determine the soil water holding capacity and other components of the water balance.
   2) To determine the soil wetting patterns by drip emitters.
   3) To compare the water application rate and stomatal conductance of my best treatment with a commercial operation using a different irrigation method.

7. To interpret the results of the research for application by commercial growers.

Chapter 2

Literature Review

Botany

Alpinia purpurata is a monocotyledon and a member of the order Zingiberales, known previously as Scitamineae. The Zingiberales is comprised of eight families which are divided into two groups, the banana group and the ginger group. The ginger group contains the ginger family, Zingiberaceae, which includes the genus *Alpinia*.

Alpinia purpurata is a perennial herb producing aerial shoots from 1 to 4 m tall. It has thick, fleshy, sympodially-branched rhizomes forming a dense circular clump as the plant matures. The vegetative shoots are erect, unbranched, and terminate in an inflorescence. The shoot is comprised of overwrapping leaf bases that form a pseudostem (the term "shoot" will be used interchangeably with pseudostem).

The leaves are entire, alternately positioned, distichous, rolled in bud, and with open sheaths with opposite margins overwrapping. The leaves end distally in a ligule with no petiole (Smith, 1979).

The lower leaves are reduced and sheath-like, and the inflorescence is enclosed by bladeless leaf sheaths. The general shape of the inflorescence is a spike comprised of many large, open, persistent, bright red or rich pink bracts 2 to 5 cm long. The axils of the bracts may produce single white flowers about 2 cm long and may contain lateral meristems that produce aerial offshoots.

The seed capsule is circular to oblong, fleshy, creamy white, between 1.5 to 3 cm in length, and usually 3-locular as it develops. When matured, it darkens as it dries until it dehisces longitudinally along the locules. The seeds are black, with a hard seed coat from 2 to 4 mm in size, arranged tightly in longitudinal rows, and covered with a white aril.

In Darlington's Chromosome Atlas of Flowering Plants, 1956, *Alpinia* is reported to have a basic chromosome number of 12. All *Alpinia* species listed in this reference have a somatic chromosome number of 48, therefore implying that *Alpinia* is a tetraploid.

History of *Alpinia purpurata*

Neal (1965) mentions that *Alpinia purpurata* red ginger is a native of Pacific islands from the Moluccas to New Caledonia, and Yap Island. However, Smith (1979) states that "Although it is apparently indigenous in New Caledonia, the Solomon Islands, and the New Hebrides, this species is so widely cultivated as an ornamental and so abundantly naturalized from Thailand to Micronesia, Melanesia, and Polynesia that perhaps one should be cautious in indicating its place of origin".

There is uncertainty as to the how and when red ginger came to Hawaii. The pink cultivar 'Eileen McDonald' was named by Hana nurseryman Howard Cooper after the lady who introduced this cultivar into Hawaii from her native Tahiti. The plant material was released on Labor Day 1982.

'Jungle Queen' was a release by the Hawaii Association of Nurserymen in the early 1970s. This light pink form originated from the western end of Guadalcanal Island and was sent to Dr. Horace Clay in Honolulu by Geoff Dennis in late 1967 (Dennis, 1989). In the mid 1980's, a red accession at the Wahiawa Botanical Gardens of the Honolulu City & County Botanic Gardens was released as 'Jungle King'.

In 1985, Janet Ginoza of Kahaluu discovered a seedpod on an 'Eileen McDonald' inflorescence in her front yard. She recalls 'Jungle Queen' as the only other ginger in the area. Of the 100 or so seeds in the pod, 19 seeds germinated. Three cultivars have since been released: 'Kimi' in 1988 has bright rose pink bracts with a lighter pink base; 'Kazu', released about the same time as 'Kimi', is a darker pink than 'Kimi'. The last release (about the same time as the other two) was described as having a raspberry color, thus named 'Raspberry'. Others of the first seed lot remain as numbers with some nurserymen referring to them as Ginoza #__ and others as Kimi #__.

The spherical shape of the inflorescence of the Ginoza cultivars resembles the rounded inflorescence shape of 'Jungle Queen' more than the cylindrical shapes of red ginger and 'Eileen McDonald'. The bracts of 'Eileen McDonald' and red ginger are more elongated, narrower, and the internode spacing is further apart than 'Jungle King' and 'Jungle Queen' allowing view of the central spike. The bracts of the Ginoza cultivars resemble 'Jungle King' and 'Jungle Queen' more than 'Eileen McDonald' and red ginger. Many of the Ginoza seedlings do not readily produce aerial offshoots, which is another characteristic of 'Jungle Queen' and 'Jungle King'.

I also discovered seedpods by chance in a residential yard where 'Jungle Queen', red ginger, and 'Eileen McDonald' are grown together. Seedpods were produced only on the inflorescences of 'Jungle Queen'. There were twelve seedpods in all, with most inflorescences bearing only one seedpod except for one inflorescence which bore six seedpods.

Hirano (1991) first reported production of seeds by *Alpinia purpurata*. He stated that some of the Ginoza cultivars and their seedlings (F_2) produced seed. The possibility of producing new cultivars by seed that may be different in color, shape, high yielding, and have good inflorescence life is important to the cut flower industry.

There is some confusion about whether 'Eileen McDonald' is a chimera of red ginger or the other way around. Stands of either the red or pink bracted wild forms have been reported growing by themselves (Dennis, 1989). Smith (1942) describes *Alpinia purpurata* as having bright red bracts with no mention of any other color. Criley (1989) mentioned that the "pink-bracted and multiple-headed inflorescences usually represent chimeras rather than seed selections." I observed red stripes on the bracts of 'Eileen McDonald' occasionally and in one instance variegation on the leaves of 'Eileen McDonald'.

Economic Overview of *Alpinia purpurata*

In 1988 gingers were 8% of the cut flower value of sales for the state of Hawaii, excluding orchids. In 1990, gingers increased to 10%, dropped to 9% in 1991, and dropped again to 8% in 1992 (Hawaii Agricultural Statistics Service, 1989, 1991, 1992, 1993).

Table 2.1 summarizes statistics for the red and pink gingers from the Hawaii Flowers & Nursery Products annual reports (1989, 1991, 1992, and 1993).

Table 2.1.

Hawaii Flowers & Nursery Products annual summary statistics for pink and red gingers from 1988 to 1991 (Hawaii Flowers & Nursery Products annual reports 1989, 1991, 1992, and 1993).

State Sales Figures

	Number Sold (1,000 dozens)			Sales Value ($1,000)		
Year	Red	Pink	Total	Red	Pink	Total
1988	131	90	221	606	658	1264
1989	165	95	260	734	729	1463
1990	173	104	277	915	789	1604
1991	154	98	252	791	710	1501
1992	124	71	195	711	573	1384

A market study, conducted in 1985 on the floricultural overview of world trade, predicted for the Federal Republic of Germany a fall in demand for "artificial-looking flowers, including tropical flowers such as anthuriums, heliconias, and a wide range of orchids," (ITC, 1987). In the United Kingdom and Canada, the demand for gingers was low. Gingers were not mentioned at all for the Netherlands and Switzerland. In France, on the other hand, there was a growing demand for exotic flowers like protea, red ginger, and heliconia.

Table 2.2 shows reported annual yield and related information from four farms growing red ginger in Hawaii (Hamilton, 1993).

Standards & Grades

The Hawaii Department of Agriculture (1984) published standards and grades for Hawaii-grown red ginger. The requirements of Hawaii Standard red ginger set the minimum grades for export:

A Hawaii Standard red ginger consists of "red ginger flowers which are well developed, fairly well formed, and the flower spikes shall be at least six inches (15 cm) in length and stems shall be at least eight inches (20 cm) in length."

"Red ginger flower" means the flower spike, stem, and any attached leaves of the species *Alpinia purpurata*. "Well developed" means approximately one-third or more of the bracts on the spike have opened; there is some evidence of flower development; and the stem is at least three-eighths

Table 2.2

Grower records of annual yields and cultural practices for Hawaiian farms producing red ginger (Hamilton, 1993).

Farm	Plant age	Planting density (clumps/ hectare)	Annual salable inflorescences/ hectare	Irrigation method	Irrigation rate
1	> 9 yrs	1669	40,662	Overhead	16 appls. @ 2.5 cm/appl.
2	6 yrs	1669	112,383	Drip	156 appls. @ 1.7 cm/appl.
3	5-12 yrs	4356	59,961	Furrow	16 appls. @ 2.5 cm/appl.
4	4 yrs	3704	125,926	Soaker hose	48 appls. @ 2.5 cm/appl.
This study	2-3 yrs	1333	132,598[a]	Drip	

[a] All inflorescences met the minimum standards for Small grade quality, but also included damaged, not well formed, and not well colored inflorescences.

inch (9.5 mm) in diameter at the cut end. "Fairly well formed" means the flower spike is fairly compact and not more than slightly lacking in symmetry. "Length of spike" means the distance from the axil of the uppermost leaf to the tip of the inflorescence. "Length of stem" means the distance from the axil of the uppermost leaf to the cut end of the stem (Hawaii Department of Agriculture, 1984).

A Hawaii Fancy red ginger consists of "red ginger flowers which are well developed, well formed, flower spikes shall be at least eight inches in length and stems shall be at least twelve inches (30 cm) in length", (Hawaii Department of Agriculture, 1984).

"Well formed" means the flower spike is compact and symmetrical (Hawaii Department of Agriculture, 1984).

Broschat (1988) defined red ginger marketable inflorescences as having a minimum shoot caliper greater than 8 mm and mentioned that the inflorescences are usually cut when they are about two-thirds to three-fourths open. He recommends that the shoot should be cut at ground level with one or two leaves left on it. Shoot length has a strong effect on the postharvest life of the inflorescence as a 50-cm shoot's inflorescence lasts about 2 weeks, 100-cm shoot's inflorescence about 3 to 5 weeks, and 150-cm shoot's inflorescence about 4 to 6 weeks (Broschat, 1987). Shoots comparable to Broschat's produced similar results (Sakai, 1990), while Tija (1988) reported that floral preservatives increased postharvest life.

Broschat (1988) stated that the best measurement of inflorescence size and quality is shoot caliper, but he did not specify whether it was at the base of the cut shoot or at the neck of the inflorescence. He recommended that standards for *Alpinia purpurata* should include shoot caliper and shoot length measurements. He then reported that inflorescences from young plants with small calipers have postharvest lives of five days or less.

Drip Irrigation

In drip irrigation, water is delivered through plastic tubing in the vicinity of the roots. Drip or trickle irrigation are low pressure systems ranging from 5 to 20 psi (Kruse et al., 1990). Evaporation in the air such as by overhead sprinklers is avoided. With less evaporation, less salts are left behind in the soil by the irrigation water.

Drip irrigation was originally designed for coarse-textured soils in arid and semi-arid areas, but it has gained popularity for use in orchards, grapes, citrus, cotton, sugarcane, vegetables, and on steep slopes, (Hillel, 1990; Kruse et al., 1990). Drip irrigation reduces high labor and water costs and is used in areas with limited and/or saline water supply and areas with difficulty in watering the production area due to slopes and hillside areas. Drip irrigation can reduce water stress and is used to satisfy the ET requirements of the crop through efficient water application.

The amount of water to be applied, its application rate, and the location of the emitters determine the wetting pattern of the soil based on the soil's infiltration rate and water holding capacity (Kruse et al., 1990). The area to be watered is restricted by the water's ability to move laterally in the particular soil.

Advantages of drip irrigation can include enhanced plant growth, quality, and yield; reduced saline content in soil; combined fertilizer and chemical application with irrigation possible; and limited water distribution results in less weeds. Possible disadvantages are constant maintenance, restricted plant root growth, and high initial cost.

Plant Water Stress Measurements

One way to determine water stress of plants is to monitor the crop. By direct visual inspection, it is possible to detect early signs of water stress in the foliage. Young leaves are most sensitive to water stress as they start to curl or lose their turgor.

Growth of young leaves is measured by linear dimensions, area or weight. Linear and area changes are associated with expansion of the leaves and may be characterized by changes in length, diameter, and area. Fresh weight is dependent on the water content of the leaf which varies widely throughout the day, as transpiration reduces fresh weight as the day progresses (Salisbury &

Ross, 1985). Dry weight is preferred over fresh weight as a measure of growth. It generally increases slightly during the day as the leaf photosynthesizes and absorbs mineral salts from the soil during the morning.

Fresh weight and dry weight are also used to measure the water content of the plant, while stomatal conductance is a measure of water stress. An expression of leaf water content as a percentage of turgid water content is known as relative water content (RWC) (Eq. 2.1).

$$RWC = \frac{(\text{fresh weight - oven-dry weight})}{(\text{turgid weight - oven-dry weight})} * 100 \qquad \text{Eq. 2.1}$$

Water deficit can be defined as 100 - RWC.

Leaf RWC of well-watered plants are generally 88% or higher at midday. A RWC in the 72 to 88% range occurs when water stress reduces pressure potential or turgor pressure to near zero. Visible symptoms are wilted or rolled leaves and greatly reduced stomatal opening. If RWC is reduced to 50 to 60% for several hours, leaf cells die and the damage is irreversible (Hsiao et al., 1984).

Water Loss of the Plant

More than 90% of the water lost by the plant is transpired by the stomata. The epidermis contains guard cells that regulate the stomata controlling the movement of gases, such as water vapor, in and out of plants. Although stomata are found on all aerial parts of the plant, they are most abundant on leaves and comprise about 1% of the total leaf surface.

The opening and closing of the stomata determines stomatal conductance and resistance. Stomata close either partially or completely when the rate of water intake into plants does not equal the rate of water loss. This occurrence depends on the soil water status and on the ability of plant roots to extract the available water. As soil water becomes less available to plants transpiration decreases.

The stomatal response to water stress appears to change throughout the plant's life cycle. Stomata of corn and sorghum respond to water stress during the vegetative growth stage but were insensitive during the reproductive stage (Ackerson and Krieg, 1977).

Environmental variables such as leaf temperature, light, leaf water potential, and probably vapor pressure deficit affect stomatal resistance. Light, particularly photosynthetically active radiation, has a strong negative effect on stomatal resistance at visible flux densities below approximately 200 Wm^{-2} (Rosenberg, 1983).

Water movement from the soil through the plant and into the atmosphere occurs along a gradient of decreasing water potential. The largest drop of water potential occurs between the leaves and the air as water vapor passes through the stomates. The resistance to flow in the vapor phase is the greatest of all resistances as water is moved from the soil through the plant and into the atmosphere (Cowan and Milthrope, 1968). Boyer (1974) has shown that most of the change in the total resistance in the plant occurs with varying transpiration rate due to changes in resistance within the leaves.

Measuring Evapotranspiration

Evapotranspiration (ET) describes the total process of water transfer into the atmosphere from vegetated land surfaces. A technique used to estimate ET requires climatological data. Some of the formulas are based on air temperature such as the Hargreaves Method, on solar radiation such as the Jensen-Haise Method, and on a combination of energy and wind data such as the Penman Method and Priestly-Taylor Model (Rosenberg, 1983).

Water loss by ET can be measured by a lysimeter. Lysimeters are large blocks of soil isolated from surrounding soils that allow detection of changes in the soil water content. They provide the only direct measure of water loss from plants, thus providing a standard (the best ones include certain design characteristics that keep the water content of the inside soil like that outside) against which other methods can be tested and calibrated.

A weighing lysimeter is used to determine ET by filling a container with soil and burying it in the ground. The container can be removed from the soil periodically and weighed on a scale.

ET can also be measured by an evaporimeter. The most frequently used are evaporation pans. The most widely used type is the Class A pan standardized by the U.S. Weather Bureau, 1.2 m diameter and about 0.3 m high (Van't Woudt, 1963). Evaporation pans, which characterize the evaporative demand from an open water surface, are used commonly because they are inexpensive, relatively easy to use, and simple to operate. However, one must be cautious when relating pan evaporation to actual ET. Under certain conditions, water loss by pan is less than water loss by vegetation under the same conditions (Rosenberg, 1983).

The ratio of ET for a given crop to pan evaporation is commonly called the crop coefficient K_C (Eq. 2.2; Ritchie & Johnson, 1990). A locally calibrated K_C can be used to assess water requirements from crops when used in combination with pan evaporation data.

$$K_C = \frac{\text{Crop ET (Eq. 3.3)}}{\text{Pan evaporation}} \qquad \text{Eq. 2.2}$$

Screens are used to prevent animals from drinking or debris from falling into pans because they are open receptacles of water. Screens reduce evaporation by 10 to 13% due to reduced radiation (Campbell & Phene, 1976).

Chapter 3

Materials and Methods

Experimental Site

The experimental site was at the Hawaii Institute of Tropical Agriculture & Human Resources of the University of Hawaii Waimanalo Research Station located on the windward side of Oahu, lat. 21^{O}N, long. 157^{O}W. The elevation is 20-29 m, and the station is exposed to northeast tradewinds.

The soil is a Mollisol, subgroup Vertic Haplustolls, and a Waialua series variant (Ikawa et al., 1985). The available water capacity of the soil is 0.13-0.15 mm of water/mm of soil (Soil Conservation Service, 1972).

Environment

Annual rainfall is 1520 mm (60 in) with most of the rainfall occurring between November and April. Average temperatures are 20^{O}C minimum and 28^{O} maximum. The mean annual soil temperature is 23^{O}C (Ikawa et al., 1985).

The annual total rainfall for 1991 through 1993 was 1280, 600, and 497 mm, respectively. The annual pan evaporation for the same period was approximately 1459, 1202, and 1487 mm, respectively.

Plant Material

Four rows of seventeen four-liter-sized clumps of 'Eileen McDonald' were transplanted in the summer of 1989.

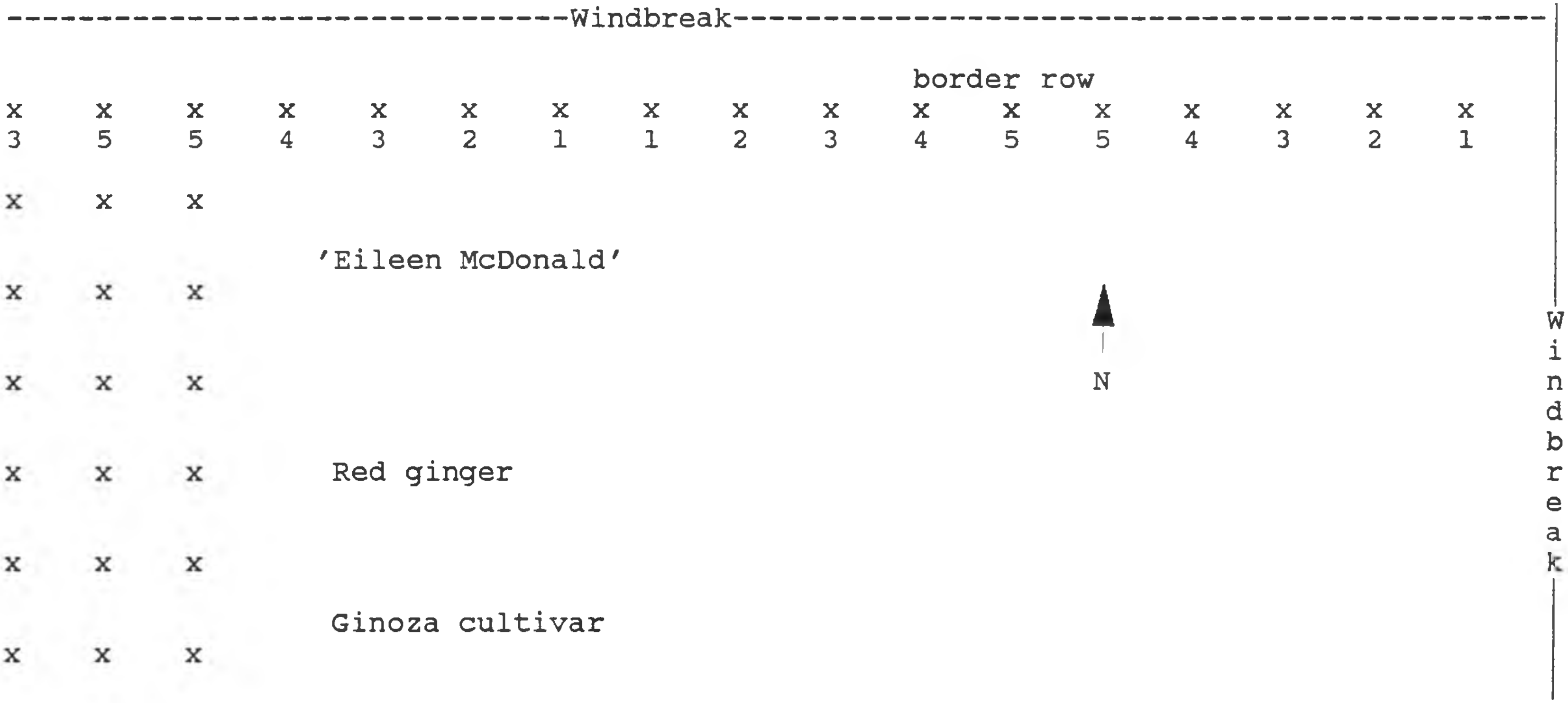
Later that year, one row of red ginger was added, and in early 1990, two rows of a Ginoza cultivar (we believe to be Ginoza No. 5 or 6) were transplanted. With 17 columns of clumps, each irrigation treatment was comprised of 3 replications with one extra replication assigned to irrigation treatments 1.00 and 1.67 (Fig. 3.1). The irrigation treatments consisted of pan factors (PF) 0.33, 0.67, 1.00, 1.33, and 1.67 times ET as calculated from Class A pan evaporation. We were interested in the higher irrigation treatments and selected to replicate those two pan factors.

The spacing of the clumps was 2.4 m within rows (between adjacent clumps in each row lying east to west) and 3.0 m between rows (between adjacent clumps in each column lying north to south). A single row of 4.6-m high *Erythrina* spaced about 60 cm apart lines the north and east ends of the field. The clumps were irrigated with municipal water delivered through drip emitters.

Irrigation Equipment

To uniformly apply the desired amount of water to the developing *Alpinia* clumps, the irrigation method needed to apply the water near or in the clump's root zone without overlapping adjacent treatments. Drip irrigation was the main system considered to achieve this.

A continuous function irrigation design was installed in August 1991 using three emitters per clump. Five 51-m



1 = Pan factor 0.33
2 = Pan factor 0.67
3 = Pan factor 1.00
4 = Pan factor 1.33
5 = Pan factor 1.67

Figure 3.1

The arrangement of material consisted of 17 rows, each row consisted of 4 'Eileen McDonald', 1 red ginger, and 2 Ginoza cultivar clumps. Each pan factor was replicated 3 times with 2 pan factors replicated one extra. The first row was a border row.

lines of 19-mm poly tubing were installed running the length of the field, one for each of the irrigation treatments.

Three 18.5-m laterals of 12.7-mm poly tubing running off an irrigation treatment line, supplied water for the 7 clumps in each replicate. In August 1992, a pressure reducer ($6.9 * 10^4$ Pa (10 psi), Spot Systems, Westminster, CA.) was installed in the main line. Although the system was flushed every 6 months and checked for plugged emitters, there were problems with PF 1.33. A balanced granular fertilizer, 16-16-16 (16N - 7P - 13K) was supplied every 3 months at 275 grams per clump by broadcasting from the perimeter of the clumps toward the center.

The drip system consisted of a mainline, submains, laterals, and emitters. The main line manifold, a 19-mm (3/4 in.) PVC riser, included a valve, sand filter, and a plastic pressure reducer (Fig. 3.2). The main line included a valve which allowed irrigation to the windbreak.

The main line fed into five 19-mm PVC submain manifolds. Each submain manifold was raised and included a flow meter (Precision, Orlando, FL.) and a timer. The experiment started using Nelson^R RainDate^R (L.R. Nelson Corp., Peoria, IL.) electronic water timers, but RainMatic model 2500 (Rainmatic^R Corp., Omaha, NE.) were substituted later for two timers that malfunctioned.

Each submain represented a single irrigation treatment and the replicates branched from the submain were not

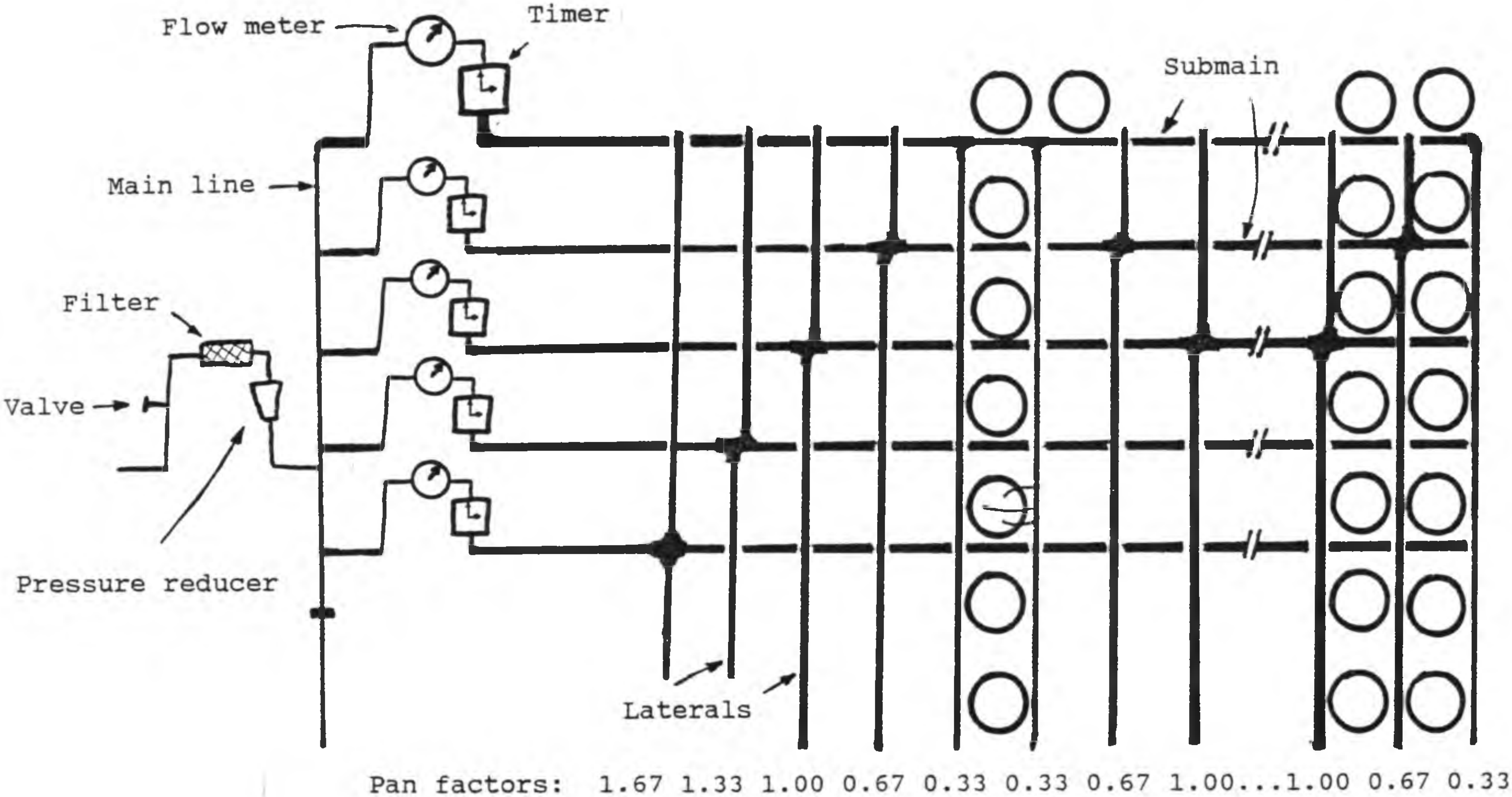


Figure 3.2

A portion of the continuous function irrigation design installed at Waimanalo using pan factors of 0.33, 0.67, 1.00, 1.33, and 1.67 times ET as calculated from Class A pan evaporation. The replicates are not individually plumbed. The flow meter and a timer shown expanded for the first lateral also occurs for the other laterals.

independent for plumbing. The valve on the submain for pan factor 1.33 was not physically operating properly during the course of the experiment. Although the keypad appeared to be operating, the ball valve was not opening as much as it should have. There is uncertainty as to how long the valve was inoperable.

Each clump was irrigated by three 3-mm (1/8-in. I.D.) poly tubing connected to the 12.7-mm poly tubing by barbed or threaded connectors. At the end of each 3-mm tube was a drip emitter (Vortex^{TM}, Model 3001-1, $3.78 * 10^{-3}$ m^3 h^{-1} (1 gph), Spot Systems).

Irrigation Treatments

The water application rate of the drip system was determined by measuring the amount of water collected for 5 minutes for 3 emitters from one clump (3 emitters = 1 set). The rate at the beginning of the experiment, August 1991, was 235 ml/min. (n=20), and 296 ml/min. a year later (n=48), and 176 ml/min. in April 1993 (n=25). The average rate was 166 ml per minute per set of emitters at the end of the experiment (n=51). This was also a check for system uniformity. Uniformity for the four dates were pooled and produced a standard deviation of ± 16 ml/min.

The calculated amount of water to irrigate the plants for each pan factor is shown in equation 3.1.

Time to irrigate 3 times a week (min./irrigation) =

$$\frac{\text{Pan evaporation in 7 days (cm/week)}}{3\ \text{(irrigations/week)}} * \frac{\text{Pan factor} * \text{Area per plant (cm}^2\text{)}}{\text{Emitter flow rate (ml/min.)}} * \frac{\text{ml}}{\text{cm}^3} \qquad \text{Eq. 3.1}$$

Weather Station

The weather station sensors were mounted on a mast supported by a tripod base, except for the rainfall gauge installed on a concrete block. The evaporation pan was situated near ground level and constructed to U.S. Weather Bureau Class A specifications. The station was powered by a 12V low-maintenance battery recharged by a solar panel. The station was surrounded by grass except for the northwest side where corn was grown.

The data logger used was Campbell Scientific's (Logan, Utah) model CR21X. The weather parameters and their sensors were:

1. Windspeed at 3 m elevation, MetOne 014A Wind Speed Sensor (anemometer).
2. Wind direction at 3 m elevation, MetOne Wind Vane.
3. Air temperature and relative humidity at 2 m elevation, Campbell Scientific Model 207 Temperature & Relative Humidity Probe.
4. Net Radiation at 3 m elevation, REBS Net Radiometer Q*4 (Fritschen type).
5. Solar Radiation at 3 m elevation, LiCor LI 200SB Pyranometer Sensor.

6. Pan Evaporation, screened, elevated 10 - 13 cm above ground, Qualimetrics Analog Output Evaporation Gage Model 6844-A.
7. Rainfall with gauge collection surface 0.6 m above soil, Sierra-Misco Model RG2501 Tipping Bucket Raingage.

The data logger took readings from each sensor every minute, and stored the mean or total every hour within the data logger. The data was downloaded weekly to a personal computer at the Department of Agricultural Engineering at the University of Hawaii at Manoa through a telephone modem. The computer program produced daily means, minimum, maximum, or total values for the different parameters. Also, daily potential evapotranspiration was estimated with reference equations including Penman, Jensen-Haise, Hargreaves, Priestly-Taylor, and Kohler.

Procedures for Objective 1: To determine the vegetative and inflorescence development for the water application rates.

Stages of Growth & Development

For each irrigation treatment, a sample of two emerging shoots was selected randomly among the cultivars and tagged at monthly intervals for 13 sampling dates from November, 1991 to January, 1993 (Appendix A). At monthly intervals, the length of tagged shoots was measured from ground level to the shoot tip (or top of the ligule when there were unexpanded leaves). The number of expanded leaves, presence of bud swelling, presence of color of an emerging inflorescence, and the length of time to reach these stages from shoot emergence were also recorded. After the emergence of the bud, the bud length was measured weekly until the inflorescence was fully developed and the shoot was harvested.

The presence of color at the shoot tip occurs about the same time as when the last leaf is fully expanded. This last expanded leaf is smaller than the leaves that precede it. As the inflorescence develops within the shoot, swelling occurs near the apical end producing horizontal creases in the leaf sheath.

Regression analysis was performed to determine if there were any differences among the irrigation treatments for the duration of stages of growth and development of the plant. Data analyses were performed using SAS release 6.04 for the PC (SAS Language Guide for PCs, 1988; SAS/STAT User's Guide, Vol.2, 1990; SAS/Graph Guide for PCs, 1987). The data were pooled across all irrigation treatments and all cultivars over 13 sampling dates when irrigation treatment effects and cultivar mean separation were not significant.

Four stages were defined as: the appearance of color at the shoot tip (a sign of an emerging inflorescence), the swelling of the inflorescence, the appearance of the inflorescence, and harvest of the shoot. Three yield variables -- shoot length, number of expanded leaves, and inflorescence length -- were also regressed against the irrigation treatments for all shoots over 13 sampling dates. The mean separation used was the Waller-Duncan K-ratio=100 t test.

Seasonality

Seasonal patterns for the pooled lengths of time to reach these stages were examined by their plotted means against the months in which the shoots emerged. Seasonality was checked also for shoot length, number of expanded leaves, and inflorescence length.

Growth Curves

The pooled weekly means for shoot length and number of expanded leaves regressed against the length of time from shoot emergence produced growth curves. A growth curve for each cultivar was produced by the regression of inflorescence length against the length of time from the appearance of the inflorescence.

Total Leaf Area per Shoot

Leaf expansion is an indicator of water status of the plant, therefore the total leaf area for the shoots for each irrigation treatment may reflect the treatment effects. Leaves from harvested shoots were removed, and stored in a large plastic bag placed within a styrofoam ice chest so that leaf area could be measured later. Leaf area was measured using a leaf area meter (Model 3100, Li-Cor Inc., Lincoln, NE). The shoots were harvested across all irrigation treatments and cultivars and measured for 7 sampling dates between January 1992 and January 1993 (Appendix A). The number of expanded leaves per shoot were also recorded.

Inflorescence Initiation

Shoots were cut at 5 sampling dates in July 1992 and June 1993 and a 6th sampling date was taken in September 1992 to determine at what stage of growth inflorescence initiation occurred (Appendix A). The samples taken in September were analyzed separately from the shoots sampled in the two summer months of June and July in order to avoid differences in seasons. Dissected meristems were observed under a microscope to determine if the inflorescence had initiated. Those shoots that did not initiate inflorescences were observed to have a smooth cone at the apical meristem, while those initiated inflorescences had developed floral bracts (Fig. 3.3).

Data taken were number of expanded leaves, diameter of cut end (base) of shoot, shoot length, and the distance from the cut base to the growing point of the dissected meristem. Shoot length was defined as the length from the cut shoot base to the shoot tip (or the end of the ligule last produced when an unexpanded leaf is present). Length to growing point was the length from the cut shoot base to the dissected apical meristem.

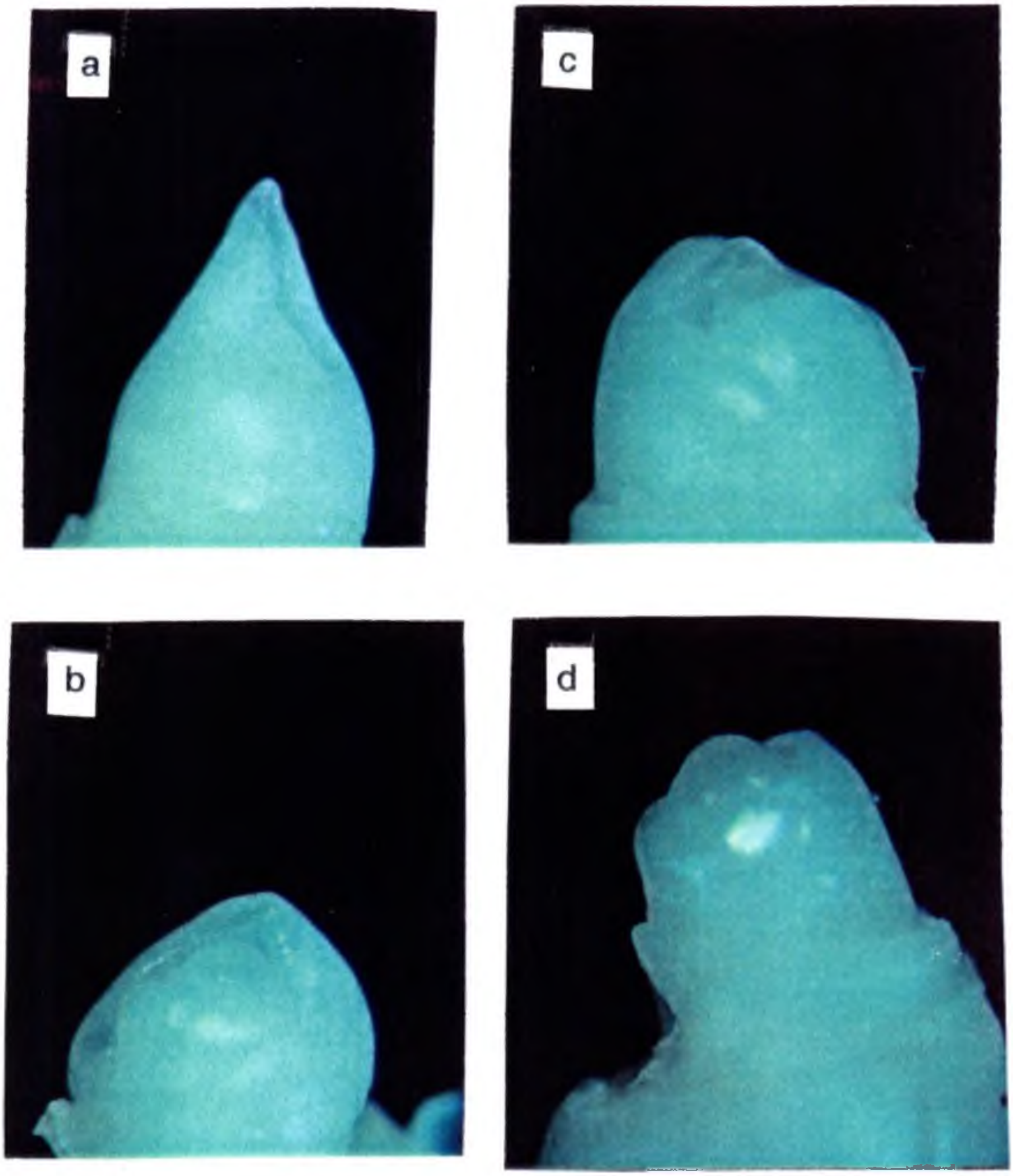


Figure 3.3

Dissected apical meristems showing the progression from no inflorescence initiation in a and b, to initiation in c and d.

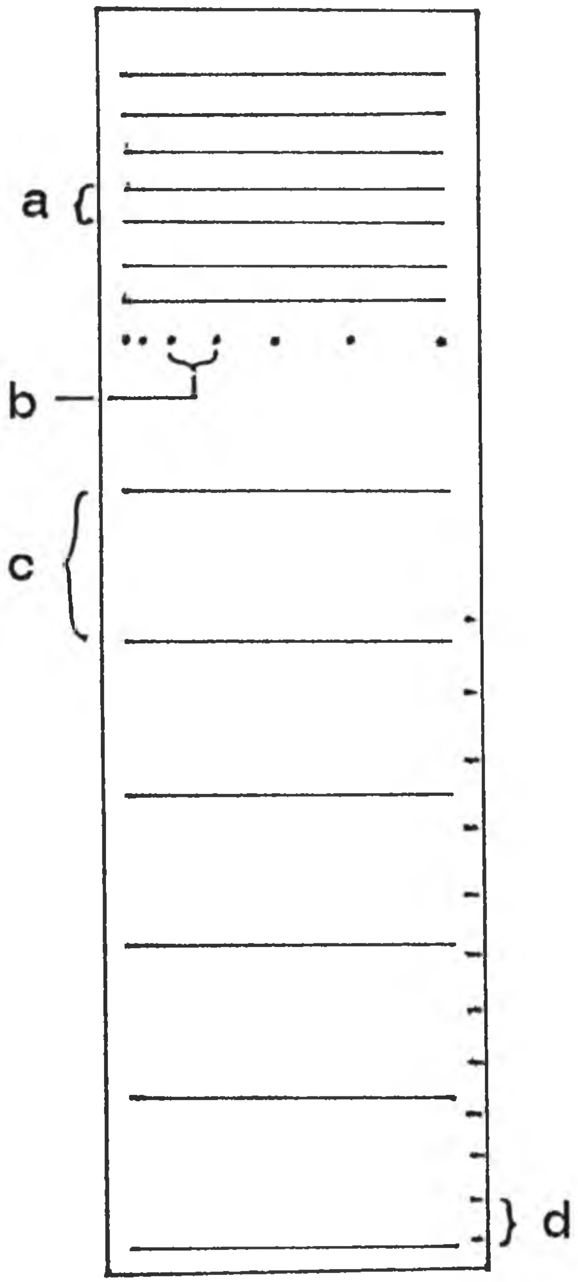
Clump Circumference

The circumferences of the clumps were measured for five sampling dates from January 1992 to June 1993 to monitor the increase in area for the clumps across all irrigation treatments and all cultivars (Appendix A). Each clump was measured for the first two sampling dates but for the last three dates, every other 'Eileen McDonald' and Ginoza cultivar clump along with all the red ginger clumps were measured. The circumference was also used to determine the clump area to be watered for the water application rates.

Procedures for Objectives 2 & 3: To determine the influence of water application rates on inflorescence yield and quality.

Qualitative Measurements

A measuring board 1.8 m x 0.3 m x 19 mm (6' x 1' x 3/4") with 0.5-cm markings starting from 3 cm was used to measure inflorescence diameter. The 2.5-cm markings were used for inflorescence length, 2-mm markings for shoot diameter, and 10-cm markings for shoot length (Fig. 3.4). Stainless steel 4D finishing nails 38 mm long were set into the board so that the distance between the heads of adjacent nails were 2 mm increments apart. Every week shoots with inflorescences at least two-thirds open or those producing initial growth of aerial offshoots were cut at ground level and measured with the board.



[a] Markings 2.5 cm apart above the nails used to measure inflorescence length.

[b] Nails set at 2 mm increments apart from the adjacent nail used to measure shoot diameter.

[c] Markings 10 cm apart below the nails used to measure shoot length.

[d] Markings increasing every 0.5 cm starting from 3.0 cm used to measure inflorescence diameter.

Figure 3.4

Drawing of the measuring board used to determine inflorescence diameter and length, and shoot diameter and length for harvested shoots.

Inflorescence diameter was taken approximately two-thirds down the length of the inflorescence from the tip. Inflorescence length was the distance from the juncture of the youngest (uppermost) expanded leaf and its blade to the tip of the inflorescence. Shoot diameter was measured at the neck of the inflorescence where the shoot joined the inflorescence. Shoot length was the distance from the cut end of the shoot to its juncture with the blade of the youngest expanded leaf.

During the period from May 15, 1992 to November 20, 1992, unmarketable shoots were subjectively omitted from the data set. These unmarketable shoots were thin (diameters < 10 mm), short (lengths < 60 cm), and had small inflorescences (diameters < 4 cm and lengths < 12.5 cm). These unmarketable shoots included those shoots classified as Small by the new grading scheme (Table 3.1). Since some harvest periods omitted records of unmarketable inflorescences, all the data analyses excluded all unmarketable inflorescences. Therefore, the number of Small inflorescences analyzed by chi-square was smaller than the actual quantity.

In addition to the yield variables, an objective grading scheme was produced with reference to the Hawaii State's Standards and Grades (Hawaii Department of Agriculture, 1984). Two classes were added -- Small and Rejects. Shoot diameters were measured at the neck of the inflorescence rather than at the base of the shoot.

Inflorescence diameter measurements were a standard of quality (Table 3.1).

Table 3.1.

Comparison of Grading for *Alpinia purpurata* Inflorescences for the State of Hawaii and a New Grading Scheme.

	Hawaii State		New			
	Standard	Fancy	Reject	Small	Standard	Fancy
IL[a]	≥15	≥20	<12.5	≥12.5	≥15	≥20
SL[b]	≥20	≥30	<20	≥20	≥20	≥30
SD[c]	≥ 9.5	≥ 9.5	-	-	-	-
SD[d]	-	-	< 6	≥ 6	≥10	≥12
ID[e]	-	-	< 3	≥ 3	≥ 4.5	≥5.5

[a] Inflorescence length in cm.
[b] Shoot length in cm.
[c] Shoot diameter at the cut end in mm.
[d] Shoot diameter at the neck in mm.
[e] Inflorescence diameter in cm.

Yield Measurements

The number of inflorescences per clump, inflorescence length and diameter, and shoot length and diameter were regressed against the irrigation treatments for 18 months (Appendix A). To determine cultivar effects, the mean separation used was the Waller-Duncan K-ratio=100 t test. Weekly means for the four yield variables, mean length of time from shoot emergence to harvest, and mean number of inflorescences per clump were compared against weekly average temperature, solar radiation, and Class A pan evaporation data collected at the Waimanalo Research Station to determine seasonal yields and their relationship to the weather variables. Counts for the number of inflorescences were tested by chi-square analysis where the null hypothesis was that the irrigation treatments had no effect on grades.

Procedures for Objective 4: To determine the influence of water application rates by various measures of plant water status, water stress, and growth.

The last expanded leaf was used as an indicator of plant water status and the differences in water status measurements reflected the irrigation treatment effects.

Selected shoots harvested across all irrigation treatments and cultivars were measured for inflorescence length and diameter, and shoot length and diameter for 12 sampling dates between April and July 1993 (Appendix A). The last expanded leaf from each shoot was removed, and stored in a large plastic bag placed within a styrofoam ice chest so that fresh and dry weight, and leaf area could be measured later. Leaf area was measured using a leaf area meter, and then the leaves were dried at approximately 68°C for at least 12 hours. The seven variables were analyzed by regression for irrigation-treatment effects. Cultivar differences for the seven variables were tested by the Waller-Duncan mean separation K-ratio=100 t test.

Measurements for Water Status

The last expanded leaves across all irrigation treatments and cultivars were enclosed to the petiole with plastic ziploc bags in the morning. The bags were left on the leaves for at least 5 minutes, and then the leaves were cut from the shoot and completely sealed in the bags. The leaves were later weighed to get fresh weight and then placed between saturated paper towels the full length of the leaves, and placed in a storage container. The leaves were left to saturate overnight, wiped dry, weighed to get turgor weight, and then dried at 68°C for about 15 hours and weighed to get dry weight. Relative water content (RWC) was analyzed by regression for irrigation treatment effects, and cultivar differences in RWC were tested by the Waller-Duncan mean separation K-ratio=100 t test in June 1993 (Eq. 2.1, Appendix A).

Measurement for Water Stress

Stomatal conductance on the lower surface of the leaf for the last or second to the last expanded leaves or for the entire shoot were measured for 4 sampling dates between January 1992 and June 1993 (Appendix A). Stomatal conductance was determined using a steady state porometer (Model LI-1600M equipped with quantum sensors which measures PAR, Li-Cor Inc., Lincoln, NE). Additional variables were recorded: transpiration, quantum, and leaf temperature.

Stomata were observed on both the top and bottom leaf surfaces of red ginger. Slivers of leaf tissue taken from the top and bottom leaf surfaces were examined under 100 times magnification, and the approximate ratio of stomata for the top to bottom surfaces was 1 to 20.

Procedures for Objective 5: To compare evapotranspiration of *Alpinia purpurata* in small weighing lysimeters with pan evaporation.

The small weighing lysimeters were eight 11.7-l plastic pots filled with soil:peat:perlite 1:1:1 medium each containing a plant consisting of a single red ginger shoot bearing 4 to 6 expanded leaves. The shoots were grown under shade in a glasshouse until roots were visible at the drain holes (about 6 weeks).

The plants were allowed to adjust to field conditions over the weekend. At the beginning of each data collection, the pots were watered until the soil was wetted and water was seen flowing from the drain holes, and left to drain until no water was seen draining from the drain holes. The pots were then weighed, and transported back to the field where the rest of the study is located (1.5-minute slow-speed drive with plants uncovered). The 8 pots were randomly placed in the field in shallow holes half the height of the pot located on the southern perimeter of each clump. During the day, the pots were periodically removed from the field and driven to be weighed on a top-loading scale. Stomatal conductance readings were measured on the last expanded leaves for the shoots in the 8 pots in the field prior to transport for weighing.

Three sampling dates between 8 and 25 August 1993 were selected. On the first date, ET was determined by leaving the pots uncovered at the soil surface. On the other two dates the transpiration component of ET was determined for all of the 8 pots by covering the soil with white plastic bags and securing the bag to the shoot above the pot by plastic ties. The difference between the two measurements was the evaporation by the soil surface.

The water use by the shoots in the lysimeters was compared to hourly Class A pan evaporation collected by the weather station (Eq. 3.2).

$$\frac{\text{cm of } H_2O}{\text{ground area (cm}^2\text{) hour}} = \frac{\text{g of } H_2O}{\text{leaf area (cm}^2\text{) hour}} * \frac{\text{leafarea(cm}^2\text{)}}{\text{ground area (cm}^2\text{)}} * \frac{1 \text{ cm}^3 \text{ } H_2O}{1 \text{ g } H_2O} \qquad \text{Eq. 3.2}$$

The number of expanded leaves on each shoot in each lysimeter were counted after each sampling date and the last expanded leaf was traced on newspaper to be later cut out and measured on an area meter. The total leaf area for each shoot was determined by the leaf area for the last expanded leaf plus the leaf areas for the leaves subtending it measured at the end of the last sampling date when all the leaves were measured for leaf area. This produced the total leaf area for each shoot in each lysimeter for each sampling date.

The second term of equation 3.2 is leaf area index (LAI). The LAI for this equation was determined in this way: a soil area of 40 cm by 40 cm was selected in a plant clump, and all shoot bases originating on or within this area were cut, counted, and their leaves were placed in a large plastic bag so that total leaf area could be measured with an area meter. A total of 9 random samples were taken representing each cultivar within each replication. This was done at the end of the study.

The number of shoots per clump were then determined for each cultivar. Total leaf area for the clump was determined by multiplying the total number of shoots per clump by the total leaf area for the shoots in the 40 by 40 cm basal area. That number was then divided by the total number of shoots in the 40 by 40 cm basal area to produce the total leaf area for the clump.

Two different ground areas were used to calculate LAI. The first ground area was the area occupied by the clump based on the perimeter at the ground surface for 22 June 1993. The second ground area was the field area. This was represented by the clump area plus the area between the clumps within the rows, 2.4 m, and the area between the clumps between rows, 3.0 m.

Procedures for Objective 6: To explain the plant responses to the range of water application rates in terms of water availability in the water balance.

Subobjective 1: To determine the soil water holding capacity and other components of the water balance.

To determine the root distribution of *Alpinia purpurata*, a bucket auger was used to remove soil 15 to 20 cm from the edge of the clump. A series of holes next to one another was formed about 1 m in length. A weeder was then used to chip the soil away from the roots digging in towards the middle of the clump. The holes were dug to approximately 75 cm deep. The formation of the roots determined the root distribution for the clump.

Soil samples were taken by a specialty auger, a push auger, and a bucket auger to determine volumetric soil water content. Bulk density was determined with very little compaction by using a specialty auger. A series of metal rings, lining the inside of the auger behind the bit were removed with the contained soil sample after the bit is removed from the shaft of the auger. The samples were placed into moisture cans and weighed before and after a 24 hour period of drying at 68^{O}C. Other components of the water balance were obtained from the literature for this site.

Subobjective 2: To determine the soil wetting patterns by drip emitters.

Soil wetting patterns were determined by taking volumetric soil samples at various depths and at distances away from the drip emitter. Soil wetting patterns among the irrigation treatments were compared.

Subobjective 3: To compare the water application rate and stomatal conductance of my best treatment with a commercial operation using a different irrigation method.

Irrigation rates, stomatal conductance, bulk density, and volumetric soil water content measurements were compared to a overhead impact-sprinkler irrigated farm specializing in *Alpinia purpurata* located 1.4 km east of the Waimanalo Research Station.

Chapter 4

Growth and Development

Management decisions depend upon knowing the stages of growth and development of the plant and when they occur. The purpose of this research was to determine when these stages occur, and how they are affected by the range of water application rates. The stages of inflorescence development in chronological order were: inflorescence initiation, the appearance of color at the shoot tip (a sign of an emerging inflorescence), the swelling of the inflorescence, the appearance of the inflorescence, and harvest of the shoot. The length of the shoot and the number of expanded leaves associated with these stages may also determine when the stages occur.

The objective for this research was to determine the vegetative and inflorescence development for the water application rates (Objective 1). There were four sets of sampling data in support of this objective: stages of growth and development, total leaf area per shoot, inflorescence initiation, and clump circumference (Appendix A).

Results

None of the times to reach the various stages from shoot emergence showed any significant linear or quadratic effects among the irrigation treatments (Table 4.1, Fig.

4.19); however, significant linear effects were produced for shoot length and inflorescence length (Appendix B). Longer shoots, more expanded leaves, and longer inflorescences were produced with the higher water application rates.

Table 4.1

The means of the timeframes to reach the various stages of development.

Stage of development	Time to reach this stage (wk)
Appearance of color at the shoot tip	20.8
Swelling of the inflorescence	21.5
Appearance of the inflorescence	23.2
Harvest of the shoot	26.4

There were no significant differences between red ginger and 'Eileen McDonald' for all the times to reach the stages. Significant differences occurred between the Ginoza cultivar and the other two cultivars (Table 4.2). The Ginoza cultivar took longer from shoot emergence to all four stages compared to the other two cultivars. The Ginoza cultivar produced the longest shoots, more expanded leaves, but shortest inflorescences compared to 'Eileen McDonald' and red ginger.

Table 4.2

Cultivar means for the lengths of time from shoot emergence to: color at the shoot tip, inflorescence swelling, inflorescence appearance, and harvest; and for shoot length, number of expanded leaves, and inflorescence length associated with the stages across all irrigation treatments for 13 sampling dates.[y][z]

	Time (week) from shoot emergence to:						
Cultivar	Color at shoot tip	Inflor. swelling	Inflor. appearance	Harvest	Shoot length (cm)	Number of leaves	Inflor. length (cm)
'Eileen McDonald'	18.6 b	22.4 b	20.5 c	24.8 b	103.3 b	8.5 b	15.4 b
Red ginger	25.1 a	29.5 ab	24.7 b	23.6 b	116.4 b	8.3 b	18.3 a
Ginoza	28.1 a	43.0 a	30.7 a	35.3 a	164.4 a	13.4 a	14.9 b

[y] The means with the same letter are not significantly different as shown by the Waller-Duncan mean separation K-ratio=100 t test

[z] All comparisons were significant at < 1%

Seasonality and the Times to the Stages of Growth & Development

Seasonality seemed to have an effect on the lengths of time to the stages as well as upon quantitative variables. Those shoots which emerged in March and April averaged shorter times to the four stages compared to shoots which emerged in autumn (November) (Figs. 4.1 to 4.4). Time from shoot emergence to shoot harvest was compared to average temperature, solar radiation, and pan evaporation recorded at the Waimanalo Research Station. Solar radiation causes average temperature and pan evaporation (with windspeed). The peak for average temperature lagged 1 to 2 months behind solar radiation and pan evaporation and matched the shoot emergence to shoot harvest curve best -- the shortest development times occur when the environmental temperature is rising (Figs. 4.5 to 4.7).

Figures 4.5 to 4.7 clearly show that shoots which emerged at the start of increasing temperatures and solar radiation has the shortest development times to harvest when compared to shoots which emerged at the end of increasing or the start of decreasing temperatures and solar radiation. This suggests that the weather conditions after shoot emergence greatly influence the development time to harvest, as shoots which emerged at the start of increasing temperature and solar radiation needed only 21 weeks to reach a harvestable stage. Shoots which emerged at the

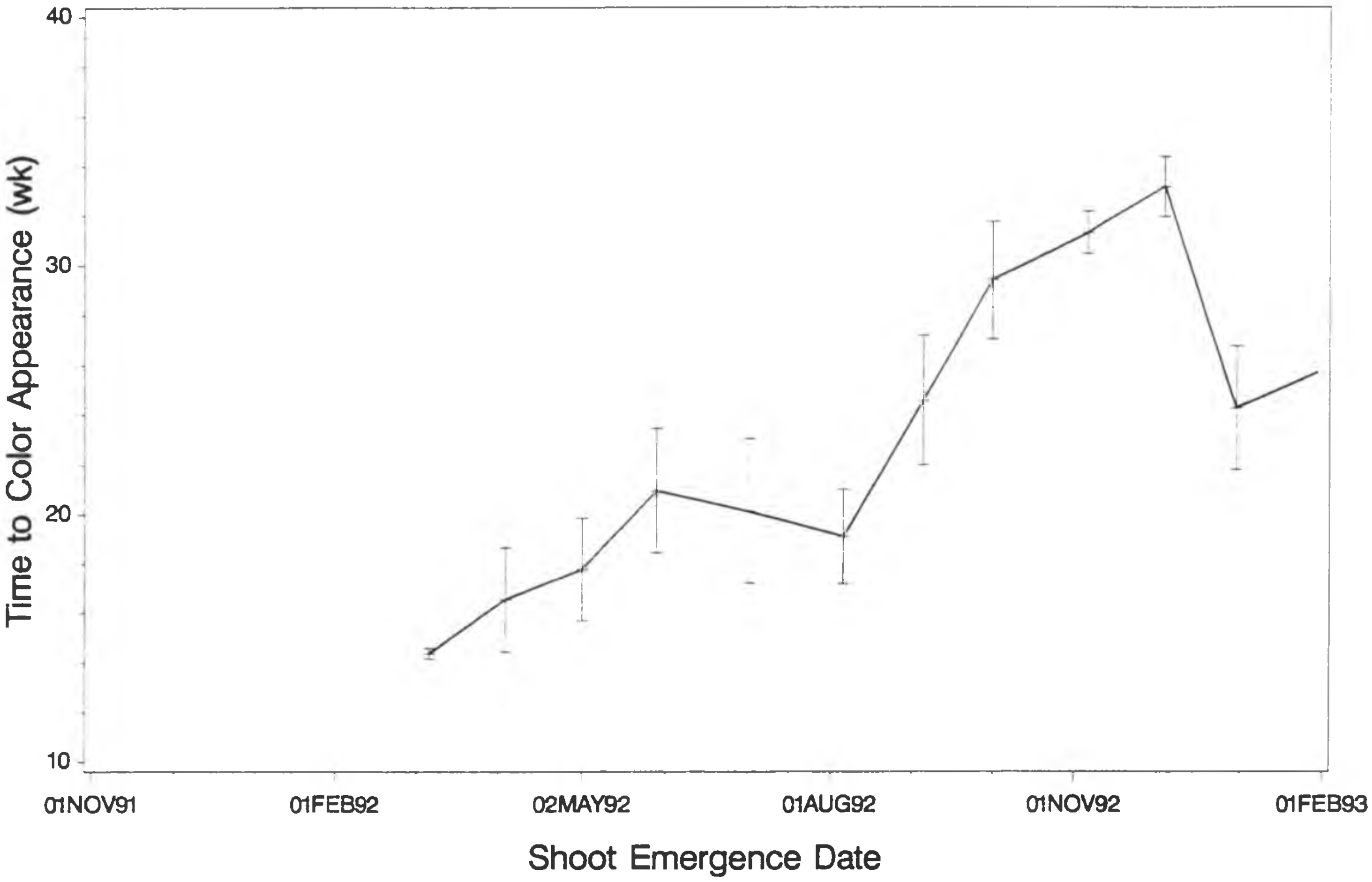


Figure 4.1

The mean length of time + SE from shoot emergence to the appearance of color at the shoot tip for all shoots across all irrigation treatments and all cultivars for the month the shoots emerged at 13 tagging dates, n=1 to 7.

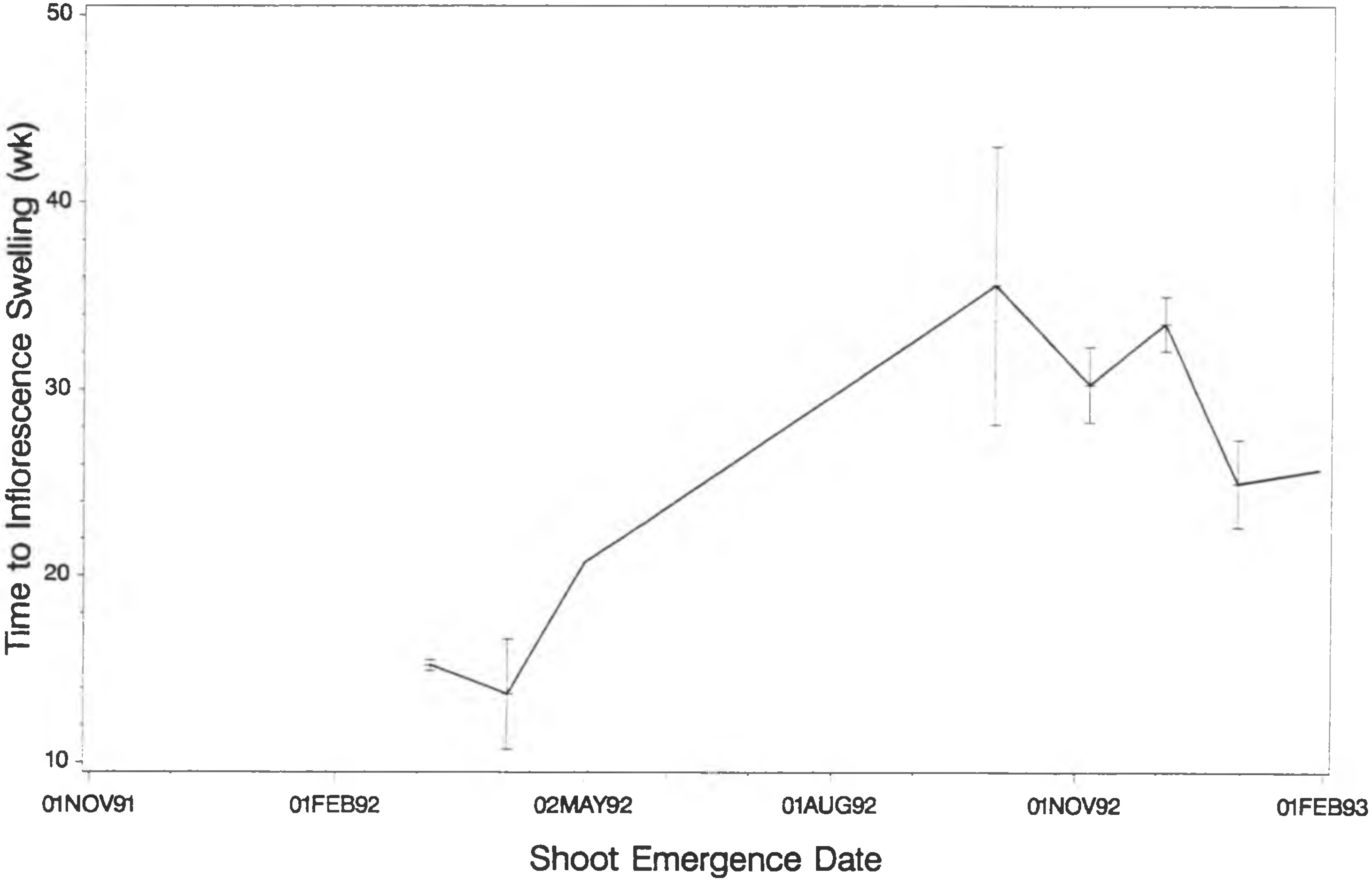


Figure 4.2

The mean length of time + SE from shoot emergence to the swelling of the inflorescence for all shoots across all irrigation treatments and all cultivars for the month the shoots emerged at 13 tagging dates, n=1 to 4.

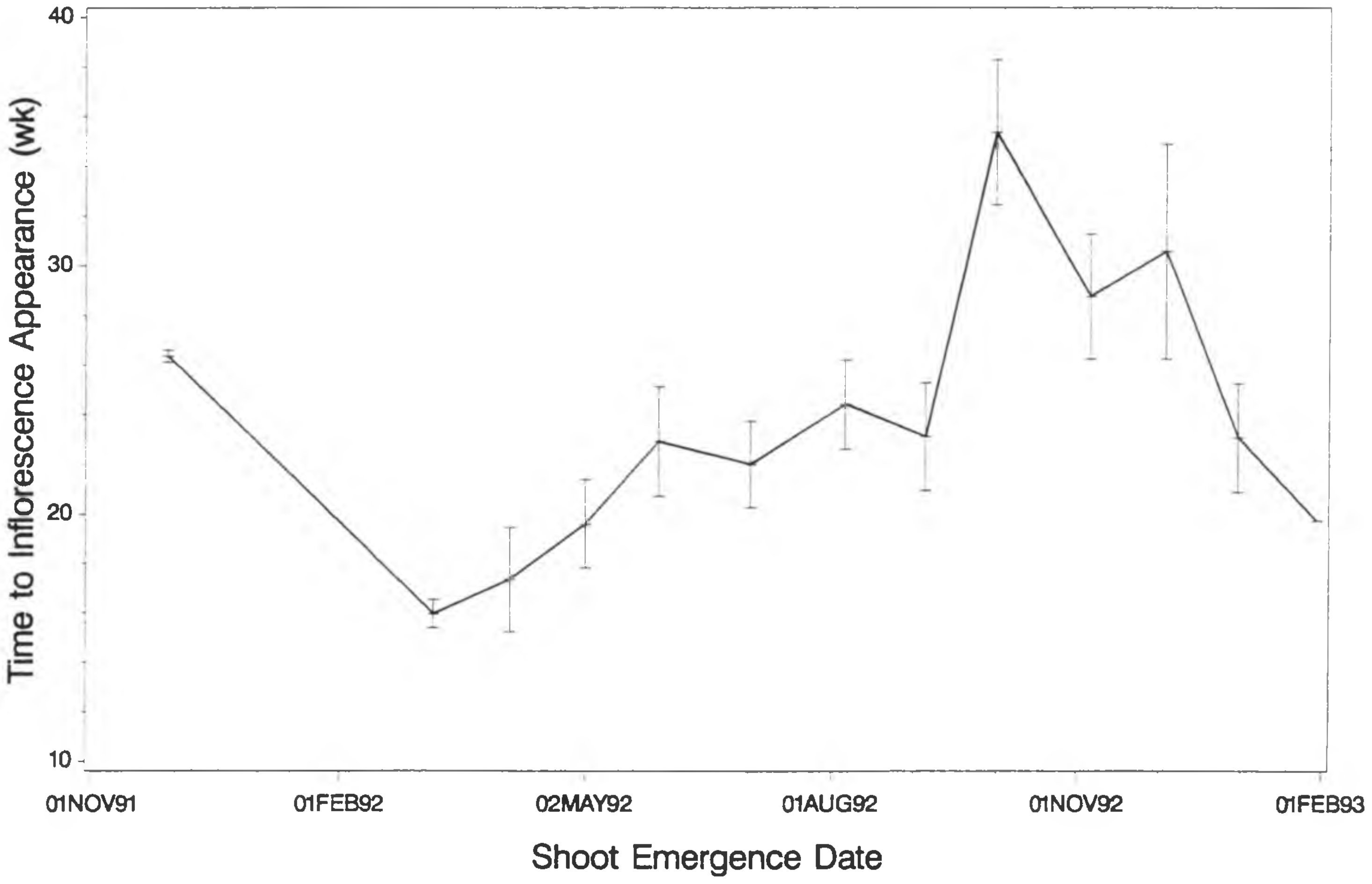


Figure 4.3

The mean length of time + SE from shoot emergence to the appearance of the inflorescence for all shoots across all irrigation treatments and all cultivars for the month the shoots emerged at 13 tagging dates, n=3 to 8.

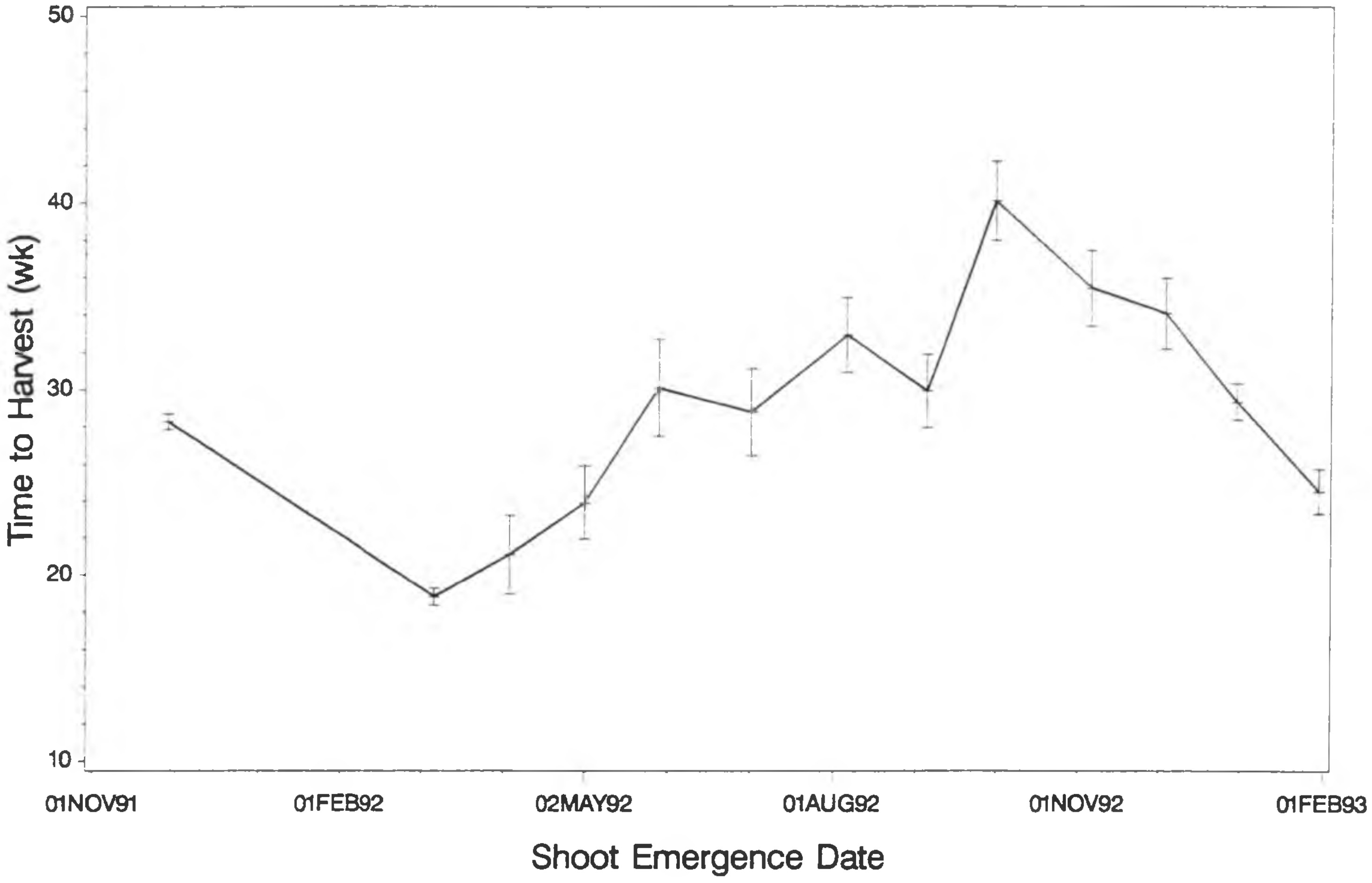


Figure 4.4

The mean length of time + SE from shoot emergence to harvest for all shoots across all irrigation treatments and all cultivars for the month the shoots emerged at 13 tagging dates, n=5 to 8.

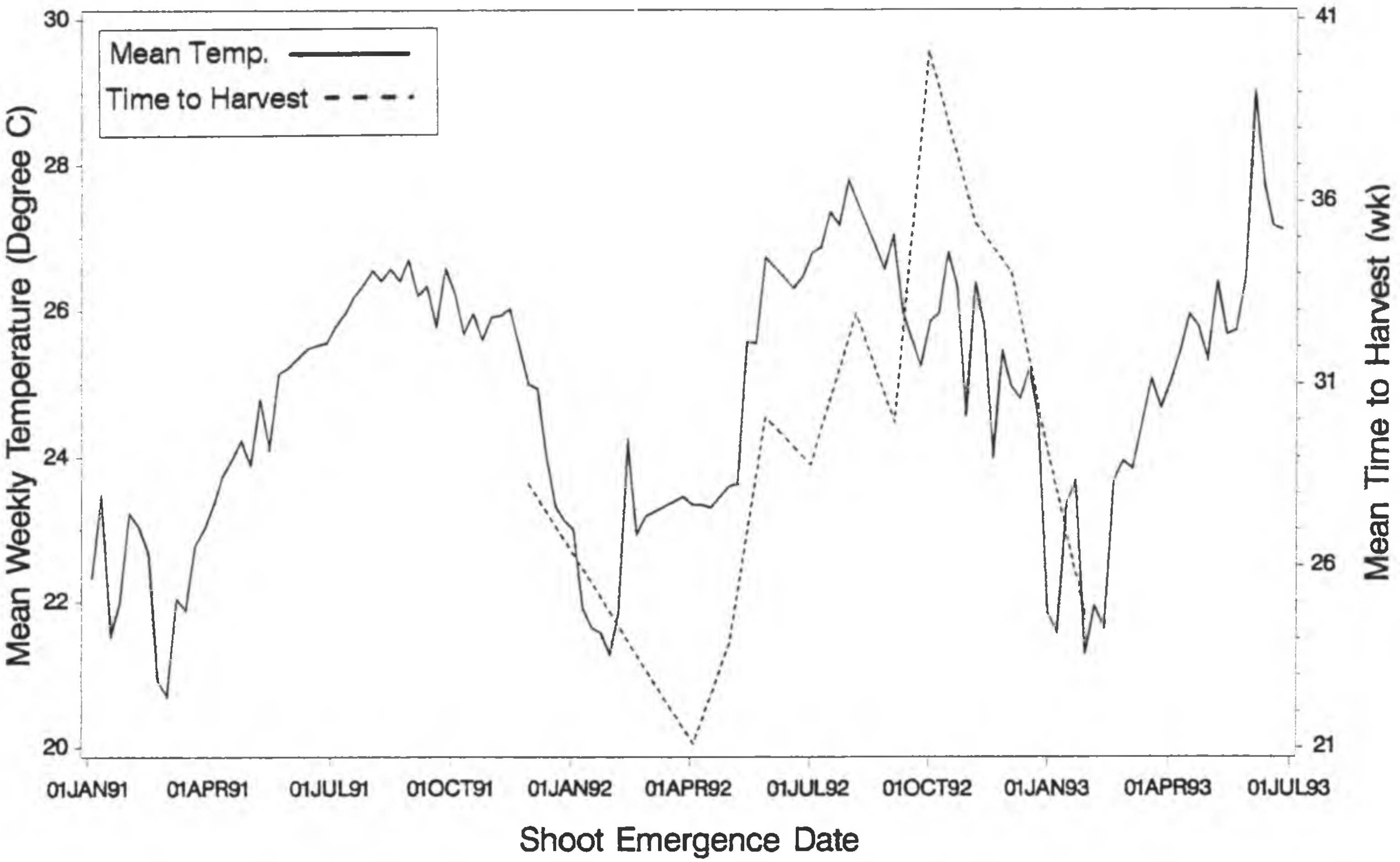


Figure 4.5

The weekly mean temperature from January 1991 to July 1993 and mean time from shoot emergence to harvest for the month the shoots emerged at 13 sampling dates

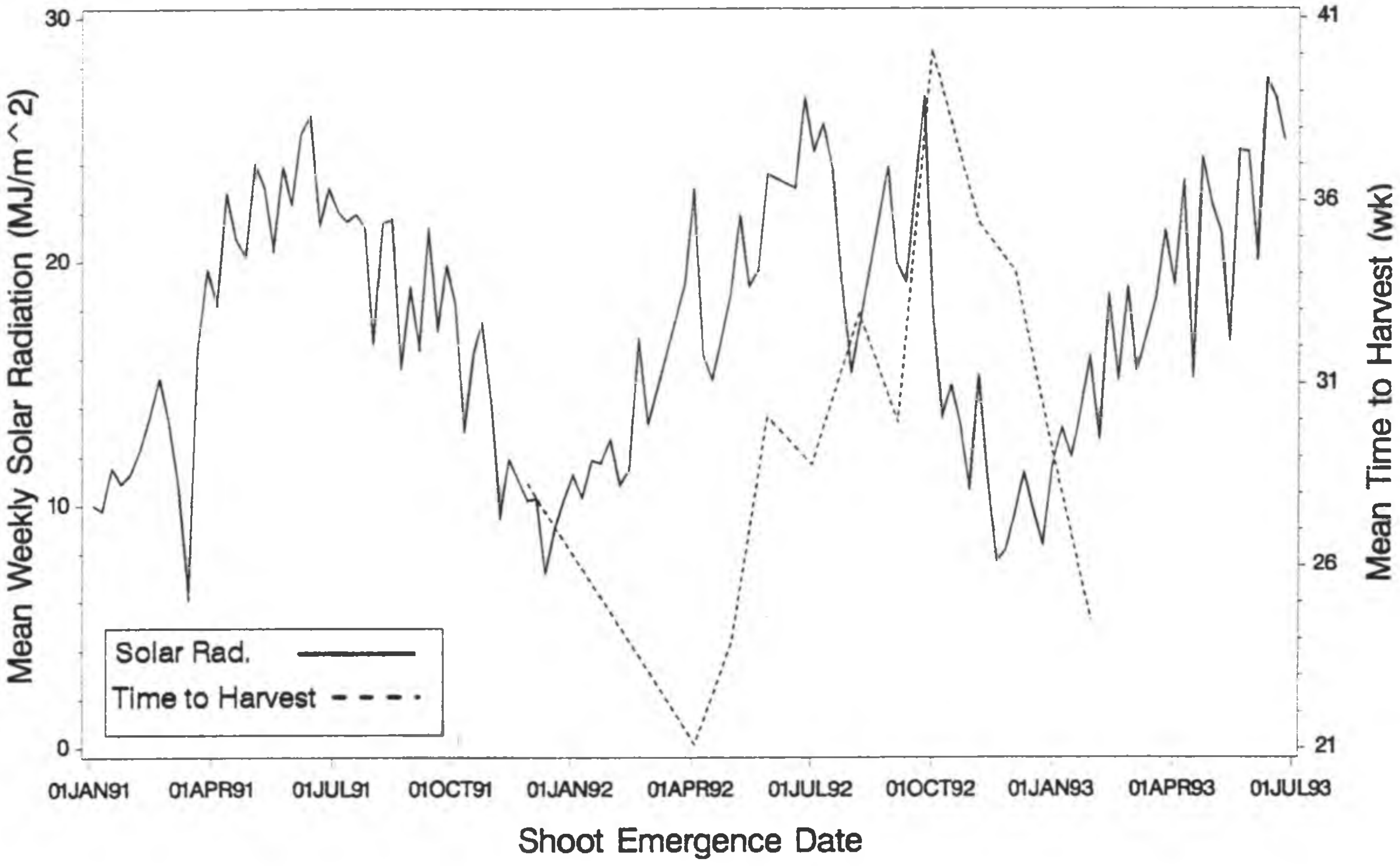


Figure 4.6

The weekly mean solar radiation from January 1991 to July 1993 and mean time from shoot emergence to harvest for the month the shoots emerged at 13 sampling dates

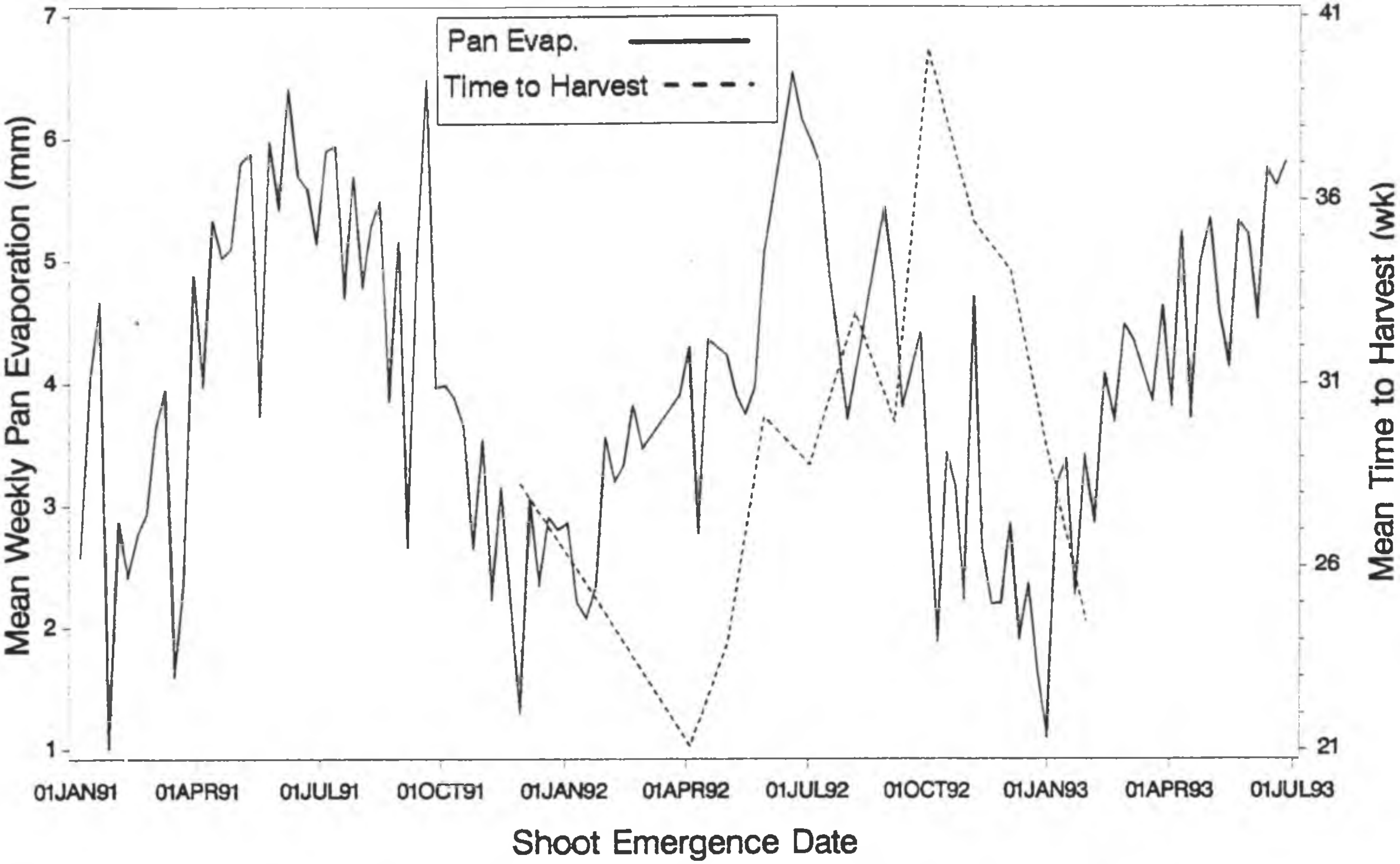


Figure 4.7

The weekly mean pan evaporation from January 1991 to July 1993 and mean time from shoot emergence to harvest for the month the shoots emerged at 13 sampling dates start of deceasing temperature and solar radiation conditions needed twice the development time.

The shortest shoot lengths and the least number of expanded leaves per shoot occur again when the environmental temperature is rising (Fig. 4.8 to 4.13). Seasonality was more unpredictable for inflorescence length as seasonal differences did not follow those of the other variables (Fig. 4.14). Another growing season may be needed to determine the seasonal effect for inflorescence length.

Growth Curves

Regression analyses for shoot length and number of expanded leaves were significant for the linear and quadratic effects against the number of weeks from shoot emergence (Figs. 4.15 to 4.16). Growth was most rapid after shoot emergence for both variables but then slowed with time.

Inflorescence length showed significant linear and quadratic effects against time from inflorescence appearance for 'Eileen McDonald' and the Ginoza cultivars. Inflorescence length for red ginger showed only significant linear effects (Fig. 4.17).

Total Leaf Area per Shoot

Regression analysis for total leaf area per shoot at harvest was not significant for the linear effects against the irrigation treatments (Appendix B).

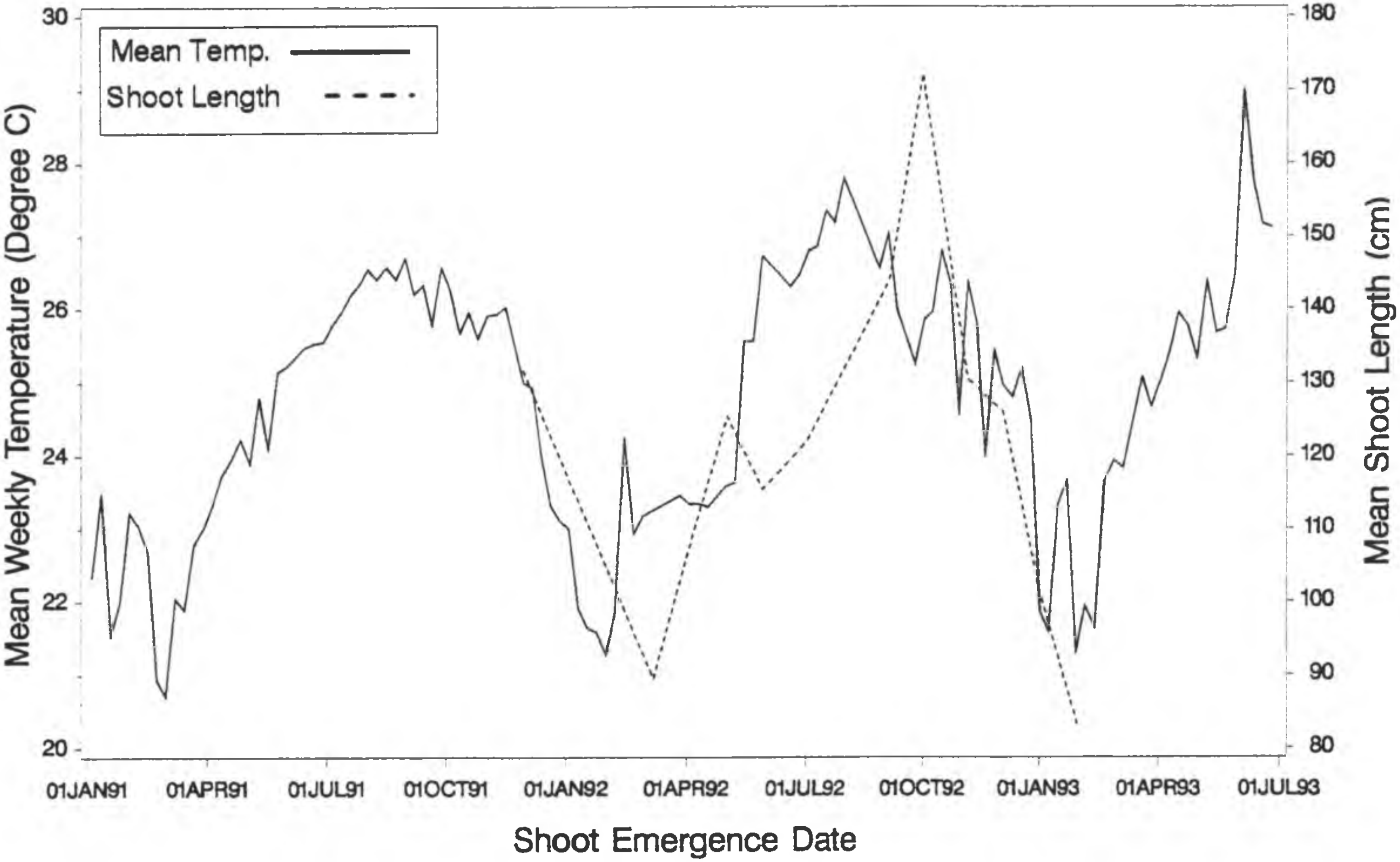


Figure 4.8

The weekly mean temperature from January 1991 to July 1993 and mean shoot length produced from shoot emergence for the month the shoots emerged at 13 sampling dates

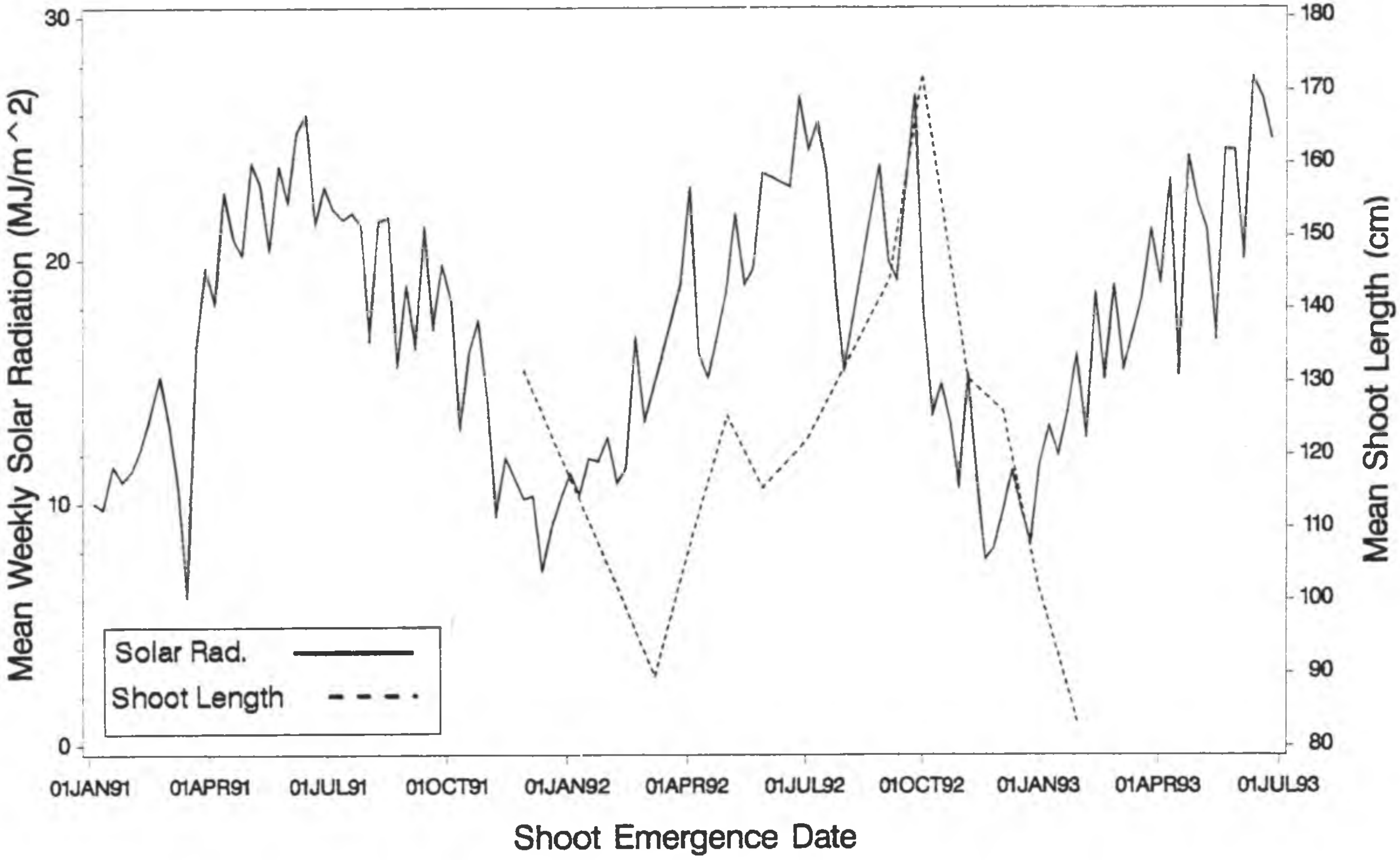


Figure 4.9

The weekly mean solar radiation from January 1991 to July 1993 and mean shoot length produced from shoot emergence for the month the shoots emerged at 13 sampling dates

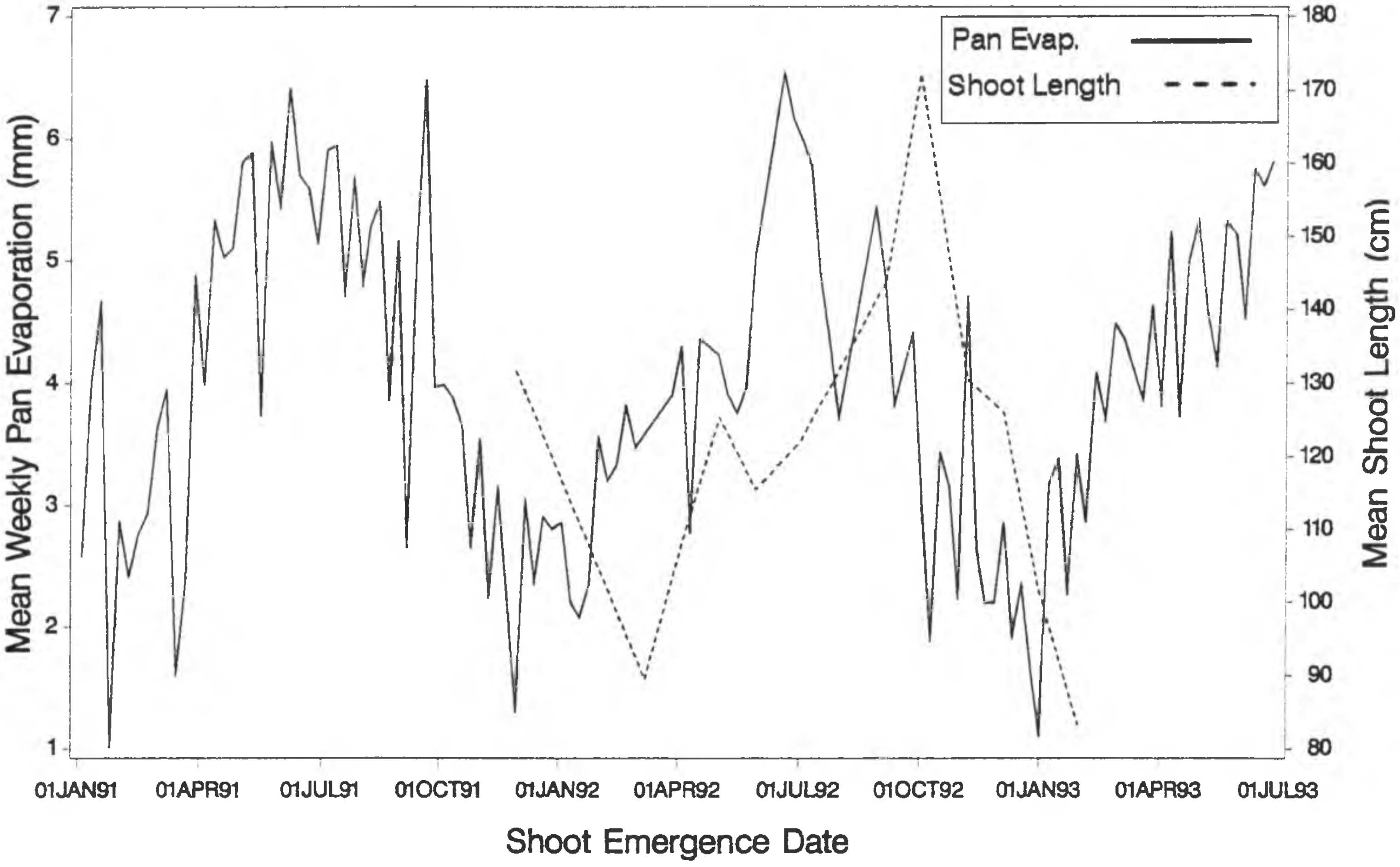


Figure 4.10

The weekly mean pan evaporation from January 1991 to July 1993 and mean shoot length produced from shoot emergence for the month the shoots emerged at 13 sampling dates

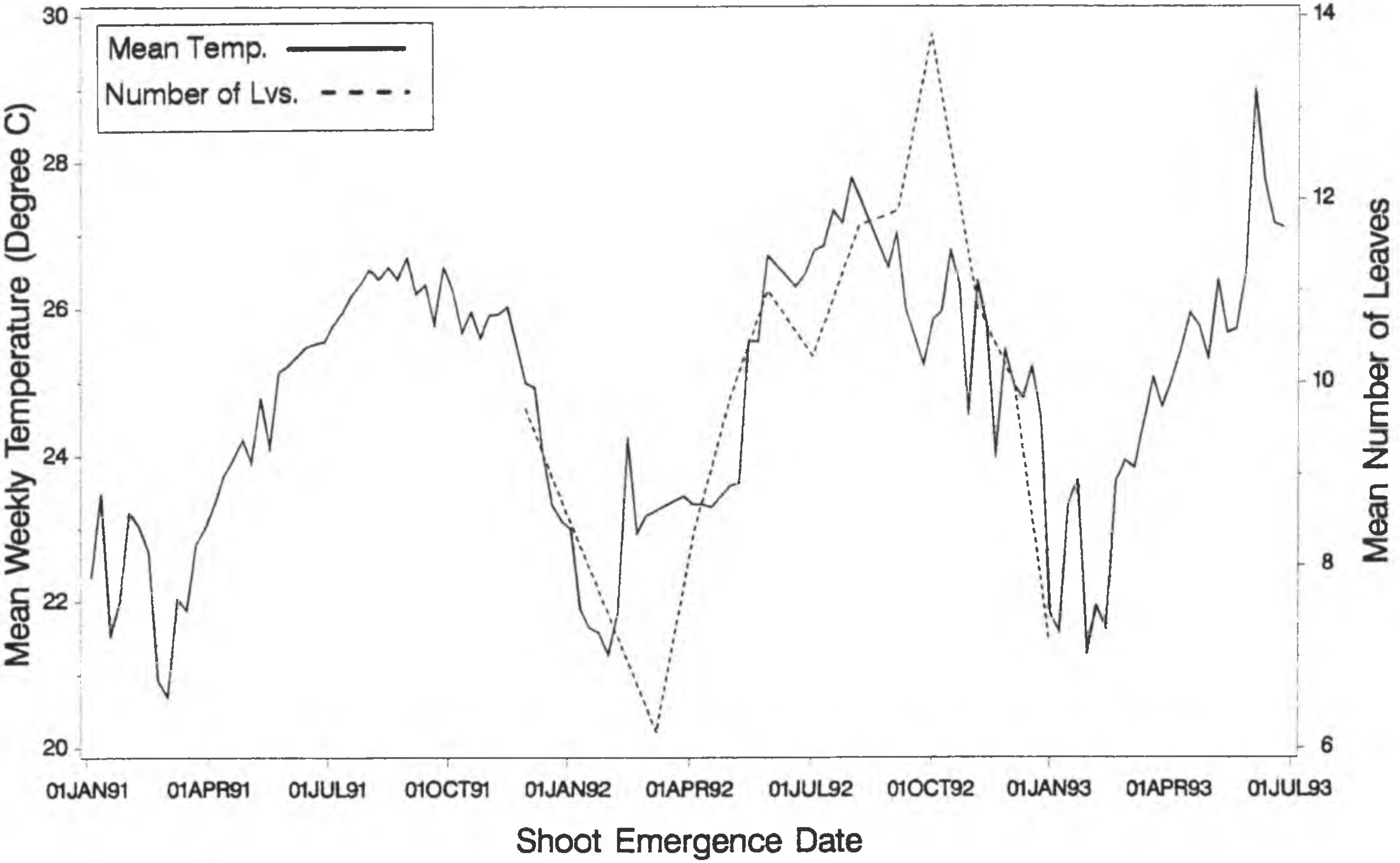


Figure 4.11

The weekly mean temperature from January 1991 to July 1993 and mean number of expanded leaves produced from shoot emergence for the month the shoots emerged at 13 sampling dates

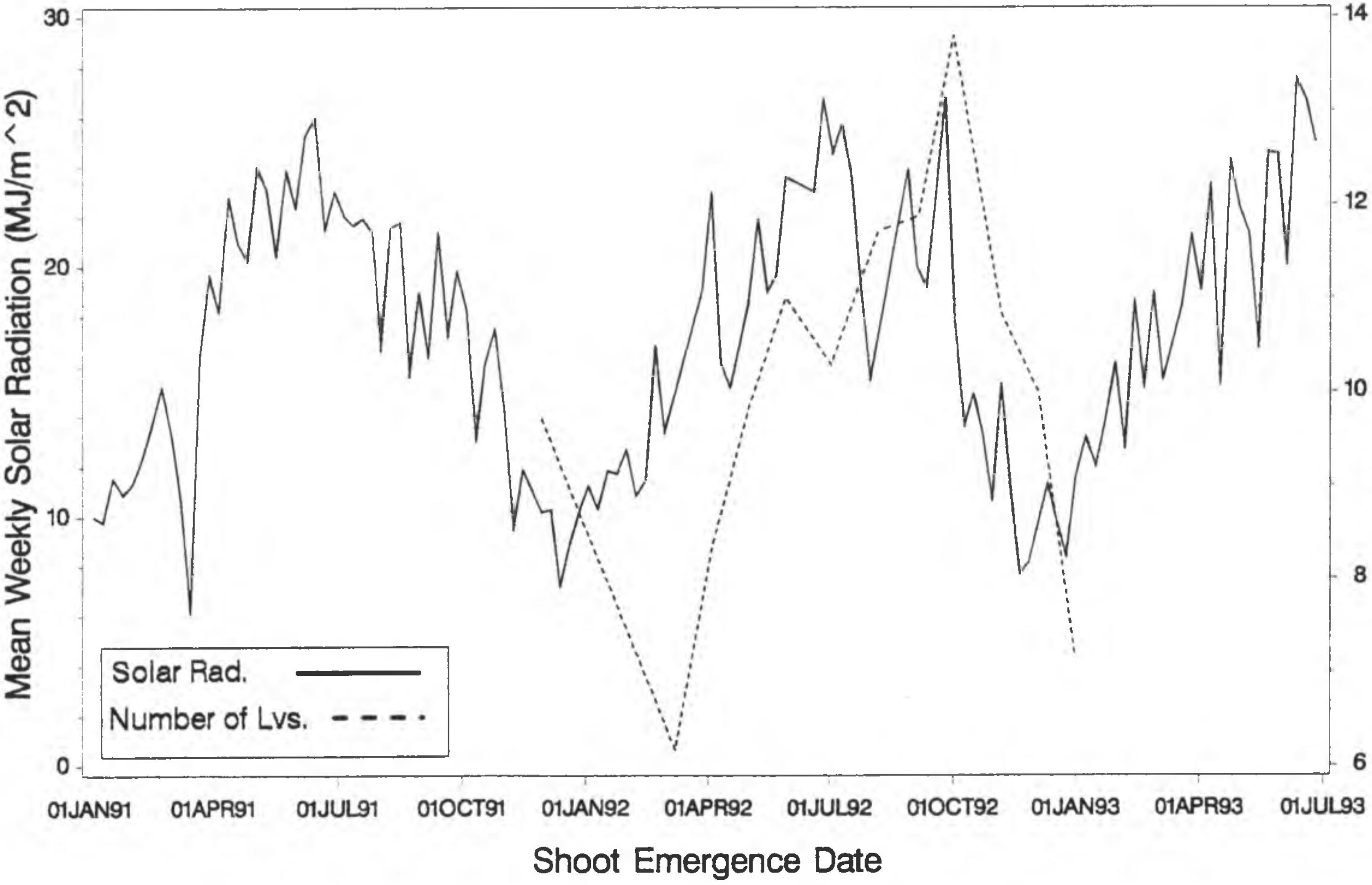


Figure 4.12

The weekly mean solar radiation from January 1991 to July 1993 and mean number of expanded leaves produced from shoot emergence for the month the shoots emerged at 13 sampling dates

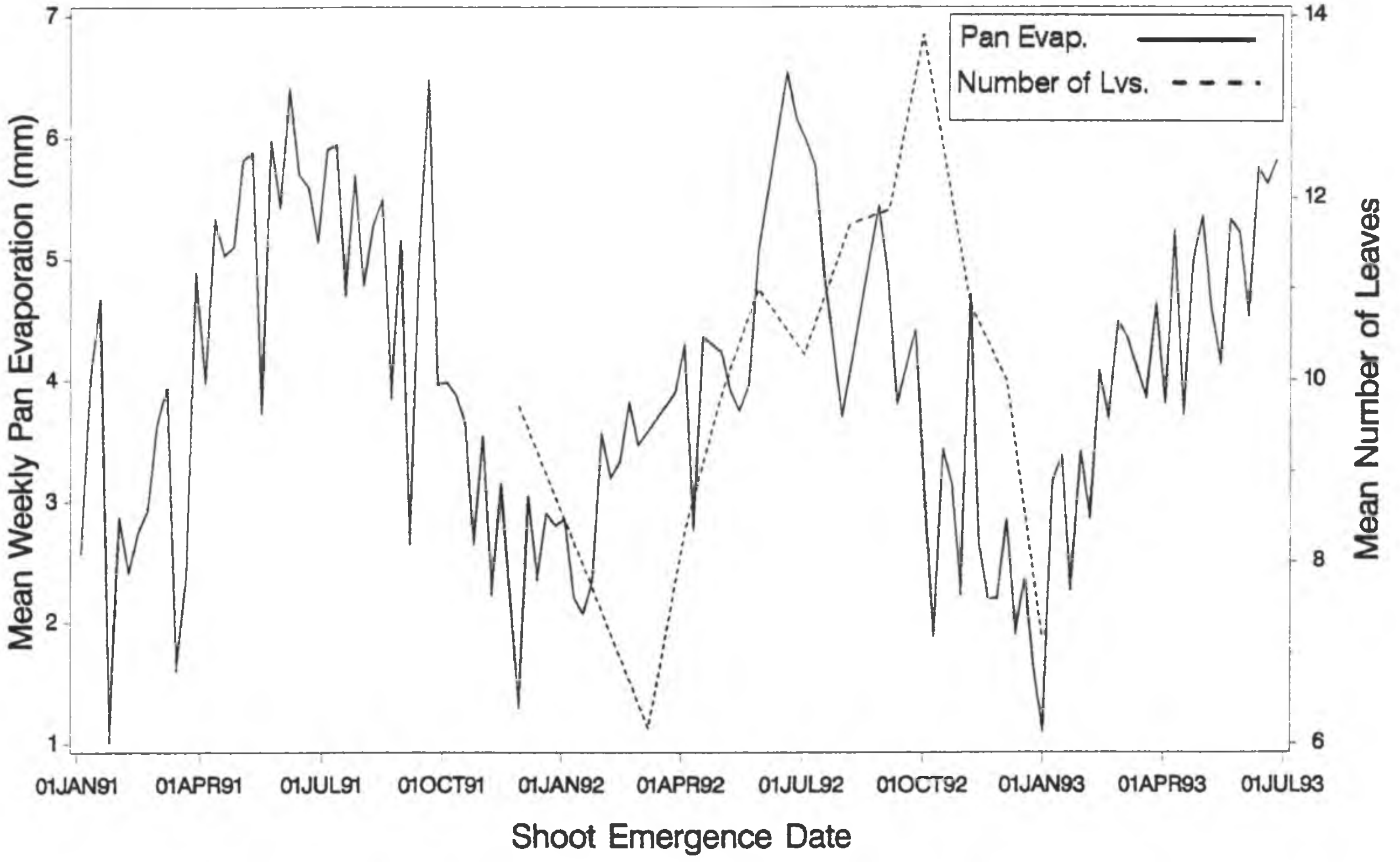


Figure 4.13

The weekly mean pan evaporation from January 1991 to July 1993 and mean number of expanded leaves produced from shoot emergence for the month the shoots emerged at 13 sampling dates

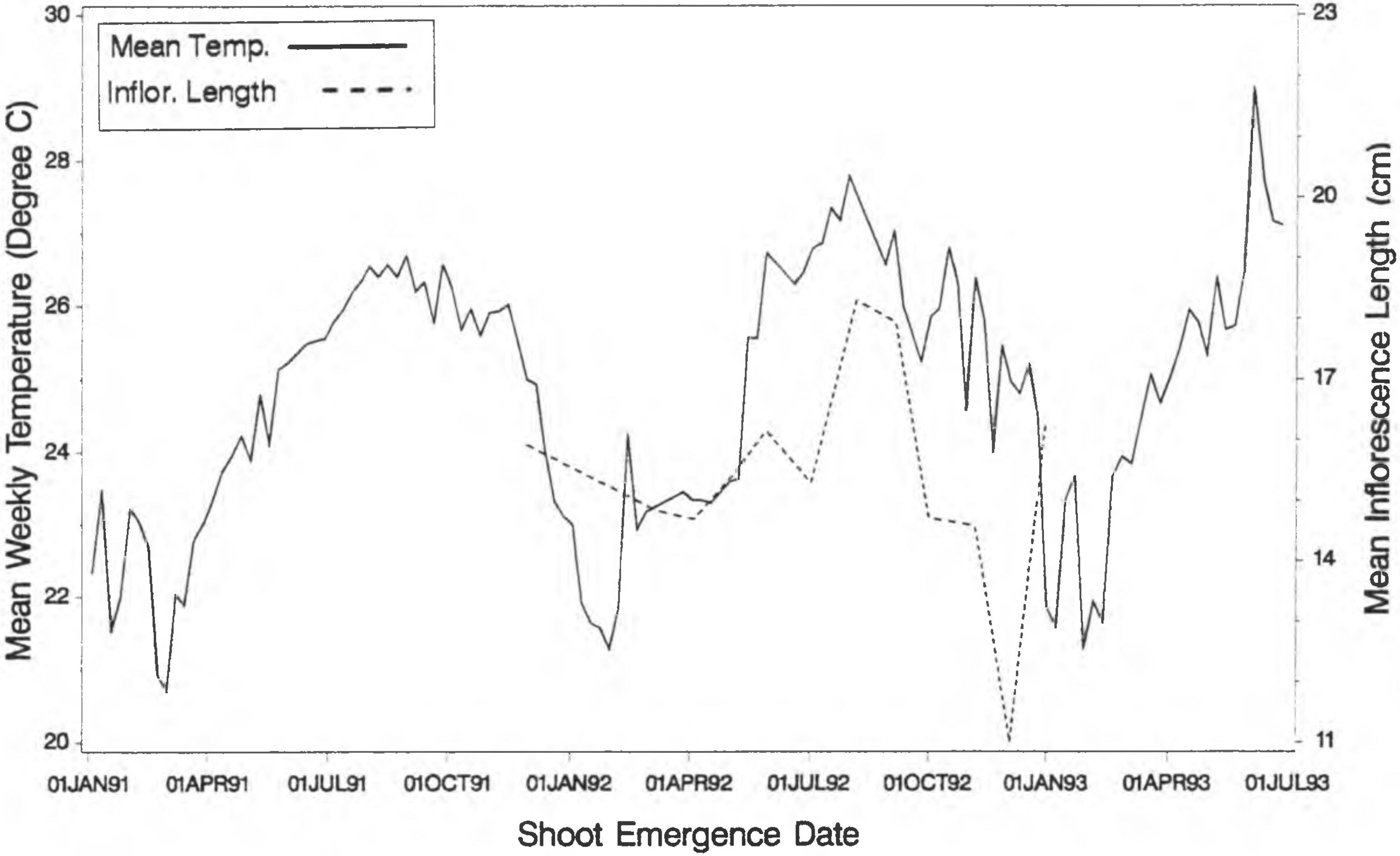


Figure 4.14

The weekly mean temperature from January 1991 to July 1993 and mean inflorescence length produced from shoot emergence for the month the shoots emerged at 13 sampling dates

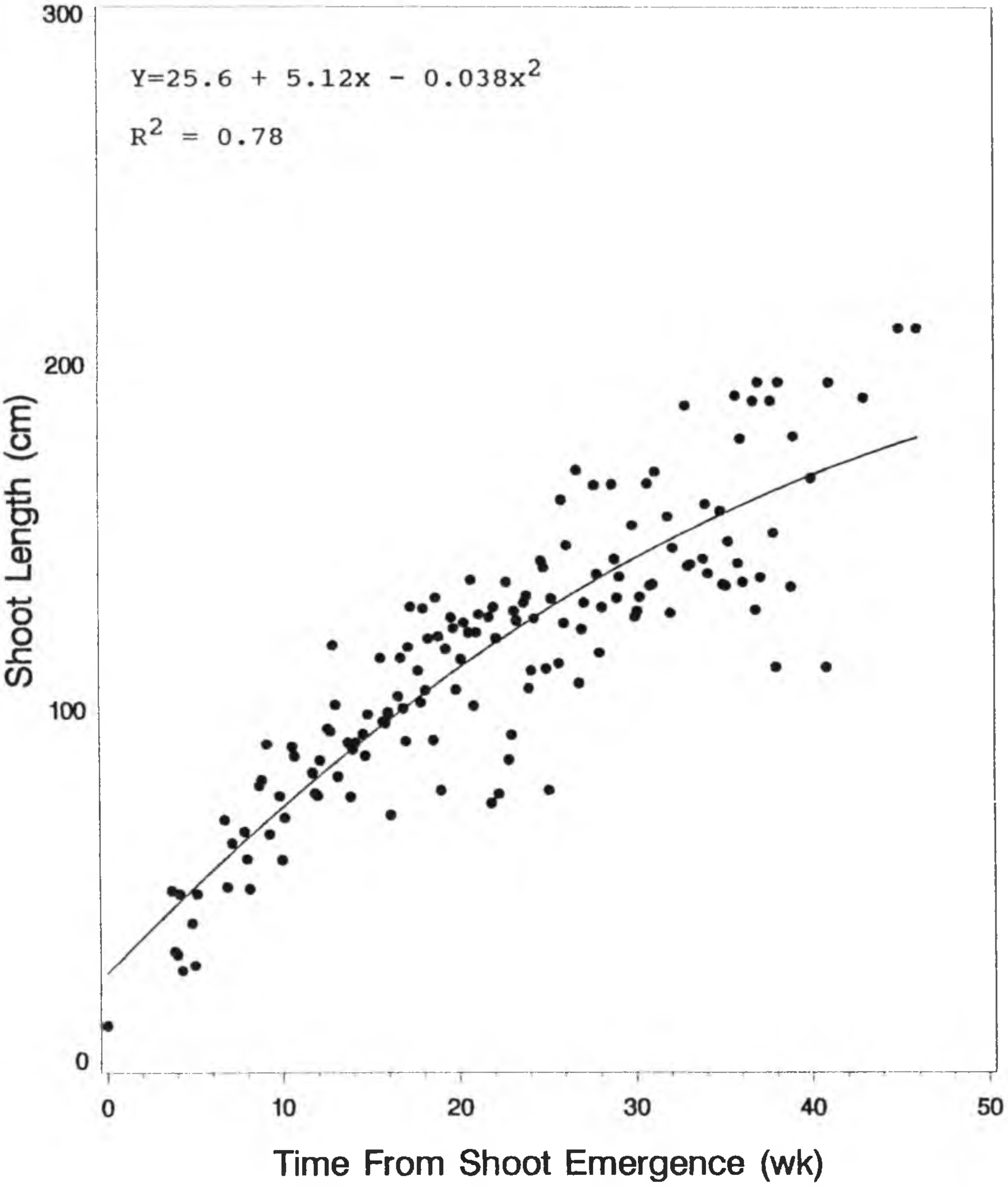


Figure 4.15

The mean shoot lengths for all shoots across all irrigation treatments and all cultivars over the number of weeks from shoot emergence for 13 sampling dates. $P<0.01$ for linear & quadratic, n=148.

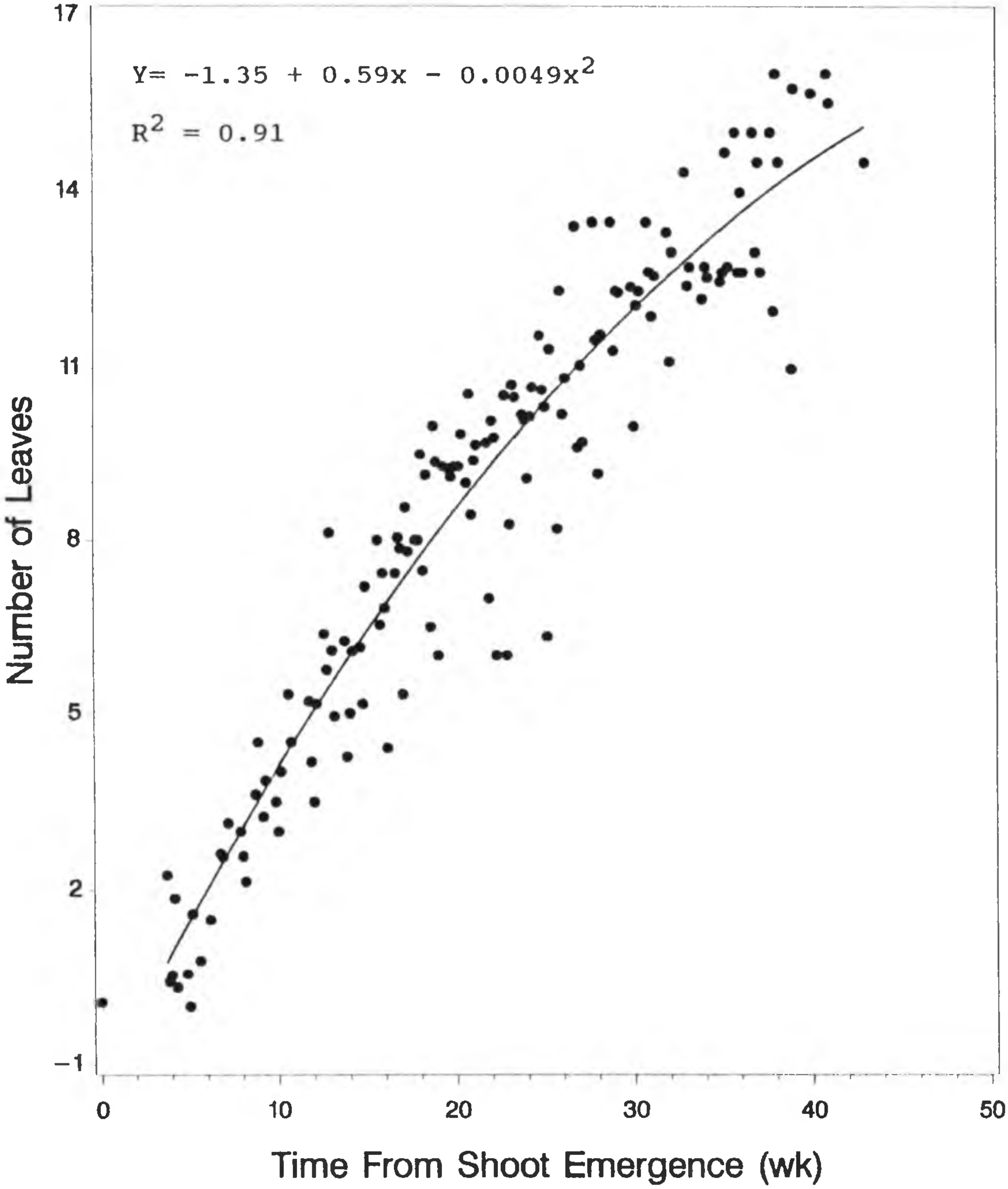


Figure 4.16

The mean number of expanded leaves per shoot for all shoots across all irrigation treatments and all cultivars over the number of weeks from shoot emergence for 13 sampling dates. $P<0.01$ for linear & quadratic, $n=148$.

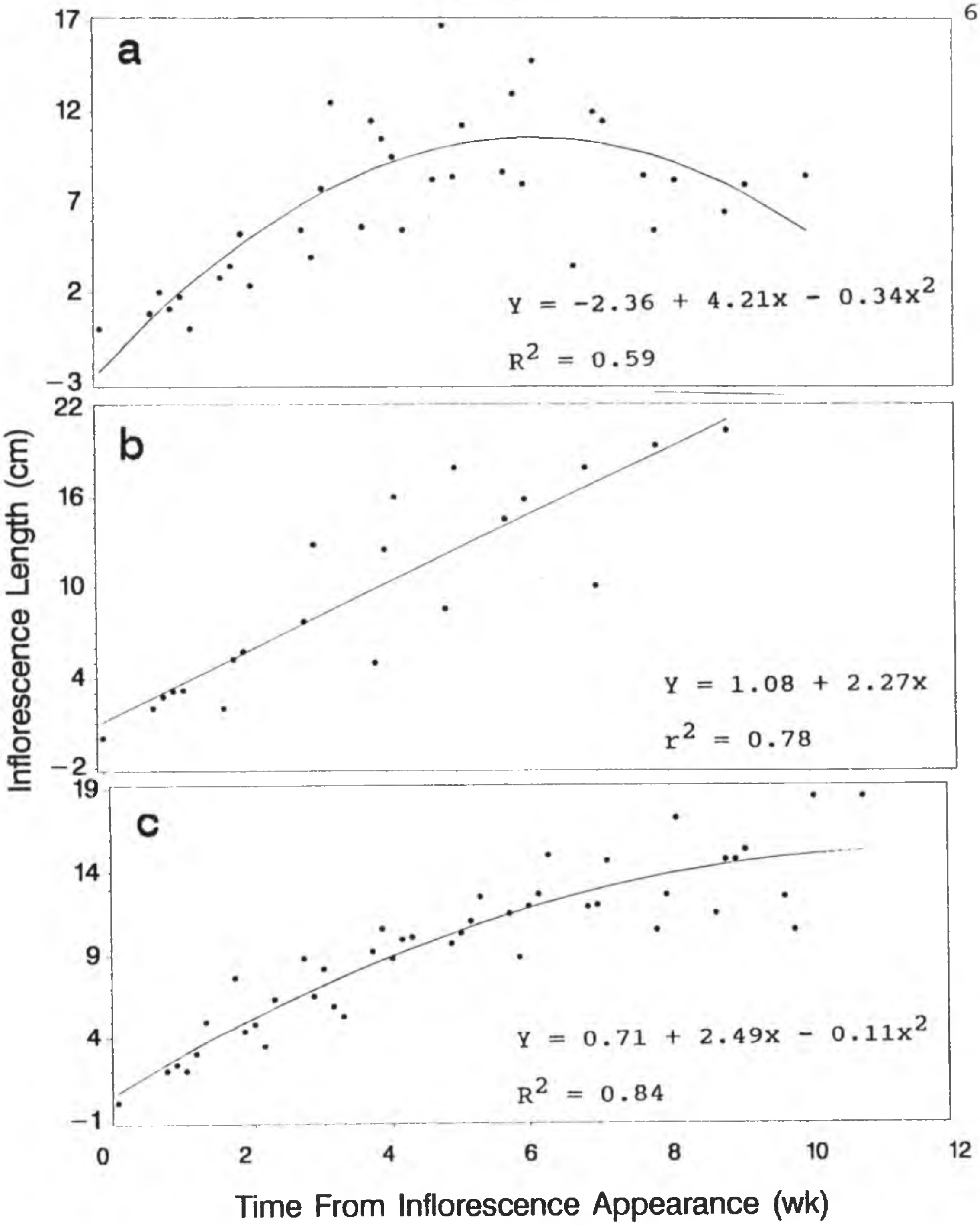


Figure 4.17

The mean inflorescence lengths for all shoots across all irrigation treatments for a) Ginoza, n=37; b) Red ginger, n=21; and c) 'Eileen McDonald', n=44 cultivars over the number of weeks from shoot emergence for 13 sampling dates. For Ginoza and 'Eileen McDonald', $P<0.01$ for linear & quadratic. For red ginger, $P<0.01$ for linear only.

The Ginoza cultivar produced the largest mean leaf area per shoot at harvest, and it was significantly greater from red ginger and 'Eileen McDonald' (Table 4.3).

Table 4.3

Cultivar means for total leaf area per shoot across all irrigation treatments for 7 sampling dates.[yz]

Cultivar	Total leaf area per shoot (cm^2)		n
'Eileen McDonald'	3086	a	815
Red ginger	2981	a	749
Ginoza	4737	b	994

[y] The means with the same letter are not significantly different as shown by the Waller-Duncan mean separation K-ratio=100 t test

[z] All comparisons were significant at < 1%

Inflorescence Initiation

To avoid differences in seasons, the September samples were analyzed separately from the shoots sampled in the summer to determine at what stage of growth inflorescence initiation occurred (Tables 4.4 and 4.5). Shoot length, number of expanded leaves, shoot base diameter, and length to growing point showed no significant linear effects among the irrigation treatments for July 1992 and June 1993 however, all variables were significant for quadratic effects at 10%. The ANOVA for cultivars showed no significant differences except for shoot diameter at the cut base. Data for cultivars were pooled for Table 4.4. The Ginoza cultivar had a significantly greater basal diameter

(3.9 mm) than did the other two cultivars, red ginger (2.7 mm) and 'Eileen McDonald' (2.5 mm).

Table 4.4

The pooled means of all dissected shoots ± SE which did or did not initiate inflorescences for July 1992 and June 1993.

	Initiated	Not initiate
Shoot length (cm)	89.0 ± 3.6	86.7 ± 16.3
Number of expanded leaves	5.3 ± 0.3	4.9 ± 1.5
Shoot base diameter (mm)	26.8 ± 1.1	27.4 ± 4.7
Length to growing point (cm)	46.4 ± 4.9	21.7 ± 9.2

Total number of shoots sampled = 60
Number of samples which initiated inflorescences = 23
Number which did not initiate inflorescences = 37

The same four variables in September 1992 also showed a significant difference between shoots which did and did not initiate inflorescences for length to the growing point (Table 4.5).

Table 4.5

The pooled means of all dissected shoots ± SE which did or did not initiate inflorescences for September, 1992.

	Initiated	Not initiate
Shoot length (cm)	86.0 ± 4.1	82.0
Number of expanded leaves	6.4 ± 0.4	4.0
Shoot base diameter (mm)	23.5 ± 2.8	----
Length to growing point (cm)	42.9 ± 7.2	15.0

Total number of shoots sampled = 8
Number of samples which initiated inflorescences = 7
Number which did not initiate inflorescences = 1

Inflorescence initiation occurred on shoots with as few as two or three expanded leaves (Table 4.6). Most of the shoots sampled were in the four to six expanded leaf range therefore more sampling of shoots with less than four expanded leaves were needed to determine inflorescence initiation.

Table 4.6

The pooled mean shoot lengths ± SE and frequencies for all dissected shoots which did or did not initiate inflorescences, and the corresponding number of expanded leaves for each shoot for July 1992 and June 1993.

# of expanded leaves	With inflorescences Shoot length (cm)	# Shoots	Without inflorescences Shoot length (cm)	# Shoots
2	68.2	1	57.1	1
3	61.7 ± 2.7	2	66.2 ± 1.7	6
4	93.1 ± 6.6	4	76.6 ± 2.9	9
5	76.9 ± 2.6	5	96.7 ± 2.7	8
6	95.8 ± 6.0	6	96.4 ± 4.2	8
7	106.4 ± 5.1	4	102.3 ± 3.6	3
8	98.2	1	106.0 ± 4.2	2

Clump Circumference & Clump Area

Circumference length and clump area showed no significant effect of irrigation treatments. Interestingly, the growth curves for all cultivars had similar slopes (Fig. 4.18).

Discussion

Shoot length, number of expanded leaves, and inflorescence length were affected by the water application rates. The shoot length and number of expanded leaves means

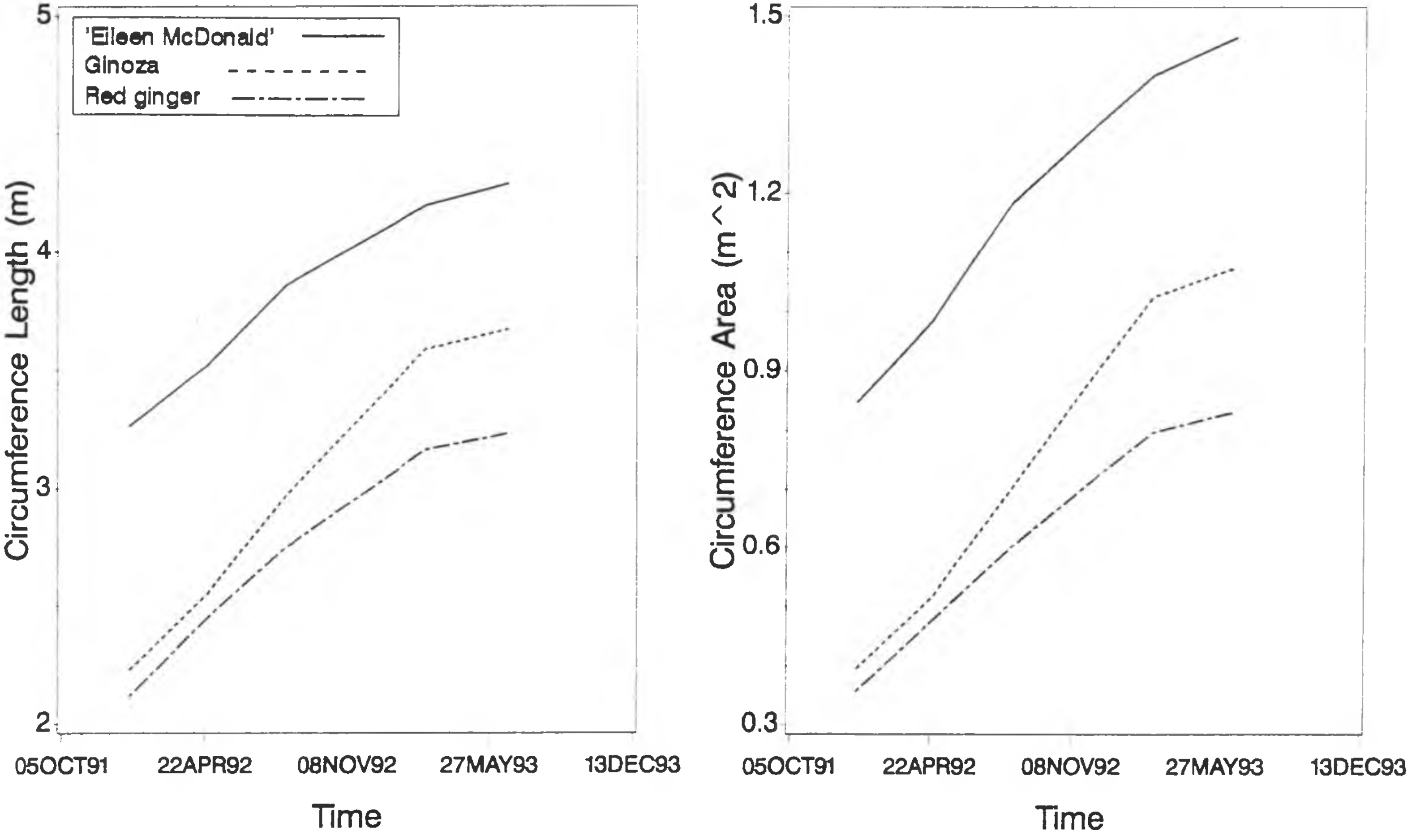


Figure 4.18

Mean circumference lengths and clump areas for all clumps across all irrigation treatments for each cultivar for 5 sampling dates for 'Eileen McDonald' and red ginger were not significantly different from each other but were significantly different from the Ginoza cultivar. For the inflorescence length means of 'Eileen McDonald' and the Ginoza cultivar, they were not significantly different from each other but were significantly different from red ginger. Red ginger was superior to 'Eileen McDonald' and the Ginoza cultivar because it produced the longest inflorescences in the shortest amount of time from shoot emergence to harvest, however, the Ginoza cultivar produced about the same inflorescence length all year round while there were greater fluctuations of the lengths for the other two cultivars.

The Ginoza cultivar produced the longest shoots with the most expanded leaves compared to the other two cultivars. The Ginoza inflorescences were more susceptible to bract tip burn than the other two cultivars. In order to avoid unmarketable inflorescences, there was a tendency to cut the Ginoza shoots before the inflorescences were fully elongated. This probably accounts for the short inflorescence lengths for the Ginoza cultivar. Another possible explanation for the decreasing inflorescence length in Fig. 4.17, is that even though inflorescence length did not seasonality, Fig. 4.14, it is possible that the inflorescences came from different times of the year. It's possible that the inflorescences that took longer to develop produced shorter inflorescences.

There were no irrigation treatment effects for the lengths of time to reach the stages of growth and development (Table 4.1, Fig. 4.19). Interestingly, the times to reach the stages were affected by cultivars. The length of time from shoot emergence to harvest for the Ginoza cultivar was approximately 30% greater compared to the other two cultivars.

Seasonality

Except for inflorescence length, the shoots which emerged during autumn (November) were longer and produced more expanded leaves than for shoots which emerged during March and April. The shoots that emerged in March and April were exposed to longer days, increasing temperatures, and increasing solar and net radiation. These conditions also resulted in more water being applied to the plants due to higher pan evaporation (Appendix C) and appeared to promote shorter shoot lengths and fewer expanded leaves. This is similar to the growing degree days/heat unit concepts. The shoots that emerged in autumn were exposed to cooler temperatures, approximately 4^{o}C cooler, and decreasing solar and net radiation which also resulted in less water applied to the plants due to lower pan evaporation values. These

Dissected Shoots

The shoots sampled in July 1992 and June 1993 did not differ from the shoots sampled in September, 1992 (Tables

4.4 and 4.5). It may be possible that the amount of time between these two sampling periods was not large enough to produce seasonal differences for the measured variables.

Although sample numbers were limited, 30% of shoots bearing three or fewer leaves had initiated an inflorescence. The percentage increased to 40% as leaf number increased, but as all shoots eventually flower, the sample was insufficient to ascertain whether a threshold leaf number existed for 100% flowering. Shoots with 2 and 3 expanded leaves initiated an inflorescence (Table 4.6), but since only a few samples were taken in this range, it would be difficult to determine at what leaf number inflorescence initiation occurred.

Total Leaf Area per Shoot

Leaf area per shoot was the greatest for the highest irrigation treatment, while the leaf area for Ginoza cultivar shoots were significantly larger than for the other two cultivars.

Clump Circumference & Clump Area

There were no irrigation treatment effects for circumference length and clump area. 'Eileen McDonald' was planted in the field earlier than the other two cultivars which resulted in significantly larger circumference lengths and clump areas. The growth curves for each cultivar had similar slopes (Fig. 4.18).

In summary, all of the stages of growth and development have been determined with the exception for inflorescence initiation. The regression equations produced by the growth curves for shoot lengths and number of expanded leaves were used to calculate the expected shoot lengths and number of expanded leaves associated with the stages (Fig. 4.19). The developmental stages were not affected by the irrigation treatments but rather were more affected by the cultivars and seasonal fluctuations of climatic conditions.

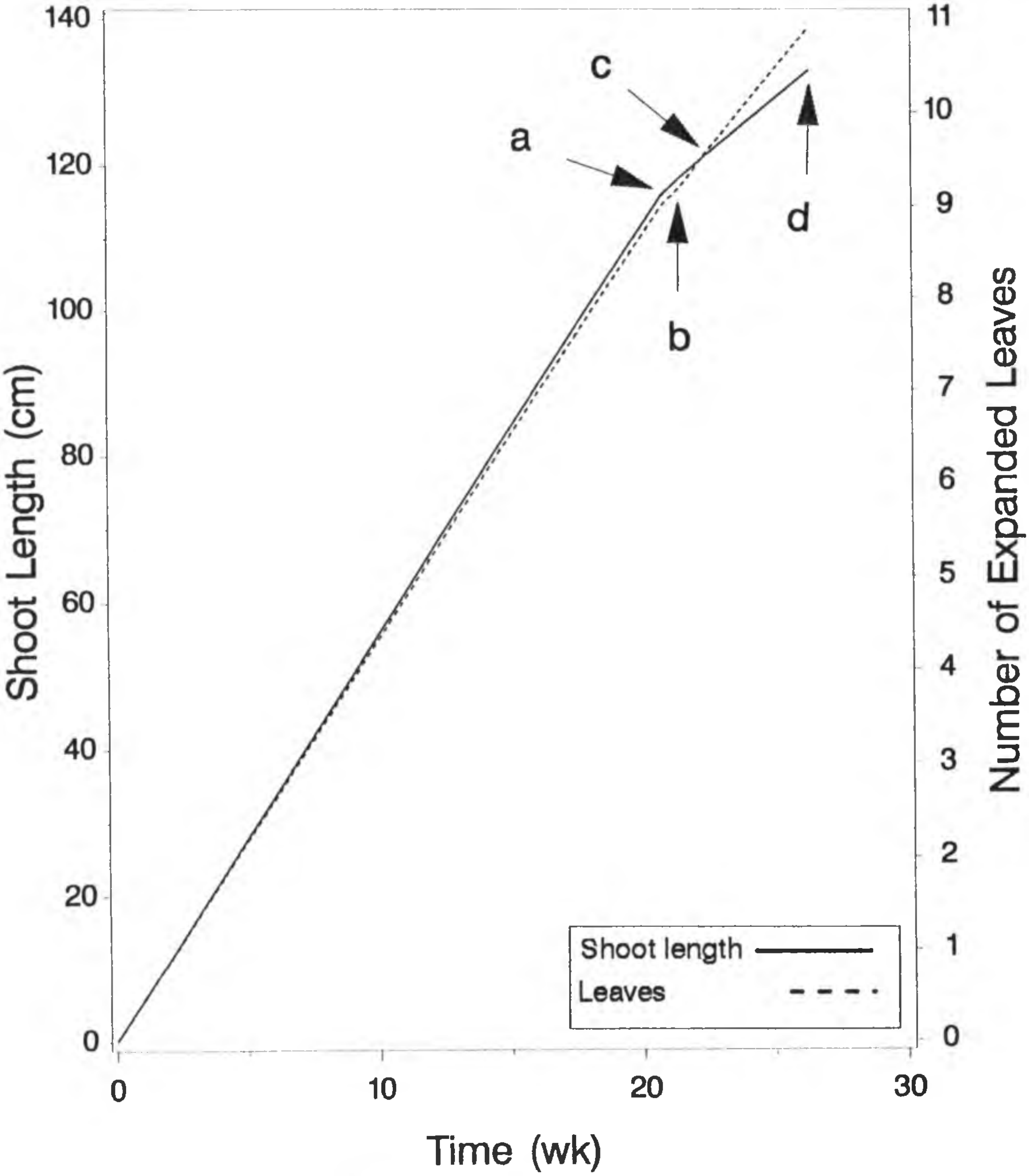


Figure 4.19

The pooled expected times from shoot emergence to: a) appearance of color, b) inflorescence swelling, c) inflorescence appearance, and d) harvest with shoot lengths and number of expanded leaves for each stage conditions favored production of longer shoots with more expanded leaves.

Chapter 5

The Effect of the Range of Water Application Rates by Drip On Inflorescence Quality and Quantity Over 18 Months

The purpose of this research was to determine the effect of water application rates on the number of inflorescences produced and their quality over 18 months from November 1991 to May 1993. Inflorescence quality was defined by the numeric variables of inflorescence length and diameter, and shoot length and diameter.

Results

The result of the regression analysis performed on the tweleve month total yield for the period of 29 May 1992 to 28 May 1993 harvested per clump across all cultivars showed a significant linear effect at < 1% for the pan factors of the irrigation treatments (Fig. 5.1). The regression produced an increase in the number of inflorescences per clump with the increasing irrigation treatments.

The Ginoza cultivar produced significantly fewer inflorescences per clump than the other two cultivars (Table 5.1). The production was two-thirds of the other cultivars.

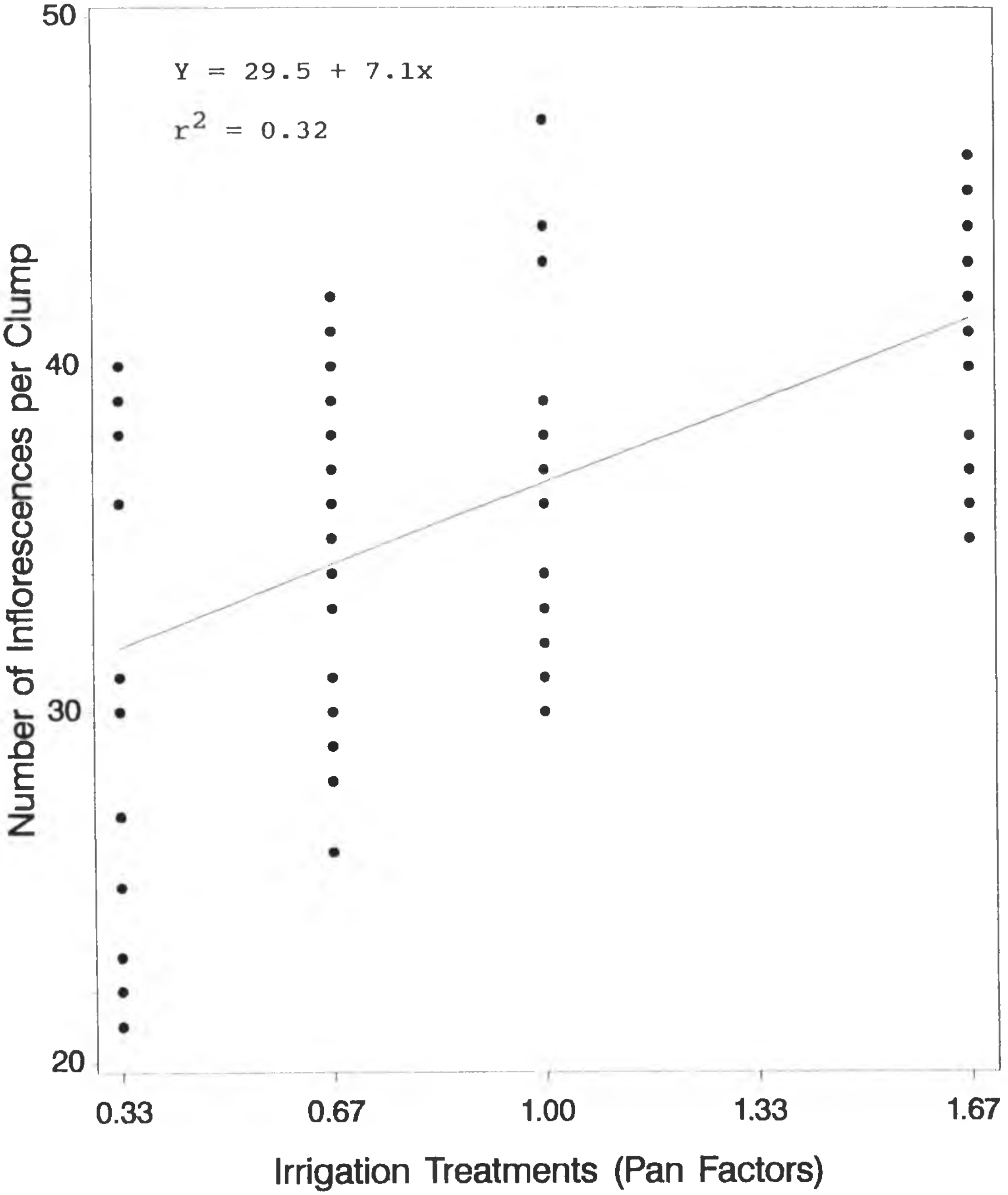


Figure 5.1

The result of the regression of the twelve month total yield harvested per clump against the irrigation treatments across all cultivars for the period from 29 May 1992 to 28 May 1993, n=72

Table 5.1

Cultivar means for the number of inflorescences harvested per clump across all irrigation treatments for 18 months.^{z}

Cultivar	Mean	N
Ginoza	87.6 a	24
'Eileen McDonald'	119.4 b	36
Red ginger'	124.8 b	12

^{z}Means with the same letter are not significantly different as shown by the Waller-Duncan mean separation K-ratio=100 t test

Inflorescence length and diameter, and shoot length and diameter for each cultivar, produced significant linear irrigation treatment effects (Appendix B).

The Ginoza cultivar produced significantly shorter inflorescences but longer shoots than the other two cultivars (Table 5.2). The cultivar means for inflorescence and shoot diameters were significantly different. The range between the largest and smallest inflorescence diameter and shoot diameter means were 0.5 cm and 0.7 mm respectively, and were not practically different.

Table 5.2

Cultivar means for inflorescence length and diameter, and shoot length and diameter across all irrigation treatments for 18 months[y][z]

	Inflor. Length (cm)	Inflor. diameter (cm)	Shoot length (cm)	Shoot diameter (mm)
'Eileen McDonald'	19.8 b	4.9 a	104.6 a	13.3 b
Red ginger	19.7 b	5.4 c	117.2 b	12.9 a
Ginoza	15.3 a	5.2 b	141.0 c	13.6 c

[y] Means with the same letter are not significantly different as shown by the Waller-Duncan mean separation K-ratio=100 t test

[z] All comparisons were significant at < 1%

Seasonality Effects

The number of inflorescences per clump for the lowest and highest pan factors were plotted against time of harvest (Fig. 5.2). The same seasonal trends occurred for both pan factors therefore the assumption was made that the intermediate pan factors fell within this range. Pan factor 1.67 was thus selected to represent the irrigation treatment trend to compare against the environmental variables.

Inflorescence yield per clump increased rapidly in May 1992 which may be due to the increasing temperatures and solar radiation starting in February. The increasing environmental variables produced a flush of inflorescences which then decreased in July (Figs. 5.3 to 5.5).

Inflorescence length was apparently inversely related to temperature, solar radiation, and pan evaporation as longer inflorescences were harvested in the winter and

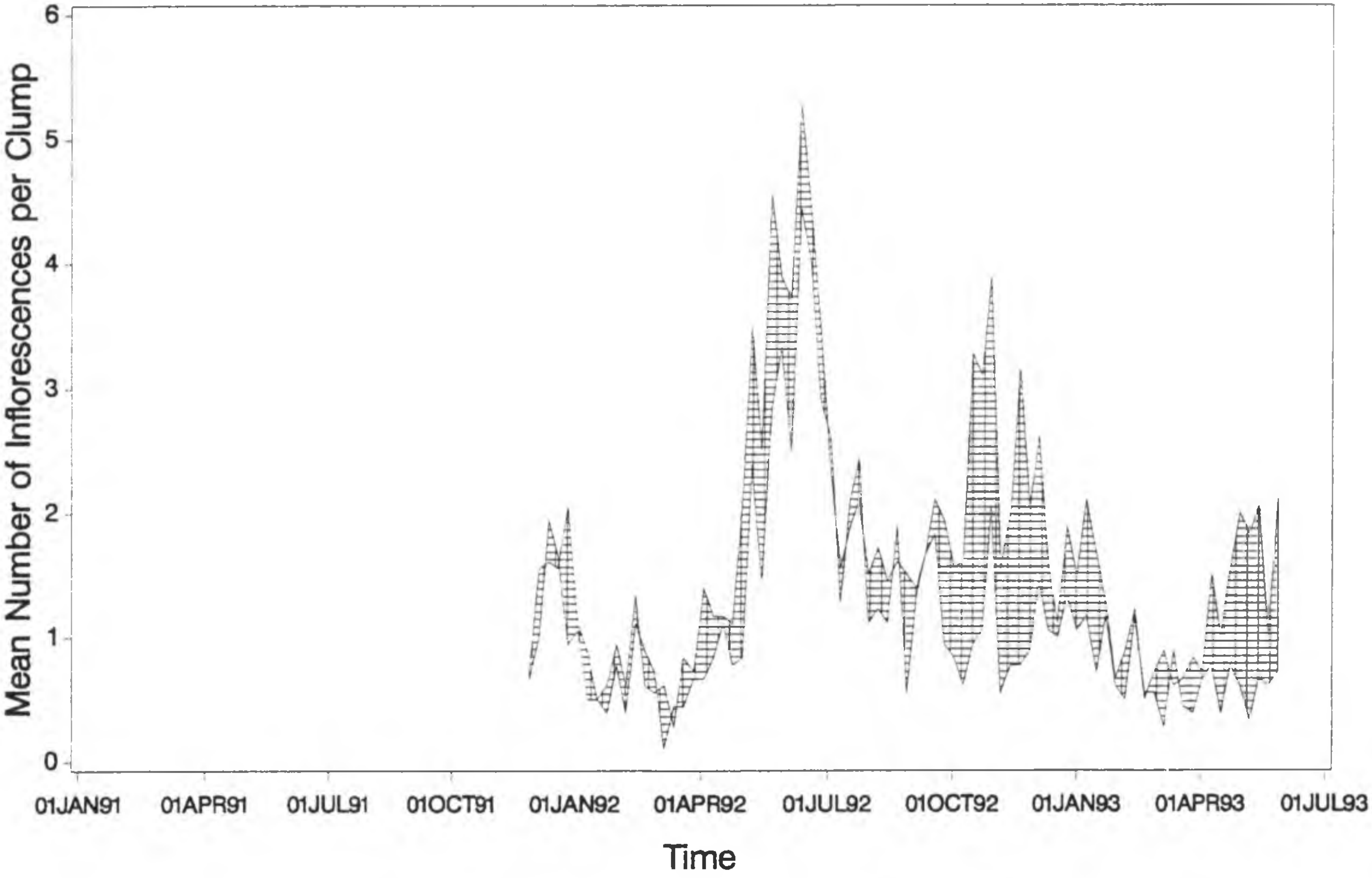


Figure 5.2

The shaded portion represented the range between irrigation treatments 0.33 (bottom line) and 1.67 (top line) for the mean weekly number of inflorescences per clump harvested from November 1991 to May 1993

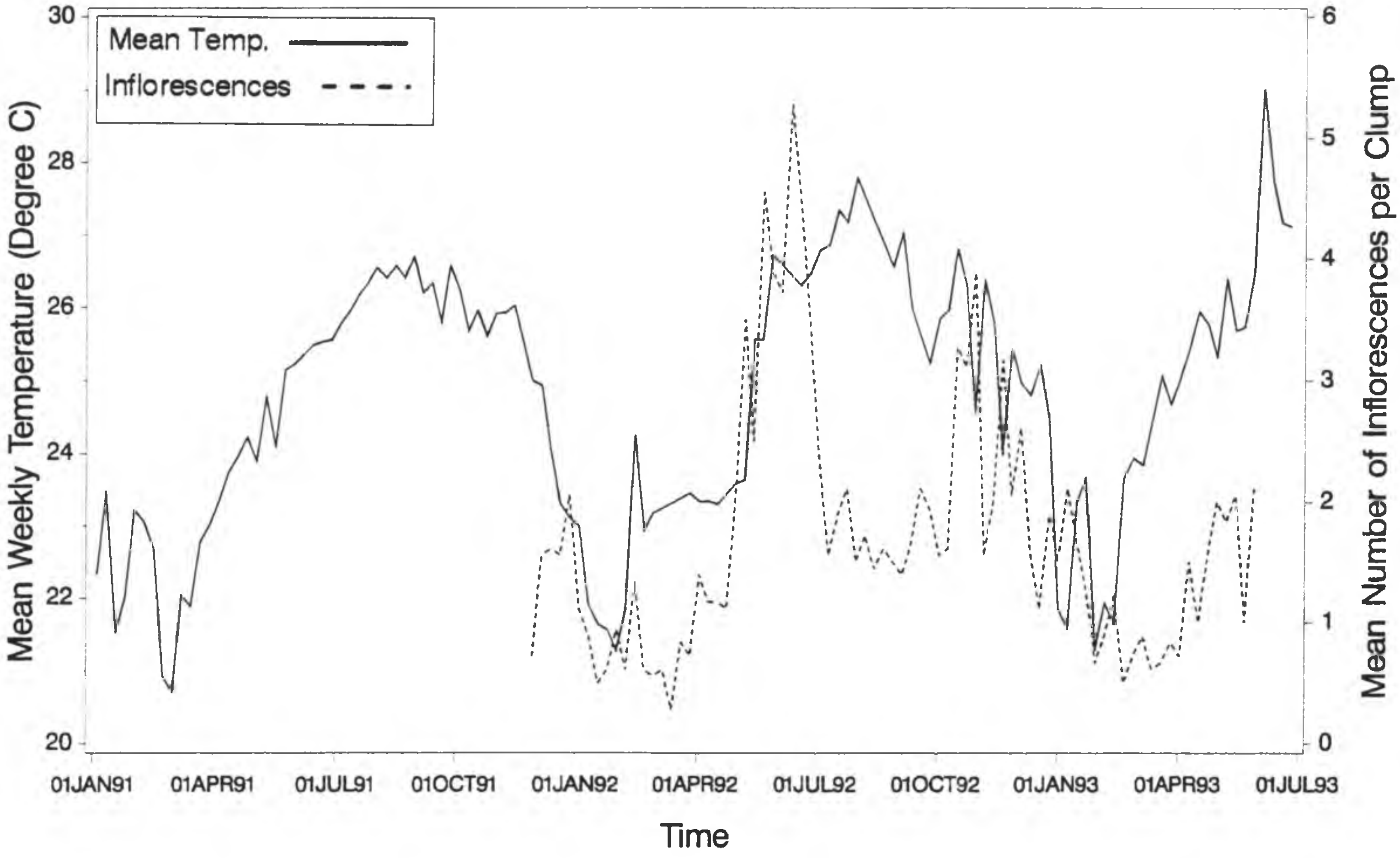


Figure 5.3

Mean weekly temperature calculated from mean daily temperatures from January 1991 to July 1993 and mean weekly number of inflorescences per clump harvested from November 1991 to May 1993 for pan factor 1.67

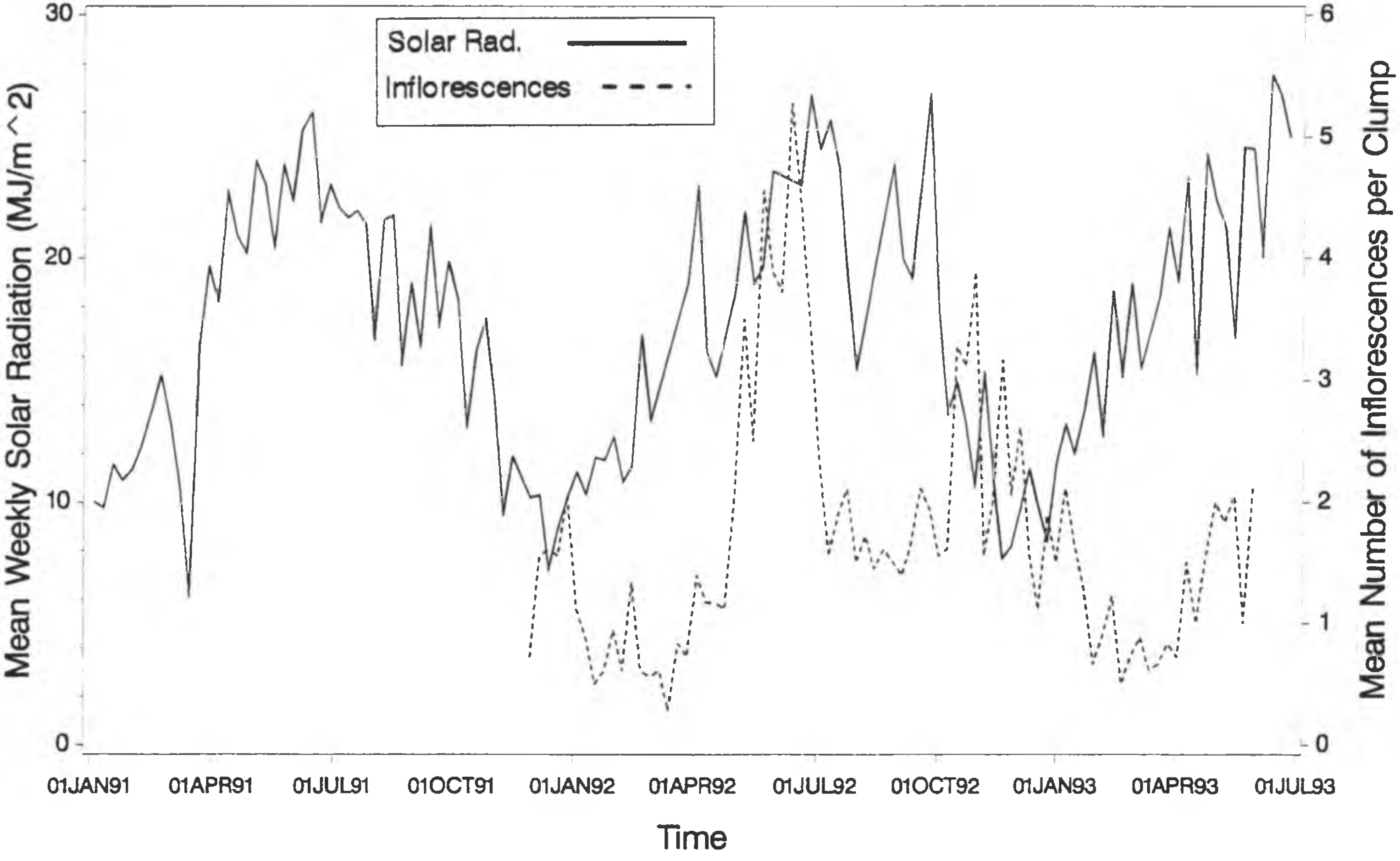


Figure 5.4

Mean weekly solar radiation calculated from total daily solar radiation from January 1991 to July 1993 and mean weekly number of inflorescences per clump harvested from November 1991 to May 1993 for pan factor 1.67

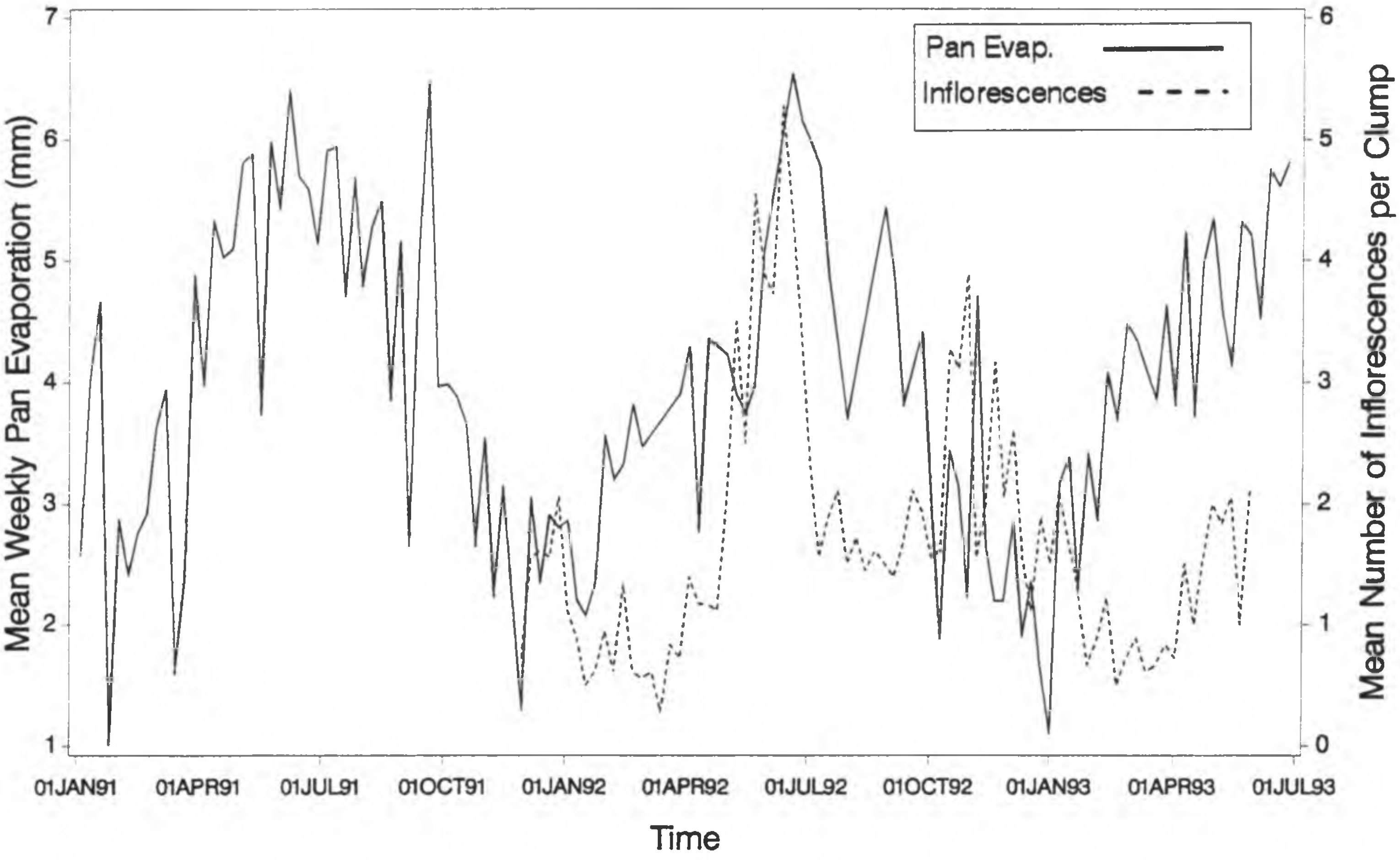


Figure 5.5

Mean weekly pan evaporation calculated from total daily pan evaporation from January 1991 to July 1993 and mean weekly number of inflorescences per clump harvested from November 1991 to May 1993 for pan factor 1.67

spring compared to shorter inflorescences harvested in the summer (Fig. 5.6 to 5.9). Aside from the winters of 1991 and 1992 versus summer of 1992, inflorescence diameter did not show a clear seasonal trend (Fig. 5.10)

Shoot diameter and length also showed seasonality (Figs. 5.11 to 5.18). Thicker and longer shoots were harvested in the winter with thinner and shorter shoots harvested in the summer.

Higher quality inflorescences were harvested in the winter and spring. The influence of increasing mean temperature, solar radiation, and pan evaporation appear to improve inflorescence quality in the winter and spring.

A little more than half of the total inflorescences harvested were Standard grade, while one-quarter were Small, and one-fifth were Fancy (Table 5.3.1). One of the interesting results of this research would be the distribution of inflorescences across the irrigation treatments. The null hypothesis for the chi-square analysis was that the irrigation treatments had no effect on the inflorescence grades.

The column percent table shows the changes in distribution within a grade level changes (Table 5.3.2). The percent distribution for the Standard grade, was nearly identical to the totals for each irrigation treatment located in the far right column in Table 5.3.1. There was a percentage increase of Small grade inflorescences for the two lowest pan factors of the irrigation treatments when

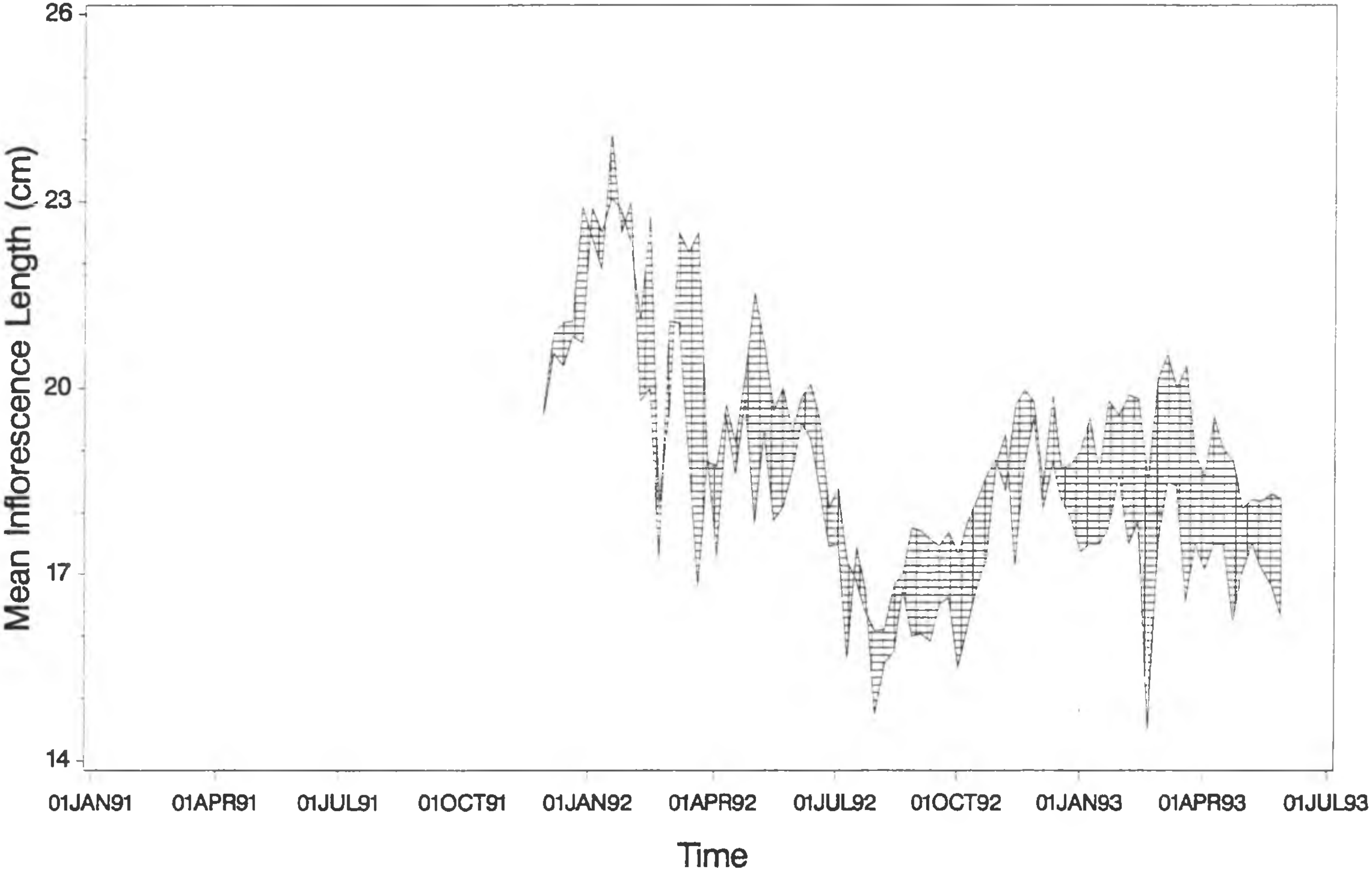


Figure 5.6

The shaded portion represented the range between irrigation treatments 0.33 (bottom line) and 1.67 (top line) for the mean weekly inflorescence length harvested from November 1991 to May 1993

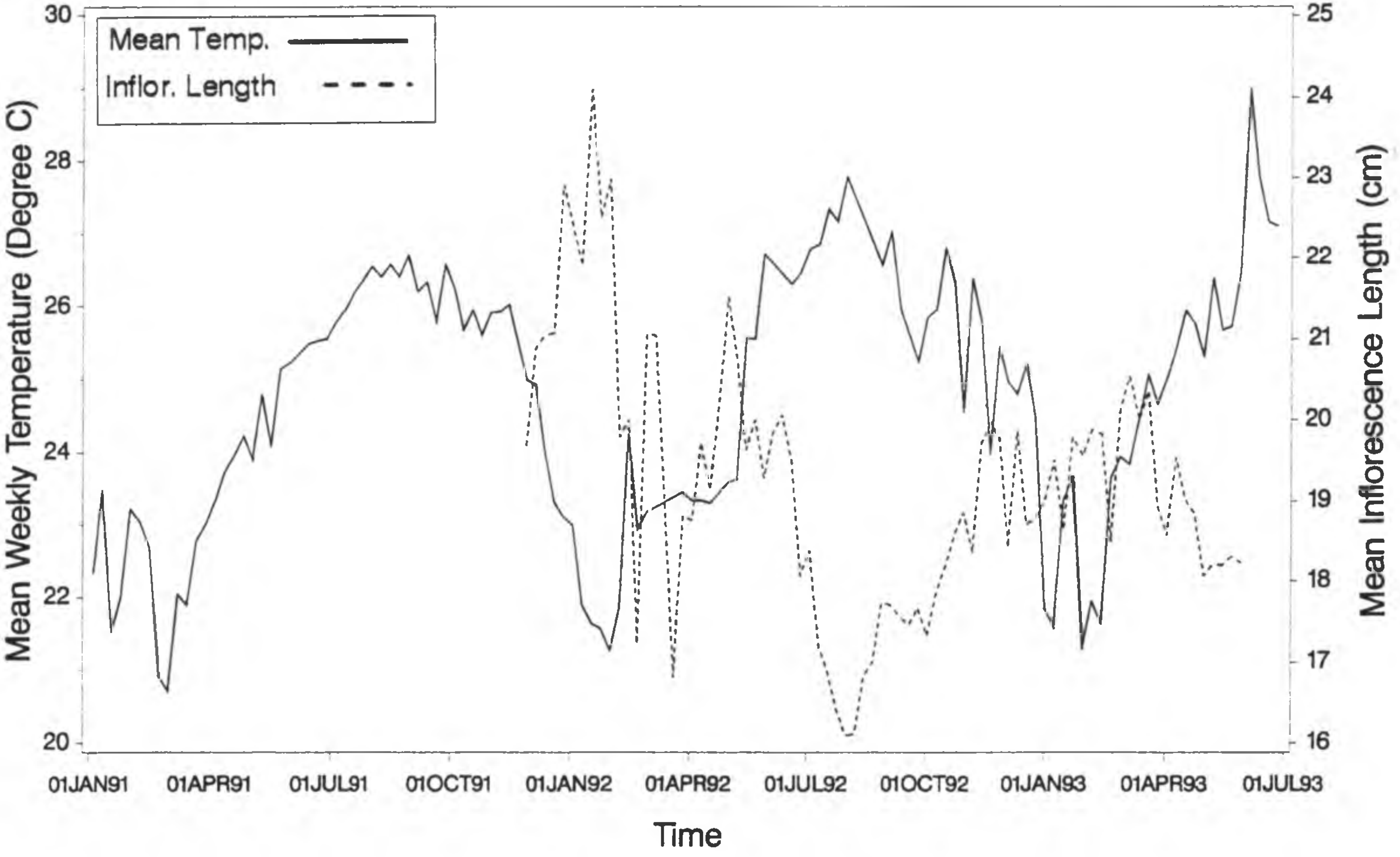


Figure 5.7

Mean weekly temperature calculated from mean daily temperatures from January 1991 to July 1993 and mean weekly inflorescence length harvested from November 1991 to May 1993 for pan factor 1.67

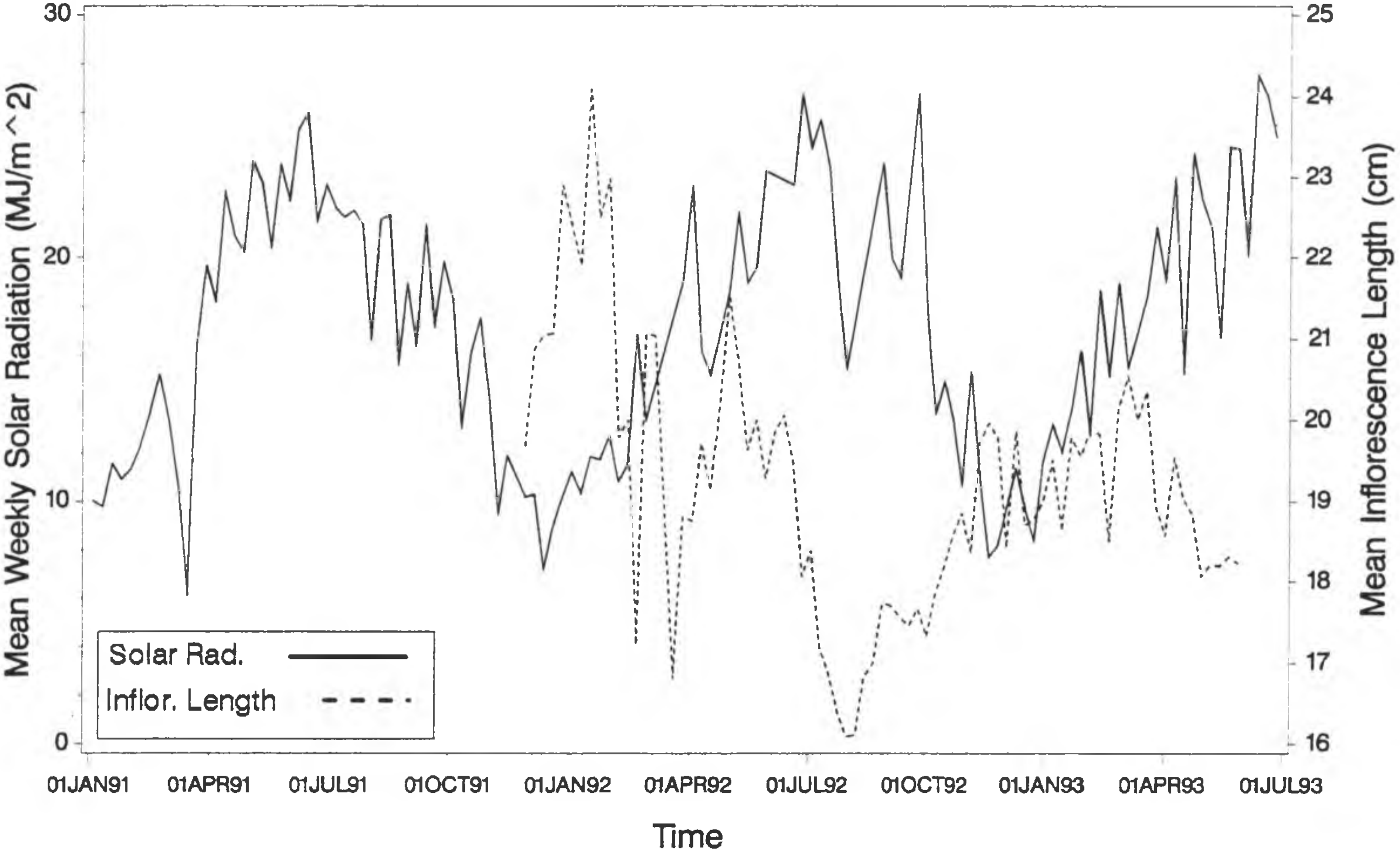


Figure 5.8

Mean weekly solar radiation calculated from total daily solar radiation from January 1991 to July 1993 and mean weekly inflorescence length harvested from November 1991 to May 1993 for pan factor 1.67

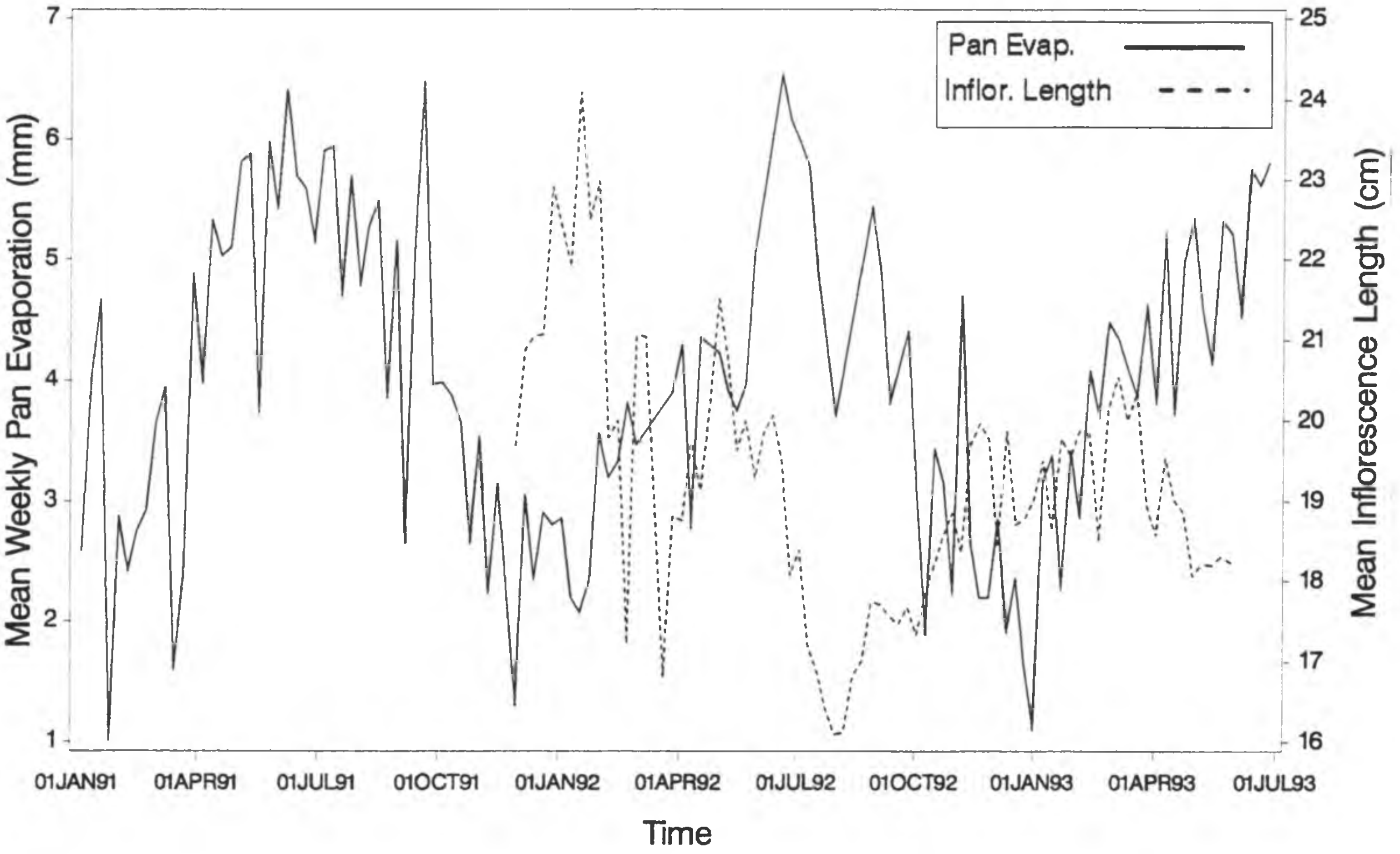


Figure 5.9

Meam weekly pan evaporation calculated from total daily pan evaporation from January 1991 to July 1993 and mean weekly inflorescence length harvested from November 1991 to May 1993 for pan factor 1.67

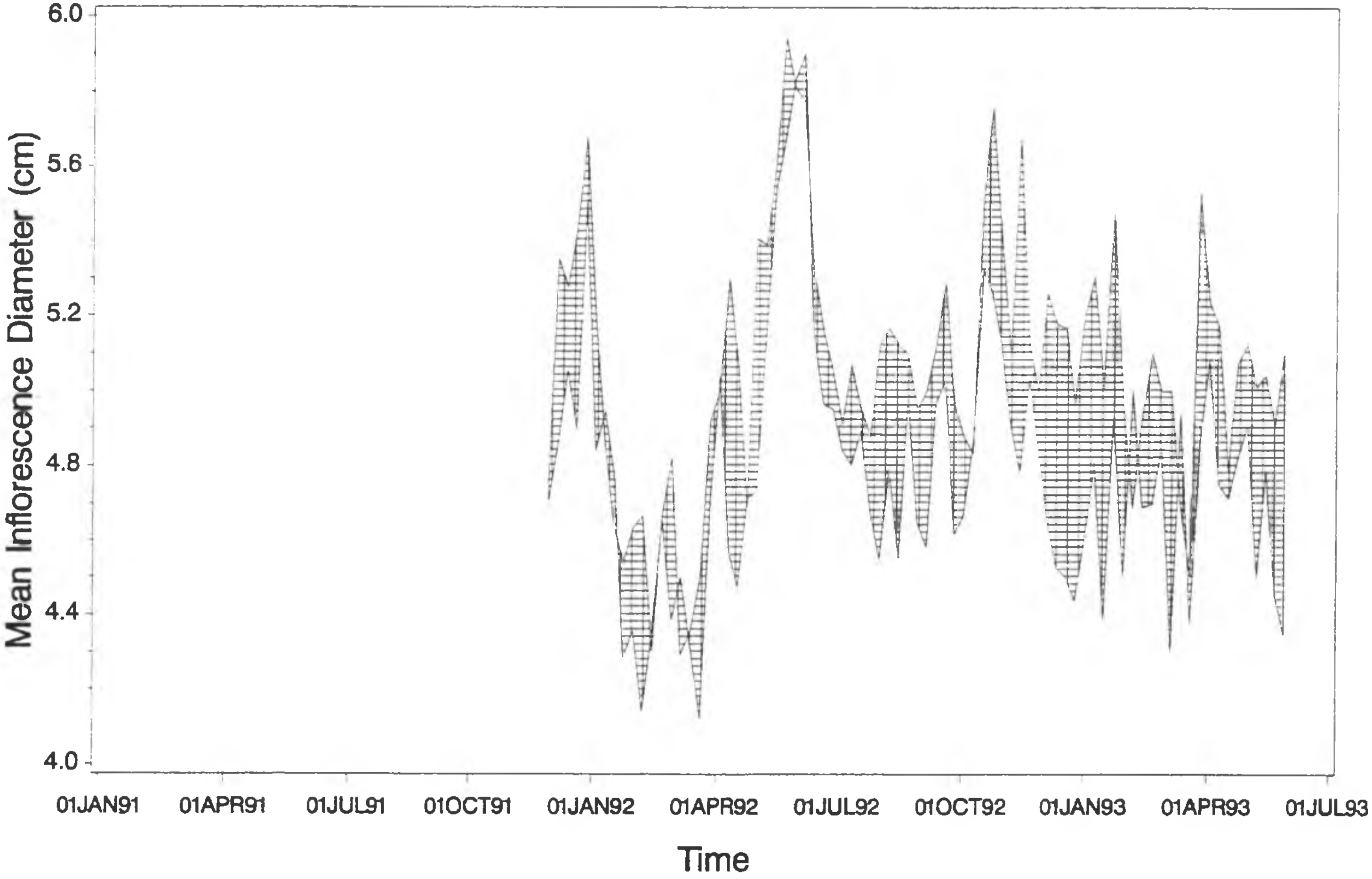


Figure 5.10

The shaded portion represented the range between irrigation treatments 0.33 (bottom line) and 1.67 (top line) for the mean weekly inflorescence diameter harvested from November 1991 to May 1993

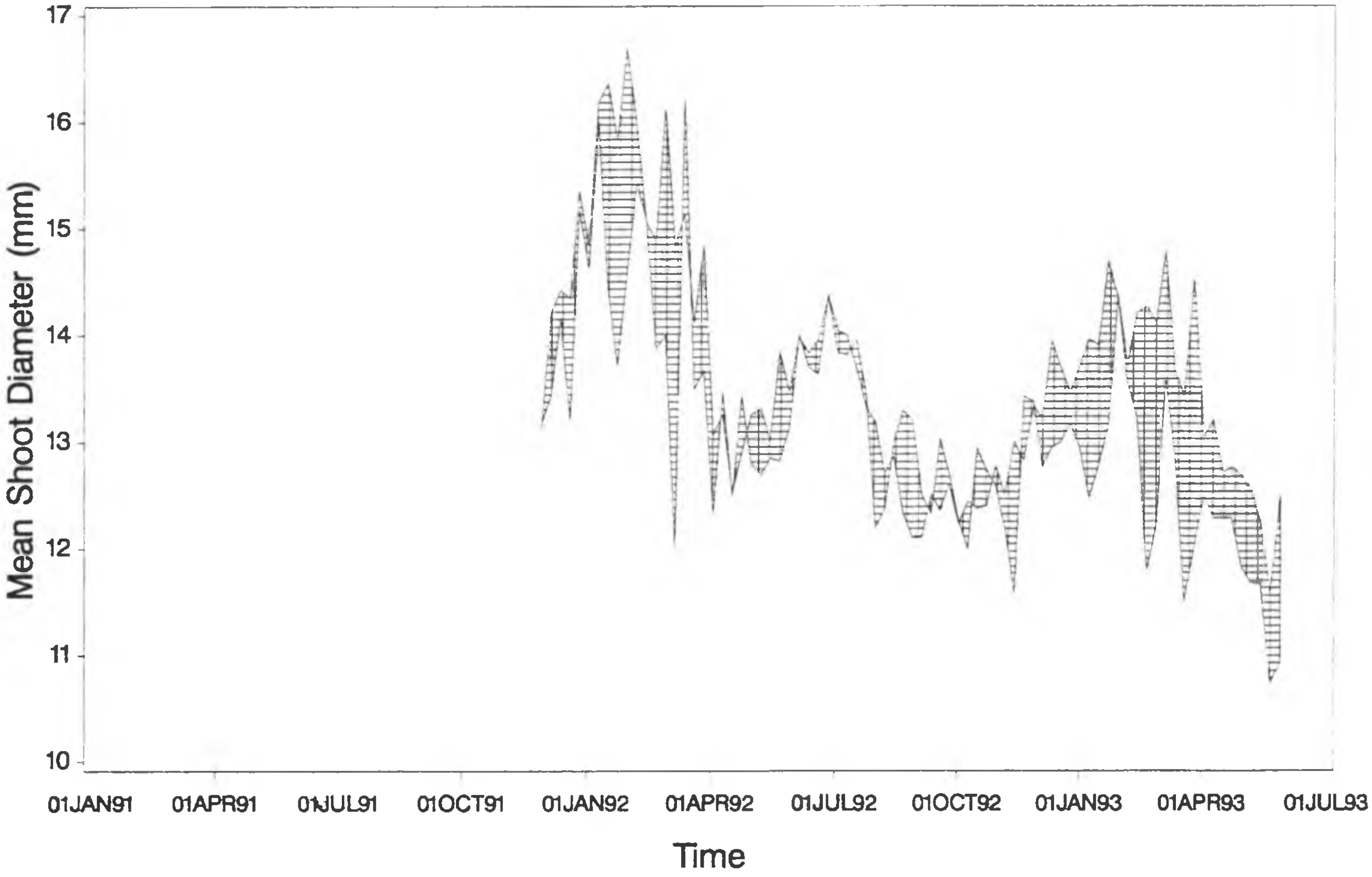


Figure 5.11

The shaded portion represented the range between irrigation treatments 0.33 (bottom line) and 1.67 (top line) for the mean weekly shoot diameter from November 1991 to May 1993

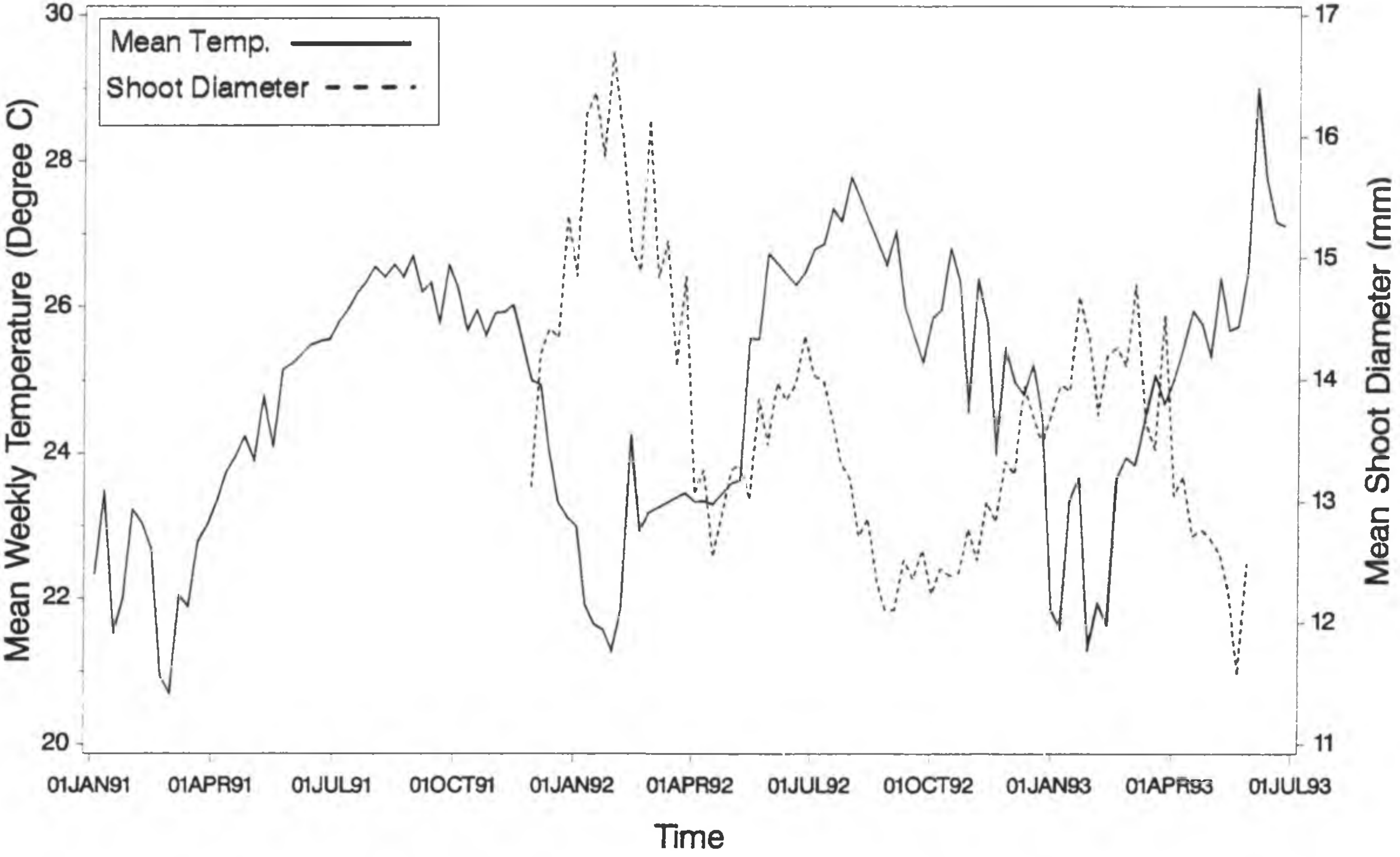


Figure 5.12

Mean weekly temperature calculated from mean daily temperatures from January 1991 to July 1993 and mean weekly shoot diameter harvested from November 1991 to May 1993 for pan factor 1.67

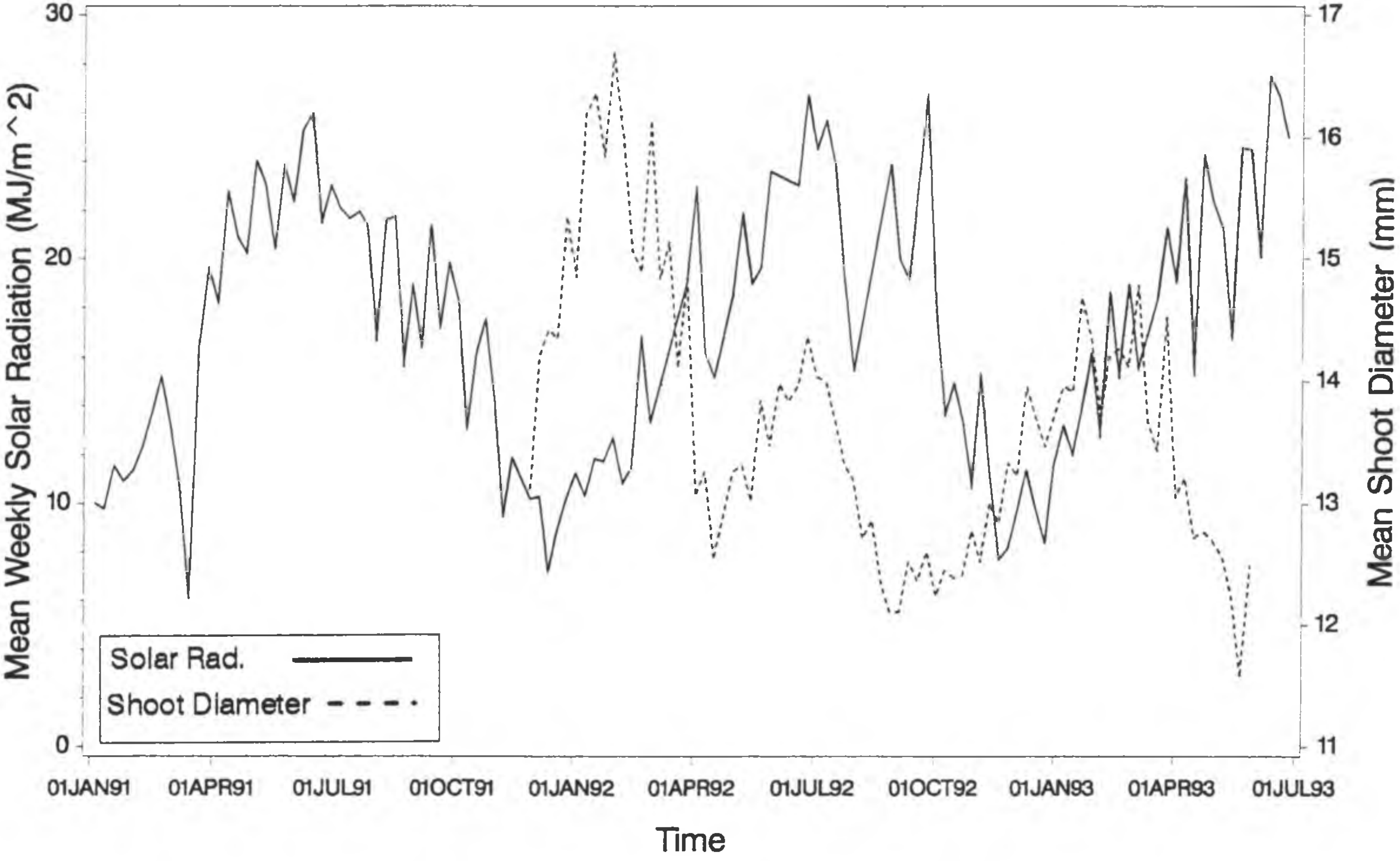


Figure 5.13

Mean weekly solar radiation calculated from total daily solar radiation from January 1991 to July 1993 and mean weekly shoot diameter harvested from November 1991 to May 1993 for pan factor 1.67

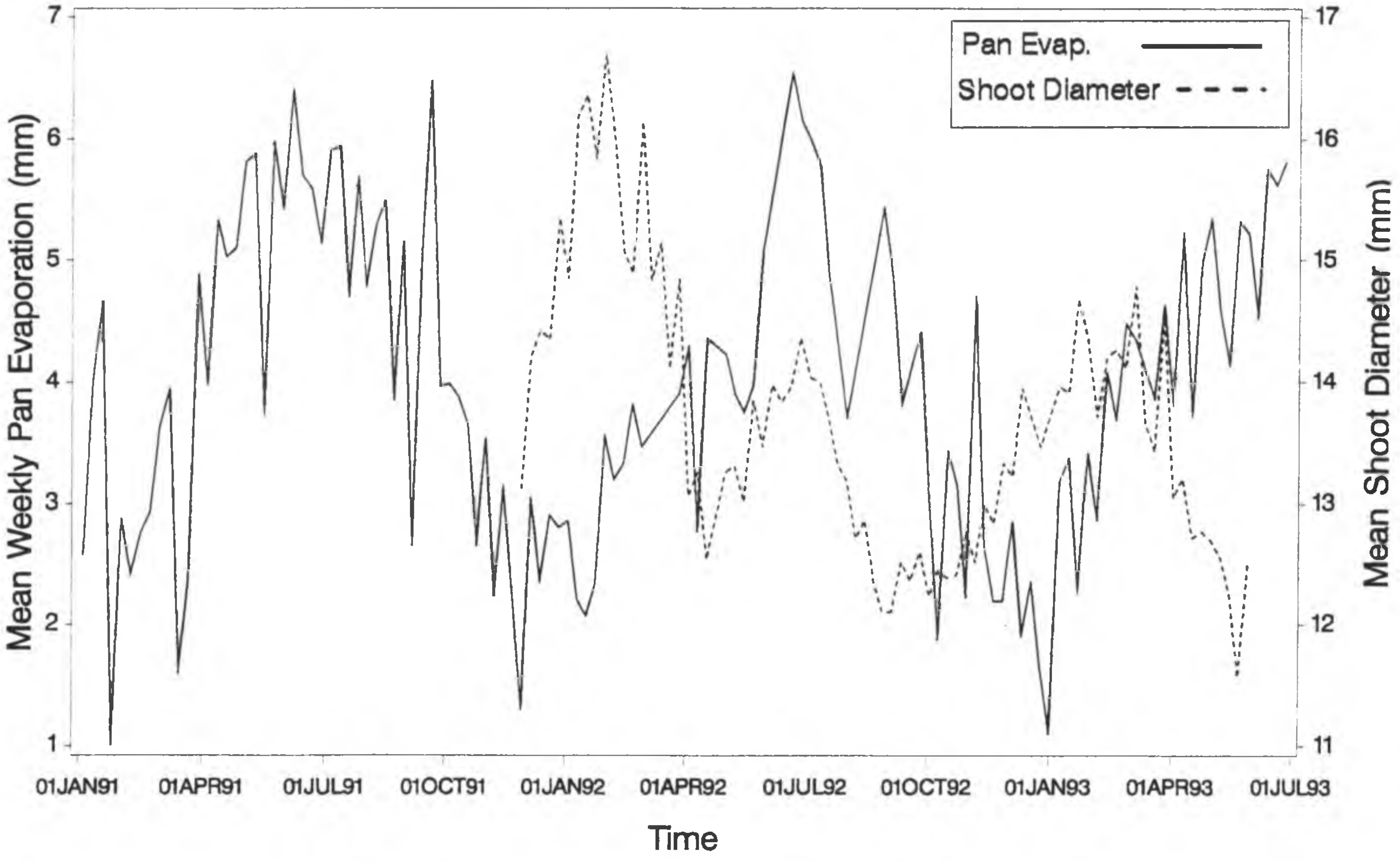


Figure 5.14

Mean weekly pan evaporation calculated from total daily pan evaporation from January 1991 to July 1993 and mean weekly shoot diameter harvested from November 1991 to May 1993 for pan factor 1.67

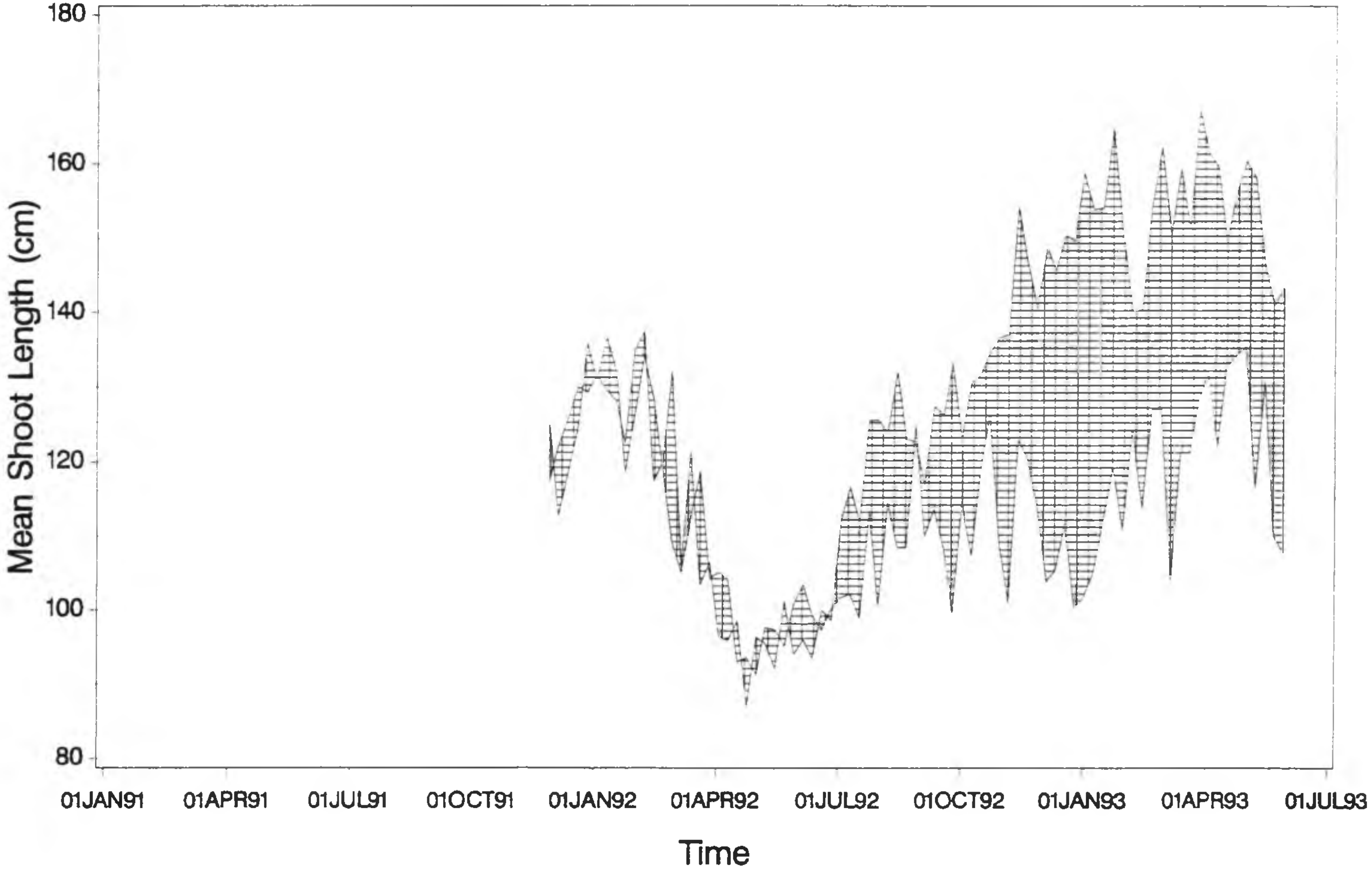


Figure 5.15

The shaded portion represented the range between irrigation treatments 0.33 (bottom line) and 1.67 (top line) for the mean weekly shoot length harvested from November 1991 to May 1993

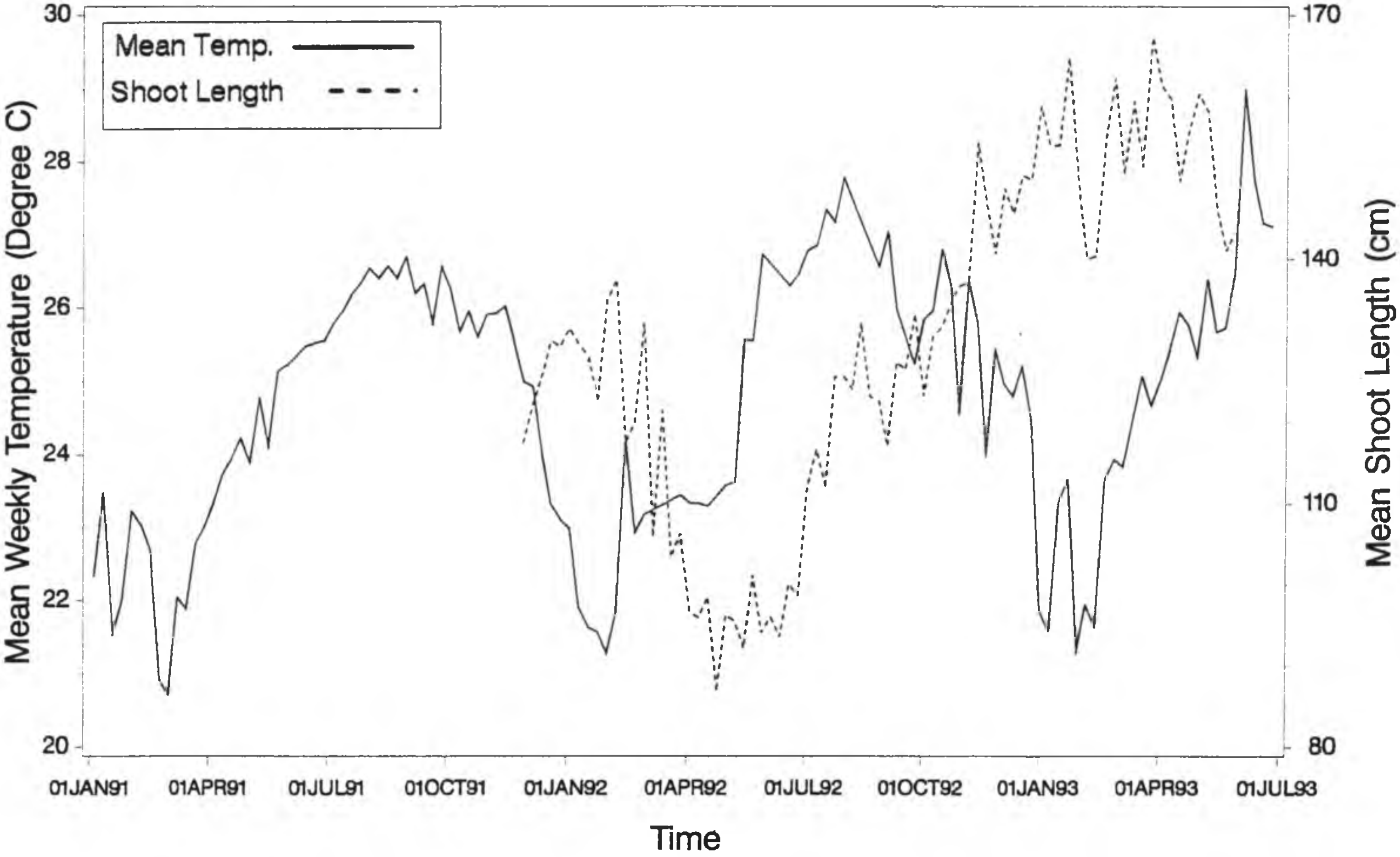


Figure 5.16

Mean weekly temperature calculated from mean daily temperatures from January 1991 to July 1993 and mean weekly shoot length harvested from November 1991 to May 1993 for pan factor 1.67

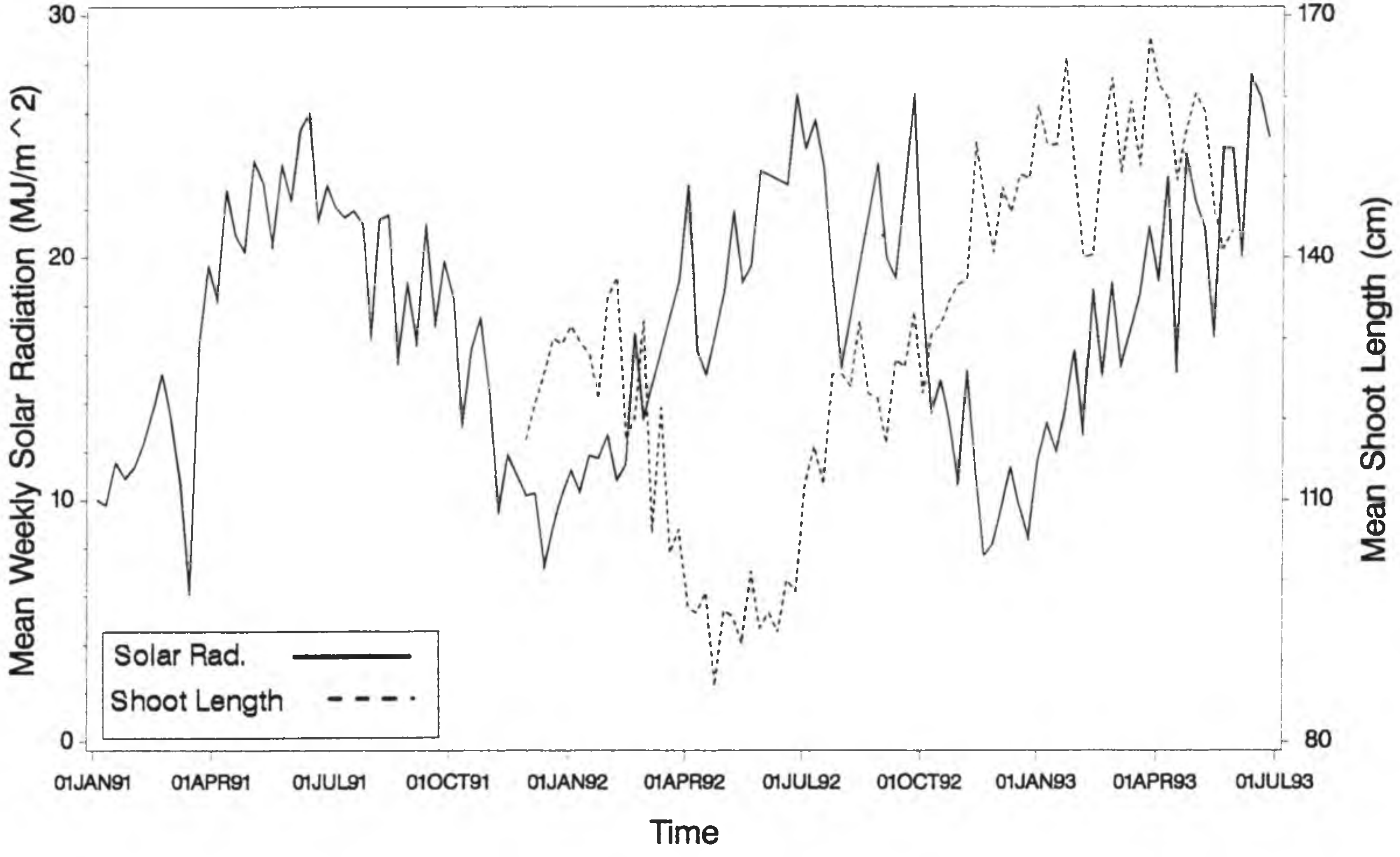


Figure 5.17

Mean weekly solar radiation calculated from total daily solar radiation from January 1991 to July 1993 and mean weekly shoot length harvested from November 1991 to May 1993 for pan factor 1.67

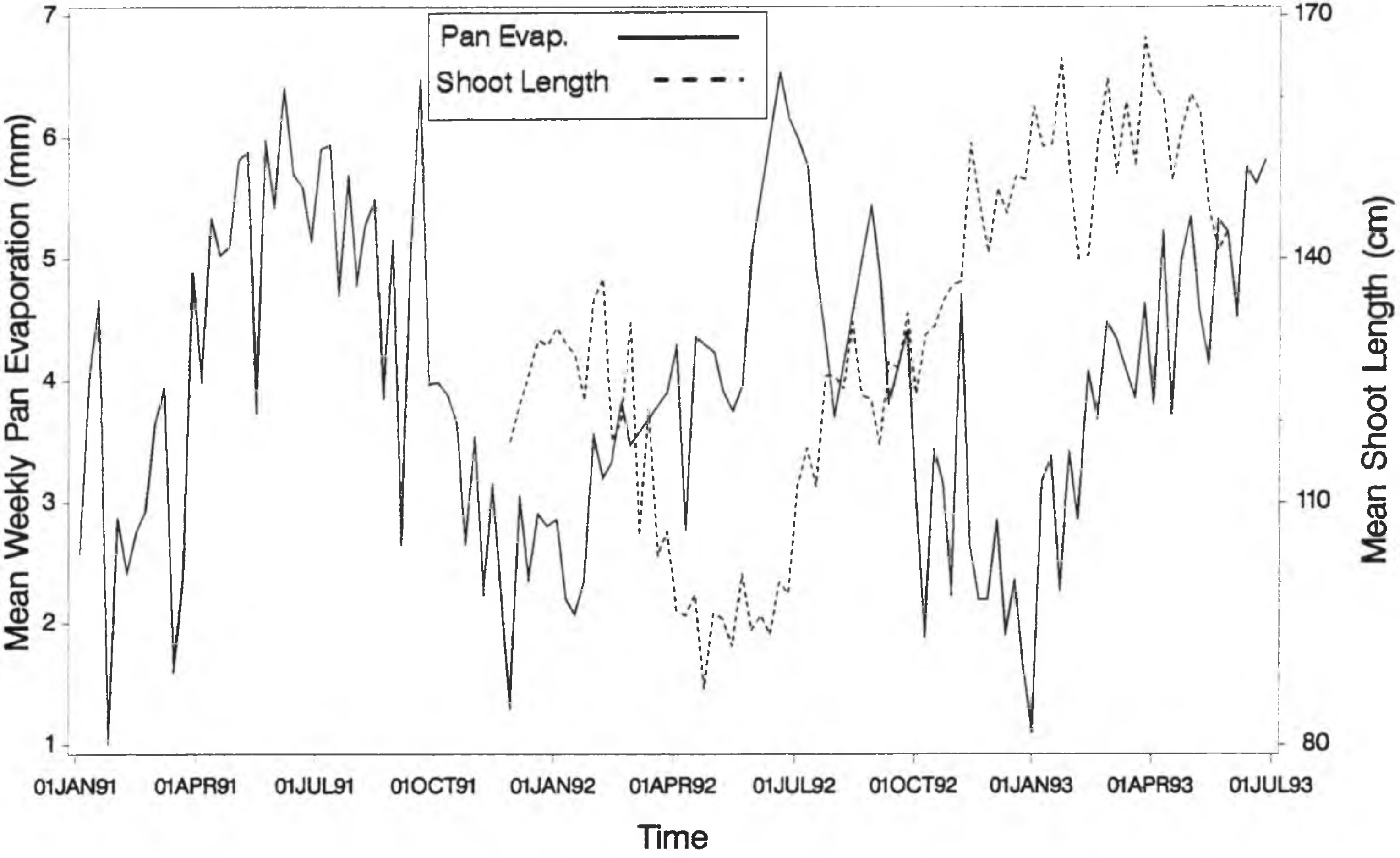


Figure 5.18

Mean weekly pan evaporation calculated from total daily pan evaporation from January 1991 to July 1993 and mean weekly shoot length harvested from November 1991 to May 1993 for pan factor 1.67

Table 5.3.1

Chi-square analysis of the distribution of harvested inflorescences by grade and by irrigation treatments for 18 months.

Irrigation treatment	Grade			
Frequency Expected Percent	Small	Standard	Fancy	Total
0.33	466	880	288	1634
	385.3	898.5	350.2	
	5.9	11.1	3.7	20.7
0.67	469	992	322	1783
	420.5	980.4	382.1	
	5.9	12.6	4.1	22.6
1.00	490	1146	420	2056
	484.9	1130.5	440.6	
	6.2	14.5	5.3	26.0
1.67	438	1326	663	2427
	572.3	1334.5	520.1	
	5.5	16.8	8.4	30.7
Total	1863	4344	1693	7900
	23.6	55.0	21.4	100.0

Table 5.3.2

Percentage distribution of the total in each grade produced by each irrigation treatment for 18 months.

Column Pct	Small	Standard	Fancy	Total
0.33	25.0	20.3	17.0	
0.67	25.2	22.8	19.2	
1.00	26.3	26.4	24.8	
1.67	23.5	30.5	39.2	
Total				100.0

Table 5.3.3

Percentage distribution of the total in each irrigation treatment by the grade for 18 months.

Row Pct	Small	Standard	Fancy	Total
0.33	28.5	53.9	17.6	
0.67	26.3	55.6	18.1	
1.00	23.8	55.7	20.4	
1.67	18.1	54.6	27.3	
Total				100.0

Statistic	DF	Value	Prob
Chi-Square	6	115.568	< 0.0005

Sample Size = 7900

compared to the Standard grade (Table 5.3.2). Likewise, there was a percentage decrease of Fancy grade inflorescences for the two lowest pan factors. Interestingly, the highest pan factor had the opposite result than the two lowest pan factors.

The row percent table the grade distribution within a given irrigation level changes (Table 5.3.3). A similar comparison can be made with the percentage distribution of pan factor 1.00 and the percent totals for the grades located on the last line in Table 5.3.1. The same percentage increase and decrease for the other pan factors are displayed when compared to pan factor 1.00 as in Table 5.3.2.

Discussion

The number of inflorescences per clump produced annually increased from the lowest pan factor to the highest pan factor. The number of inflorescences harvested per clump rapidly increased in June 1992 may be due to slow developing winter shoots that produced inflorescences in June as a result of increasing air temperatures and solar radiation (Figs. 5.3 and 5.4). These shoots along with shoots that emerged at the start of the increasing temperatures produced inflorescences which were harvested at about the same time. The number of inflorescences per clump then rapidly decreased may be due to exhaustion of photosynthate used for the increase of inflorescences in June.

The Ginoza cultivar produced significantly fewer number of inflorescences per clump compared to the other two cultivars because they were smaller when they were planted, and they were planted later than the other two cultivars. Additionally, the Ginoza cultivars possess traits of their 'Jungle Queen' parent: longer shoots, more expanded leaves per shoot, a more rounded inflorescence shape, and fewer number of shoots per clump compared to 'Eileen McDonald' and red ginger.

The increase or decrease of the quantitative variables is related to the preceding environmental conditions. Shoot lengths, and shoot diameters increased due to increasing air temperature and solar radiation during the development of the shoots, and decreased due to decreasing air temperature and solar radiation during shoot development. Inflorescence lengths appears to be inversely related to the environmental variables (Figures 5.7 and 5.8). Inflorescence diameters did not increase due to increasing air temperature and solar radiation during shoot development or decrease similar to shoot lengths and diameters. This may be a result of inconsistent data measurements.

The 'Rejects' grade was omitted in the chi-square analysis and may have provided stronger evidence for the shift of inflorescences to higher quality. There was a greater proportion of Small to Fancy inflorescences for the low pan factors. A shift occurred with a decreased proportion of Small to Fancy inflorescences for the highest pan factor. The Chi-square probability, < 0.0005, supports a rejection of H_O and the conclusion that higher irrigation treatments produced more high quality inflorescences than the lower irrigation treatments.

In summary, the highest irrigation treatment produced more inflorescences per clump, and significantly thicker and longer shoots and inflorescences. Due to the fact that thefs differences were so small, even though statistically significant, they were not practically significant. Inflorescence length showed seasonality by the increasing and decreasing values although no statistical analysis was performed to confirm this.

Chapter 6

Water Relations of *Alpinia purpurata*

The objectives of this research were to determine how the range of water application rates by drip affects various indicators of plant water relations, and to explain why the effect varies among the indicators. Objective 4 will determine how the water application rates affect the growth and water status of the plant. Objective 5 will compare plant water use by ET with Class A pan evaporation, and objective 6 considers the water balance to explain why the irrigation treatments by drip caused the differential plant responses. Three subobjectives under objective 6 include: 1) determination of the soil water holding capacity and other components of the water balance, 2) determination of the soil wetting patterns with drip emitters, and 3) comparison of the water application rate and stomatal conductance of my best treatment with a commercial operation using a different irrigation method.

Objective 4: To determine the influence of water application rates upon plant water status, stomatal conductance, and growth.

Results

Shoot diameter and length, inflorescence diameter and length for the shoots with all cultivars were significantly different at < 1% for linear effects when regressed against the pan factors of the irrigation treatments for 12 sampling dates over 3 months (Appendix A & B and Figs. 6.1 to 6.4). Leaf area, fresh and dry weights for the last expanded leaf were also significantly different at < 1% for the linear effect (Appendix A & B and Figs. 6.5 to 6.7). During the 3 months, quantitative data were collected upon the last expanded leaf in order to determine the water status of the shoots. Shoot length and diameter, and inflorescence length and diameter were analyzed in the 3 month period (Chapter 6) as a subset of the 18 month period in which data were collected over the length of the research (which was analyzed in Chapter 5).

The Ginoza cultivar means were significantly greater than those of the other two cultivars for all the yield variables except inflorescence length (Table 6.1).

Relative Water Content (RWC)

There was no significant irrigation treatment effect on RWC for the last expanded leaf sampled in June 1993 (Table

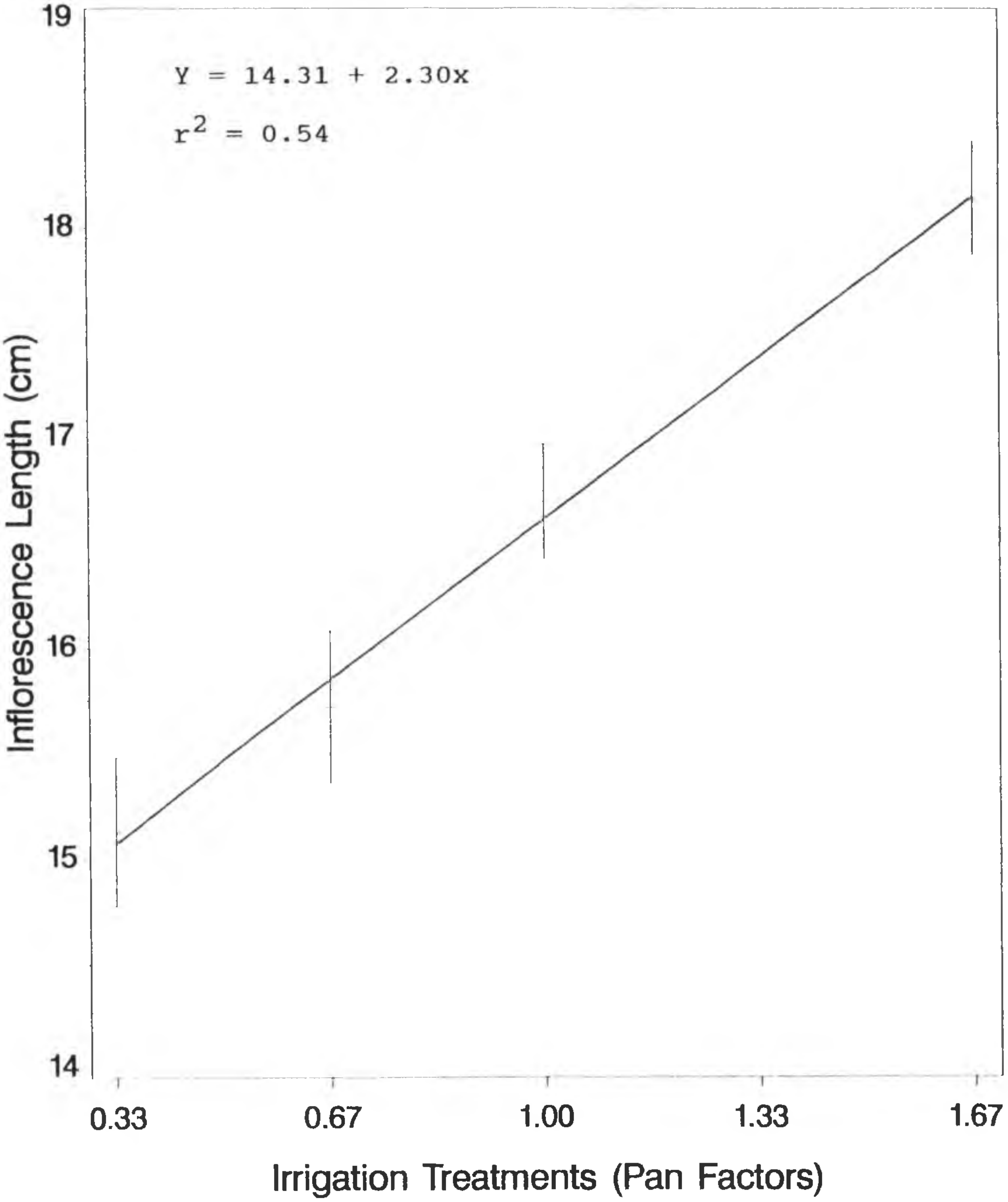


Figure 6.1

The mean ± SE inflorescence lengths at harvest on the shoots with the last expanded leaves with all cultivars against the irrigation treatments for 12 sampling dates, $P = 0.0001$, $n = 48$

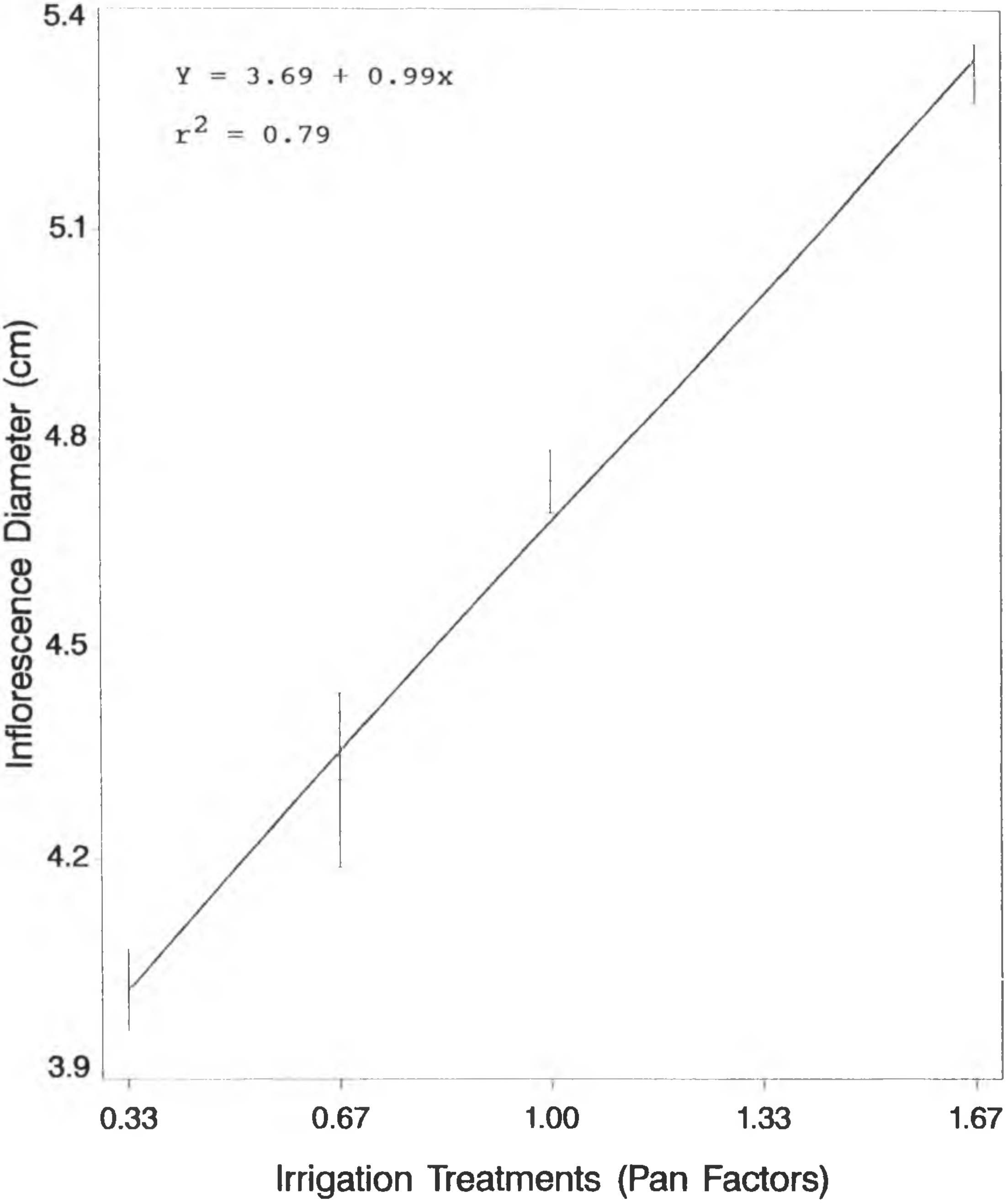


Figure 6.2

The mean ± SE inflorescence diameters at harvest on the shoots with the last expanded leaves with all cultivars against the irrigation treatments for 12 sampling dates, P = 0.0001, n = 48

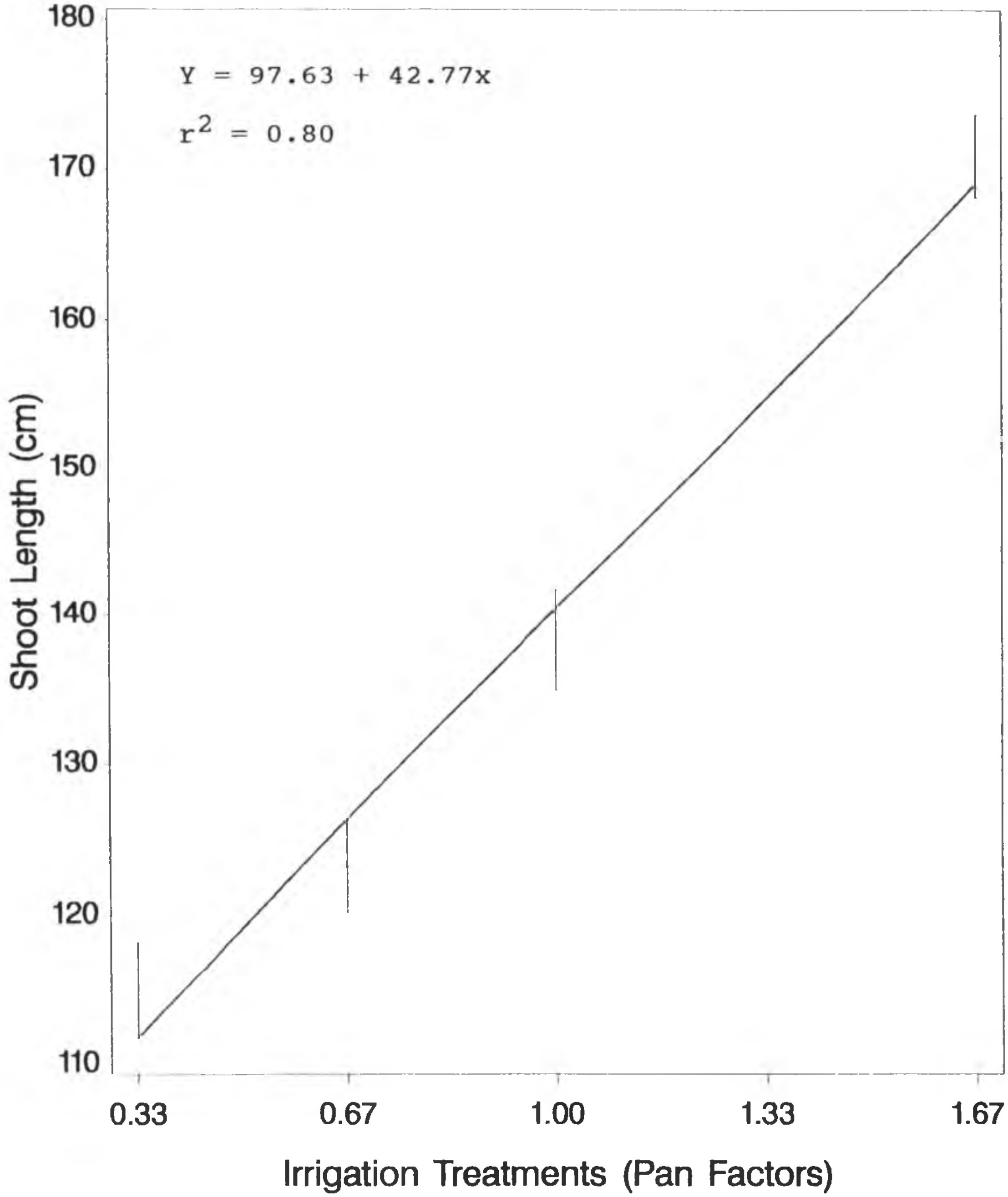


Figure 6.3

The mean ± SE shoot lengths at harvest on the shoots with the last expanded leaves with all cultivars against the irrigation treatments for 12 sampling dates, P = 0.0001, n = 48

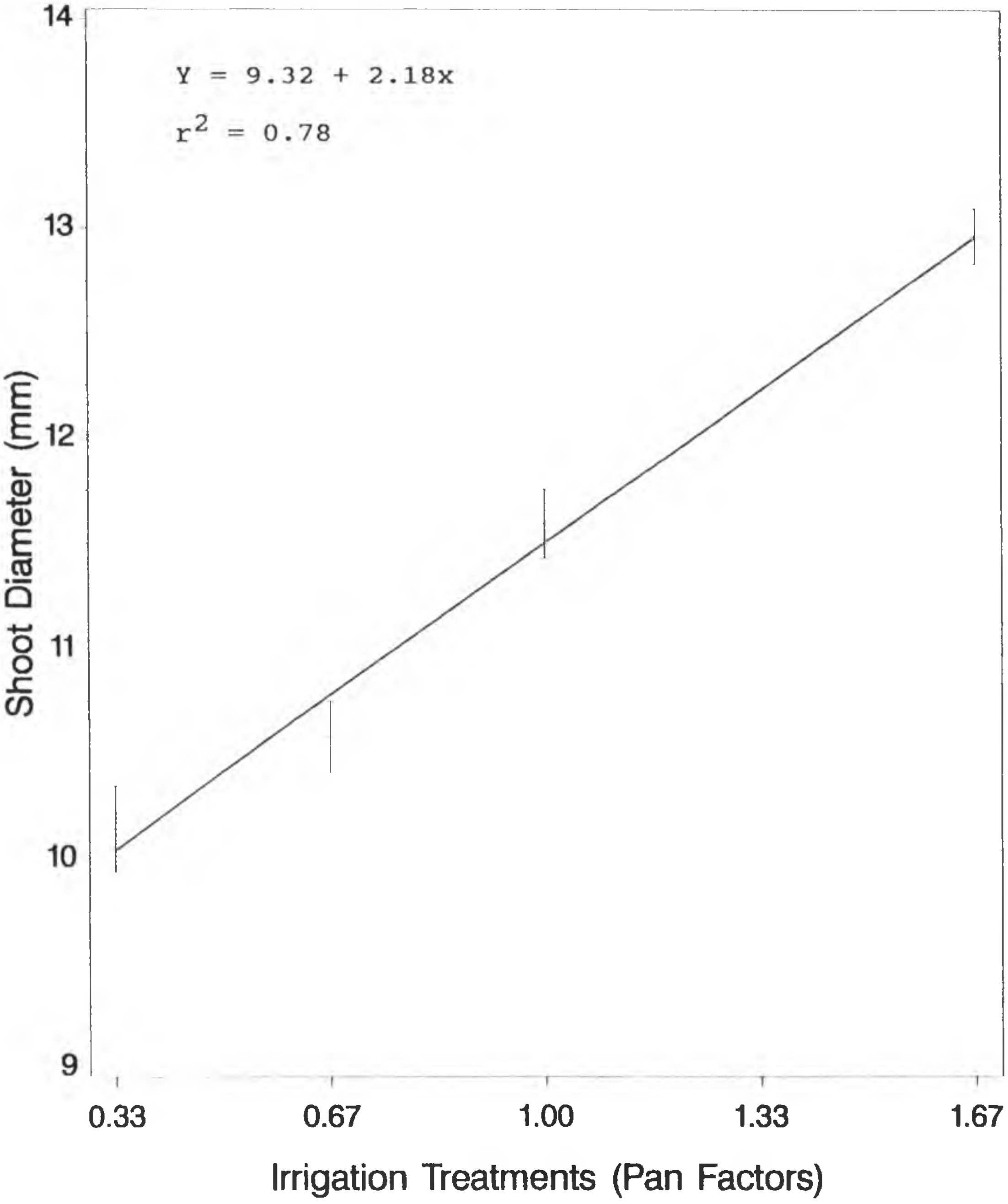


Figure 6.4

The mean ± SE shoot diameters at harvest on the shoots with the last expanded leaves with all cultivars against the irrigation treatments for 12 sampling dates, $P = 0.0001$, $n = 48$

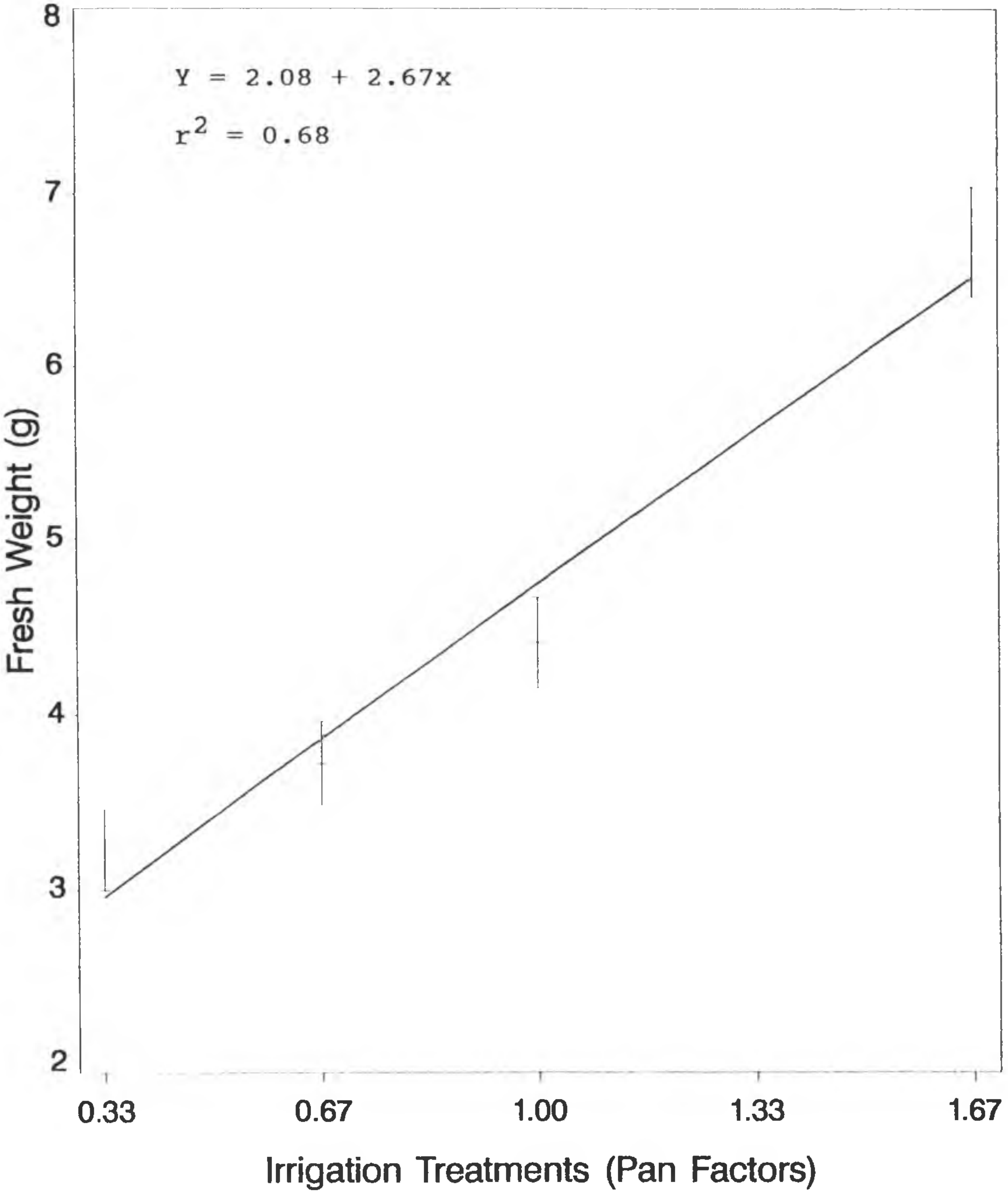


Figure 6.5

The mean ± SE fresh weight at harvest for the last expanded leaves with all cultivars against the irrigation treatments for 12 sampling dates, $P = 0.0001$, $n = 48$

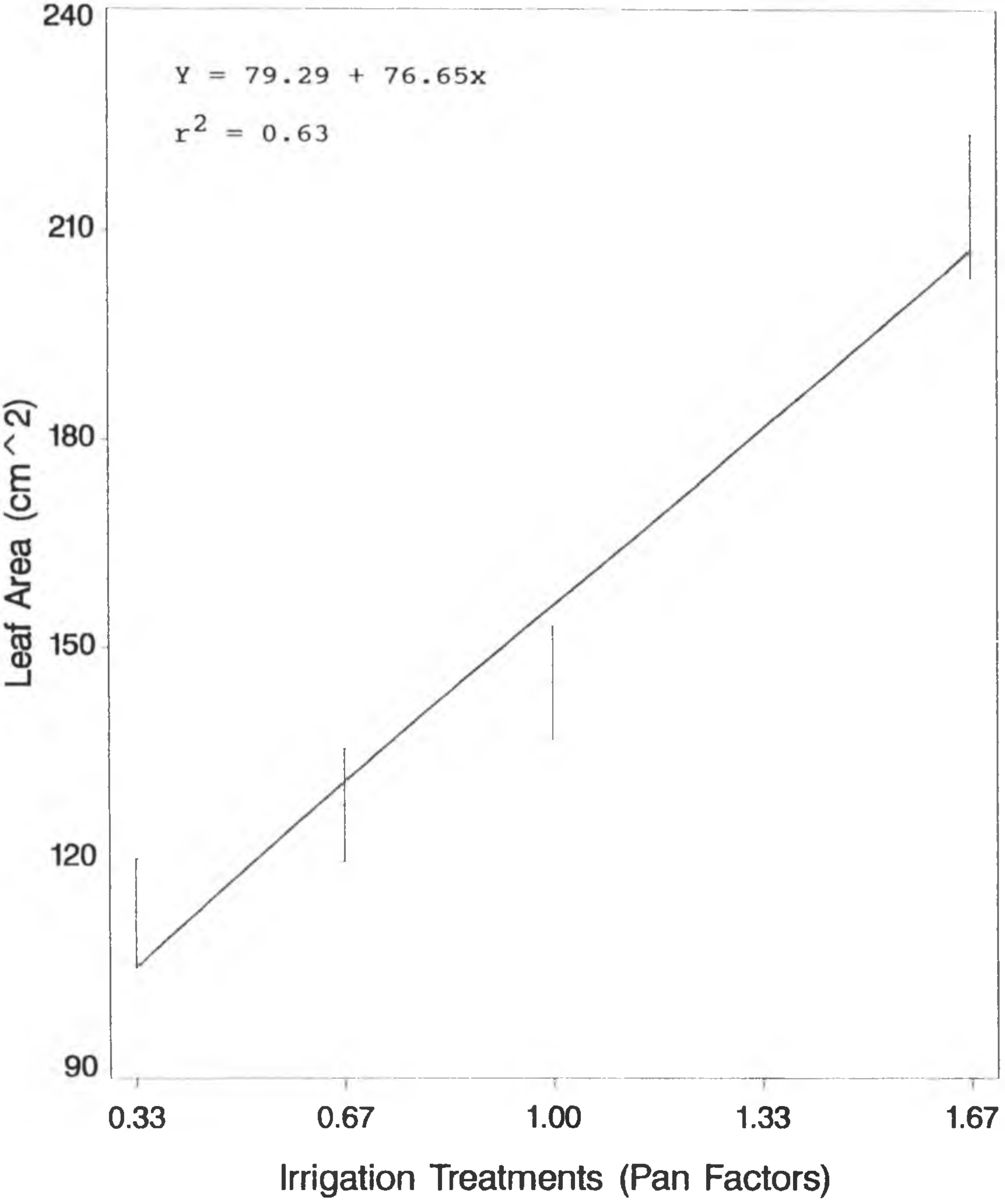


Figure 6.6

The mean ± SE leaf area at harvest for the last expanded leaves with all cultivars against the irrigation treatments for 12 sampling dates, P = 0.0001, n = 48

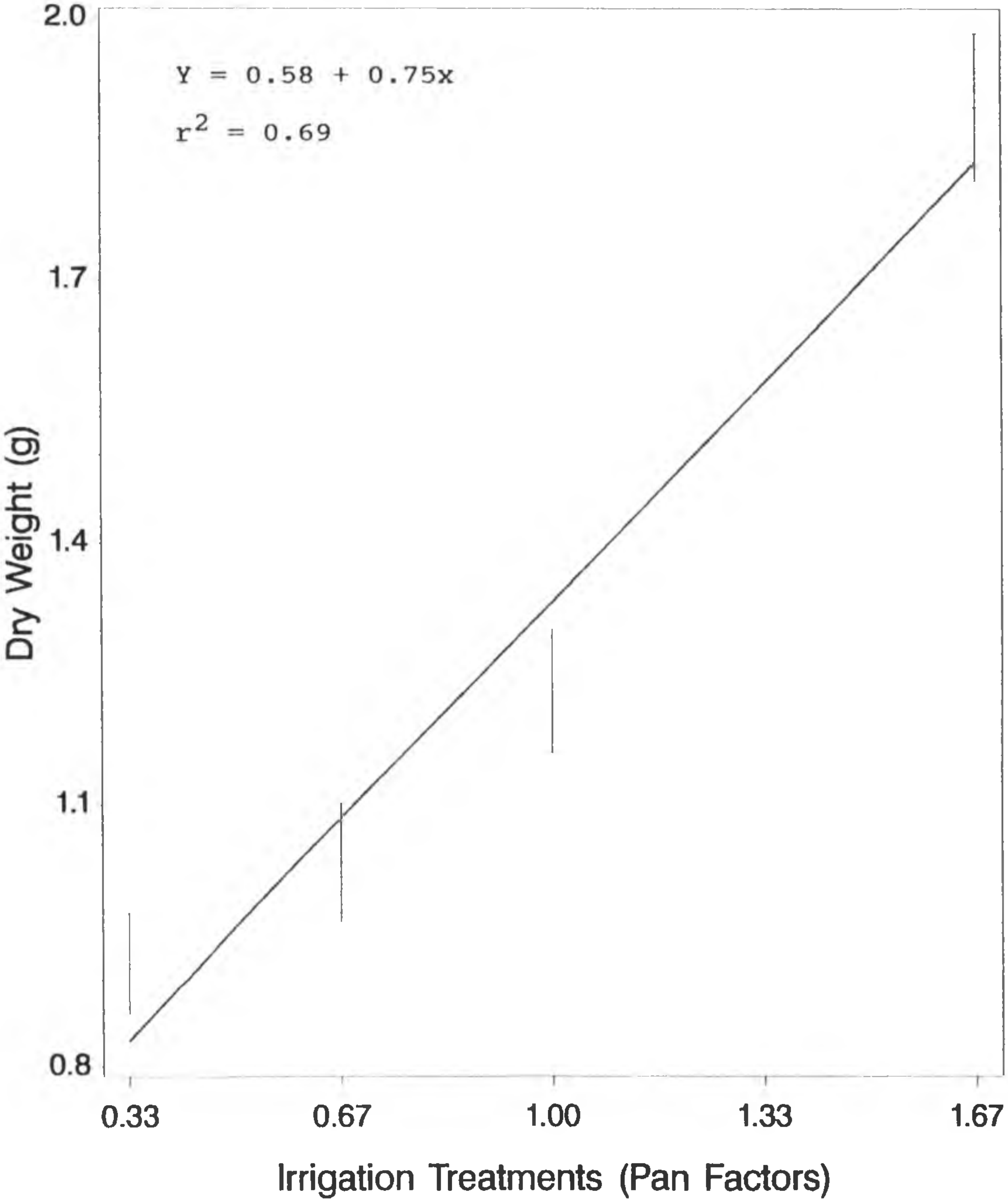


Figure 6.7

The mean ± SE dry weight at harvest for the last expanded leaves with all cultivars against the irrigation treatments for 12 sampling dates, $P = 0.0001$, $n = 48$

Table 6.1

Cultivar means for the yield variables for the last expanded leaves with its inflorescence and shoot variables across all irrigation treatments for 12 sampling dates.[z]

	Leaf						
Cultivar	Area (cm^2)	Fresh weight (g)	Dry weight (g)	Inflor. length (cm)	Inflor. diameter (cm)	Shoot length (cm)	Shoot diameter (mm)
'Eileen McDonald'	128 a	3.8 a	1.1 a	16.9 b	4.1 a	123 a	10.8 a
Red Ginger	134 a	4.3 a	1.2 a	17.6 c	4.8 b	133 b	11.5 b
Ginoza	214 b	6.2 b	1.7 b	14.7 a	5.1 c	166 c	12.1 c

[z] The means with the same letter are not significantly different as shown by the Waller-Duncan mean separation K-ratio=100 t test.

6.2, Appendix A). However, RWC for the Ginoza cultivar was significantly greater than that of the other two cultivars (Table 6.3). RWC was calculated from Eq. 2.1.

Table 6.2

Mean ± SE RWC for the last expanded leaves across all cultivars for each pan factor for the irrigation treatments sampled 11 June 1993

Irrigation treatment	RWC (%)	N
0.33	0.05 ± 0.01	15
0.67	0.13 ± 0.04	14
1.00	0.11 ± 0.02	17
1.67	0.12 ± 0.03	21
Linear[a]	ns	
Quadratic[a]	ns	

[a] Irrigation treatment effects were not significant (ns)

Table 6.3

Cultivar means for RWC for the last expanded leaves across all irrigation treatments sampled 11 June 1993.[z]

Cultivar	RWC (%)	N
'Eileen McDonald'	0.07 a	27
Red ginger	0.10 a	23
Ginoza	0.17 b	17

[z] Means with the same letter are not significantly different as shown by the Waller-Duncan mean separation K-ratio=100 t test

Stomatal Conductance

Stomatal conductance for the last or second to the last expanded leaves for 'Eileen McDonald' was measured on four sampling dates from January 1992 to June 1993 (Appendix A). Stomatal closure was most rapid between 7 AM and 10 AM (Figs. 6.8 to 6.10). After 10 AM, stomatal conductance slowly decreased the rest of the day. Stomatal conductance for the highest irrigation treatment was greater than for the other irrigation treatments on two of the three dates.

Discussion

Quantitative Variables

The effects of the irrigation treatments on inflorescence length and diameter, and shoot length and diameter were greater when compared to those in Chapter 5 because the data were measured over a shorter period of time thereby avoiding seasonal effects and were concentrated during a period where the irrigation rates had been well established.

The response curve of crop growth characteristics to nutrient and environmental factors such as water include limiting, optimum, and excess portions of the curve (Fig. 6.11). The curves shown in Figs. 6.1 to 6.7 are all in the limiting portions of the curve. *Alpinia purpurata* did not receive optimal water in this study.

The inflorescence bract tips of the Ginoza cultivar were more susceptible to browning than the other two cultivars. This problem was probably due to the combination

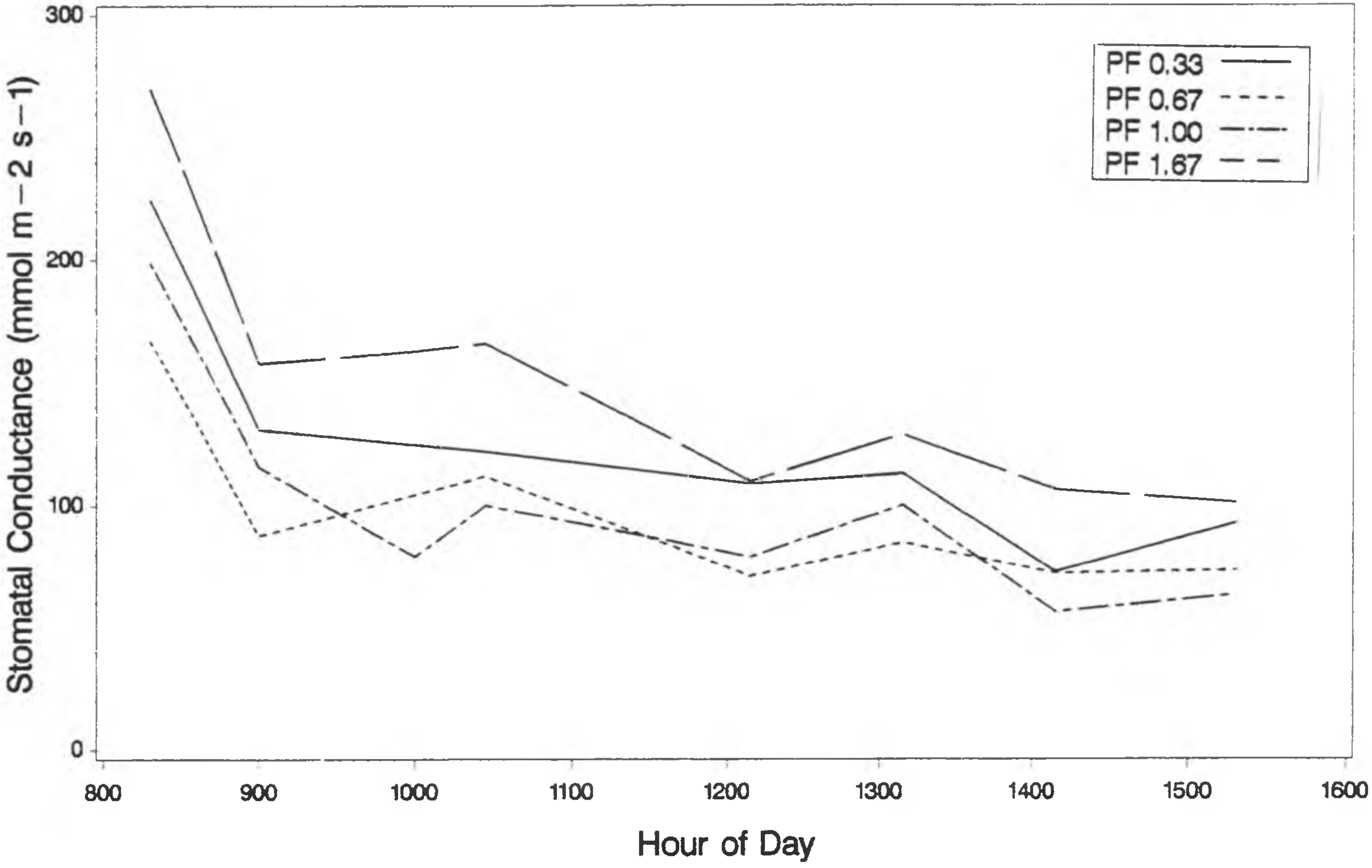


Figure 6.8

Mean stomatal conductance on the second to the last expanded leaf for 'Eileen McDonald' 3 days after irrigation on 23 March 1993, n= 2-3

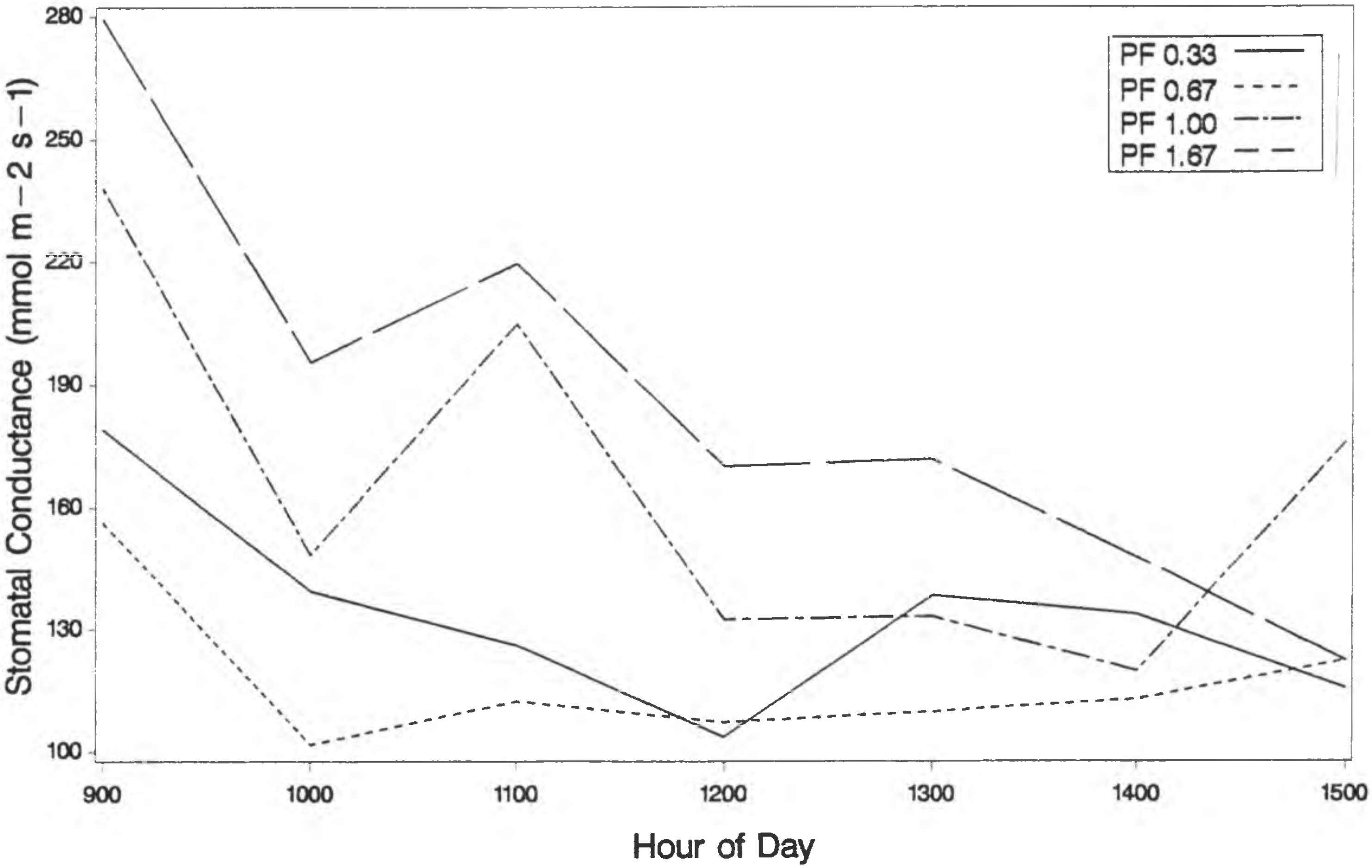


Figure 6.9

Mean stomatal conductance on the last or second to the last expanded leaf for 'Eileen McDonald' 3 days after irrigation on 10 May 1993, n= 2-3

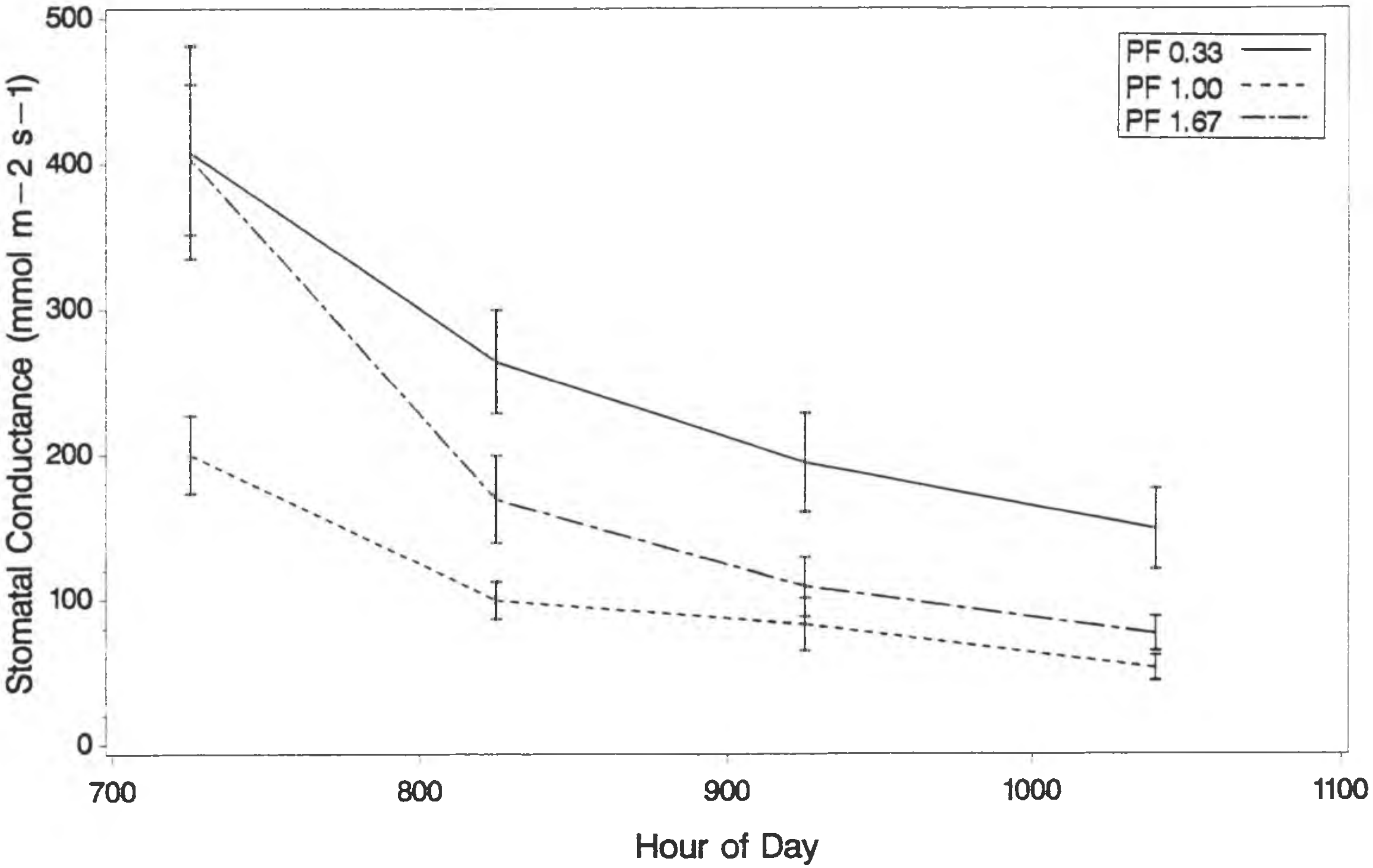


Figure 6.10

Mean stomatal conductance + SE on the last expanded leaf for pan factors 0.33, 1.00, and 1.67 on 'Eileen McDonald' 1 day after irrigation on 15 June 1993, n= 10

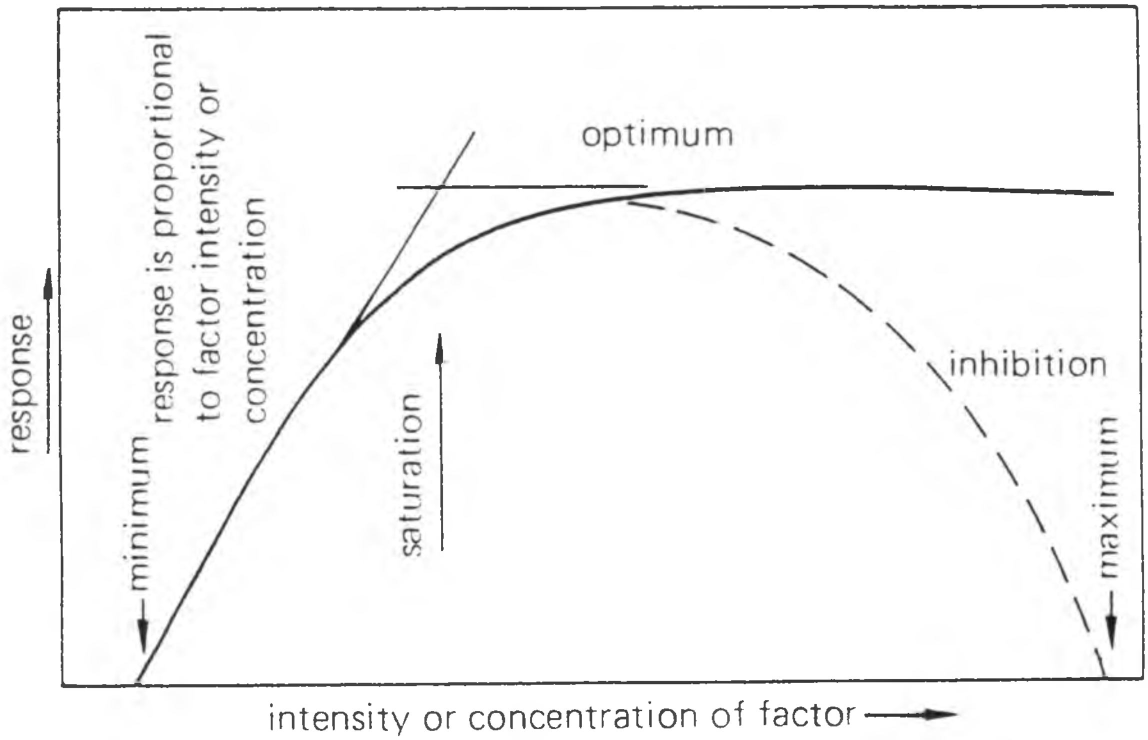


Figure 6.11

A generalized response growth curve showing the three primary phases: limiting, optimum, and excess.[z]

[z] Figure was reproduced from Salisbury F. and C. W. Ross, 1985. Plant Physiology, 3rd ed. Wadsworth Publishing Co., Belmont, Calif., p. 452.

of the sun and wind and the tendency, therefore, was to harvest the inflorescences before it occurred when the inflorescence bracts were reflexed but had not elongated to their potential. The result was shorter inflorescences. 'Eileen McDonald' also showed tip burn, but it was less evident than on the Ginoza cultivar while tip burn on red ginger was hardly noticeable.

Relative Water Content

The nonsignificant relative water content measurements may be due to the inability of the drip emitters to deliver water to the increased ground surface area occupied by the plants. As a result, all the plants across the pan factors experienced similar water stress.

In reviewing the data collection for the fresh weight of the newly expanded leaves, I realize that an error was made. The leaves were kept in the ziploc bags for at least 5 minutes before the leaves were removed from the shoot. Transpired water from the leaves within the plastic bag condensed from vapor into liquid. After the leaves were removed from the shoot, the bags were sealed which promoted further transpiration from the leaves which were heated by the morning sun. Later when the leaves were weighed, the water in the bag was not weighed as part of the samples. This resulted in lower RWC values.

RWC in the highest irrigation treatment was only 12% which is extremely low. The low values suggest that the water collected in the bag should have been included in calculation of fresh weight.

Stomatal Conductance

Stomatal conductance results from *Heliconia psittacorum* L. f. cv. Common Orange (S. Furutani, telephone interview with author, January 1994) were similar to those for the red ginger (Figs. 6.8 to 6.10). The plants were approximately 1.2 m tall and grown in 15-liter pots. Stomatal conductance was monitored from approximately 600 to 830 AM under full sun during the months of June and July 1988 in Hilo, Hawaii. Stomatal conductance was the highest between 600 and 630 AM but decreased and by 830 AM, the stomates were closed and remained that way the rest of the day.

Comparison of *Alpinia purpurata* stomatal conductance to that of peach displays a different response (Figure 6.12). Stomatal conductance increased from 7 AM until 10 AM and then decreased after 10 AM. Stomatal conductance in my field decreased after 7 AM which suggests that my plants were water stressed and closed its stomata to prevent water loss. The increase in stomatal conductance after 7 AM for the peach indicated that the water status of the plants were sufficient in order for transpiration to occur. After 10 AM, increased temperatures caused the reduction of stomatal conductance, a rapid reduction over the first 2 to 3 hours, and then a gradual reduction throughout the rest of the day which was also observed for my plants.

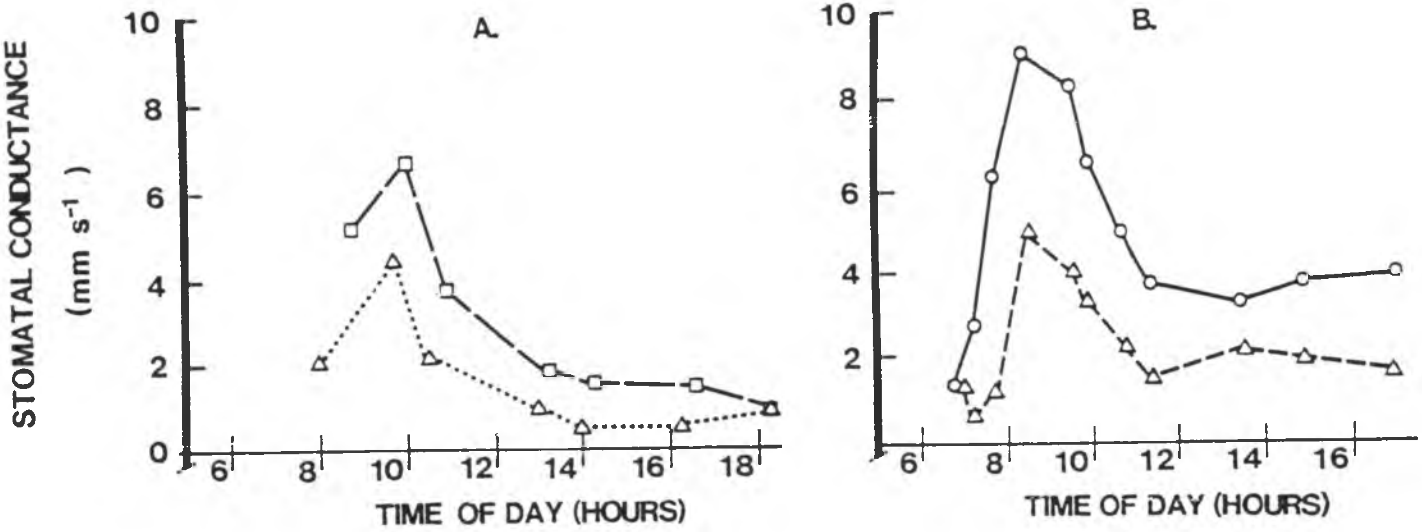


Figure 6.12

A. Daily stomatal conductance in peach trees for 33% of ET (squares) and dryland (triangles) treatments on 31 August 1979 in Winters, CA. B. Daily stomatal conductance for 100% ET (circles) and dryland (triangles) treatments on 31 May 1980 after three experimental years.[z]

[z] Figure was reproduced in part from Fereres E. and D. A. Goldhamer, 1990. "Deciduous Fruit and Nut Trees," in Irrigation of Agricultural Crops, no. 30. eds. B.A. Stewart and D.R. Nielsen. American Society of Agronomy, Inc.; Crop Science Society of America, Inc.; and Soil Science Society of America, Inc. p.991.

Objective 5: To compare evapotranspiration of *Alpinia purpurata* in small weighing lysimeters with pan evaporation.

Results

Figure 6.13 shows ET and transpiration for the plants in lysimeters. ET was measured on sampling date 1; on dates 2 and 3, transpiration only was measured (Appendix A). Water use was most rapid between 10 AM and 3 PM. For a 24 hour time period, 63% of water use occurred between 10:30 AM and 3 PM.

In the lysimeters, plant water loss by transpiration was greater than water loss by ET probably because the transpiration samples were taken on days with less cloud cover (Fig. 6.13). The mean daily air temperature on the two sampling dates for transpiration only, was higher on 18 August (28.1^{o}C) while on 25 August, the mean temperature was 26.7^{o}C. The plants used 16.6 mm (216 g) of water and 12.9 mm (167 g) on the two respective days from 10:00 AM to 3:00 PM.

In order to compare plant ET as determined by lysimeters with pan evaporation it was necessary to calculate leaf area index (LAI). There was no significant variability within the treatments, and the variation among the cultivars was not significant for the number of shoots and total leaf area within the subsamples (40 by 40 cm area). The variation among the cultivars was, however,

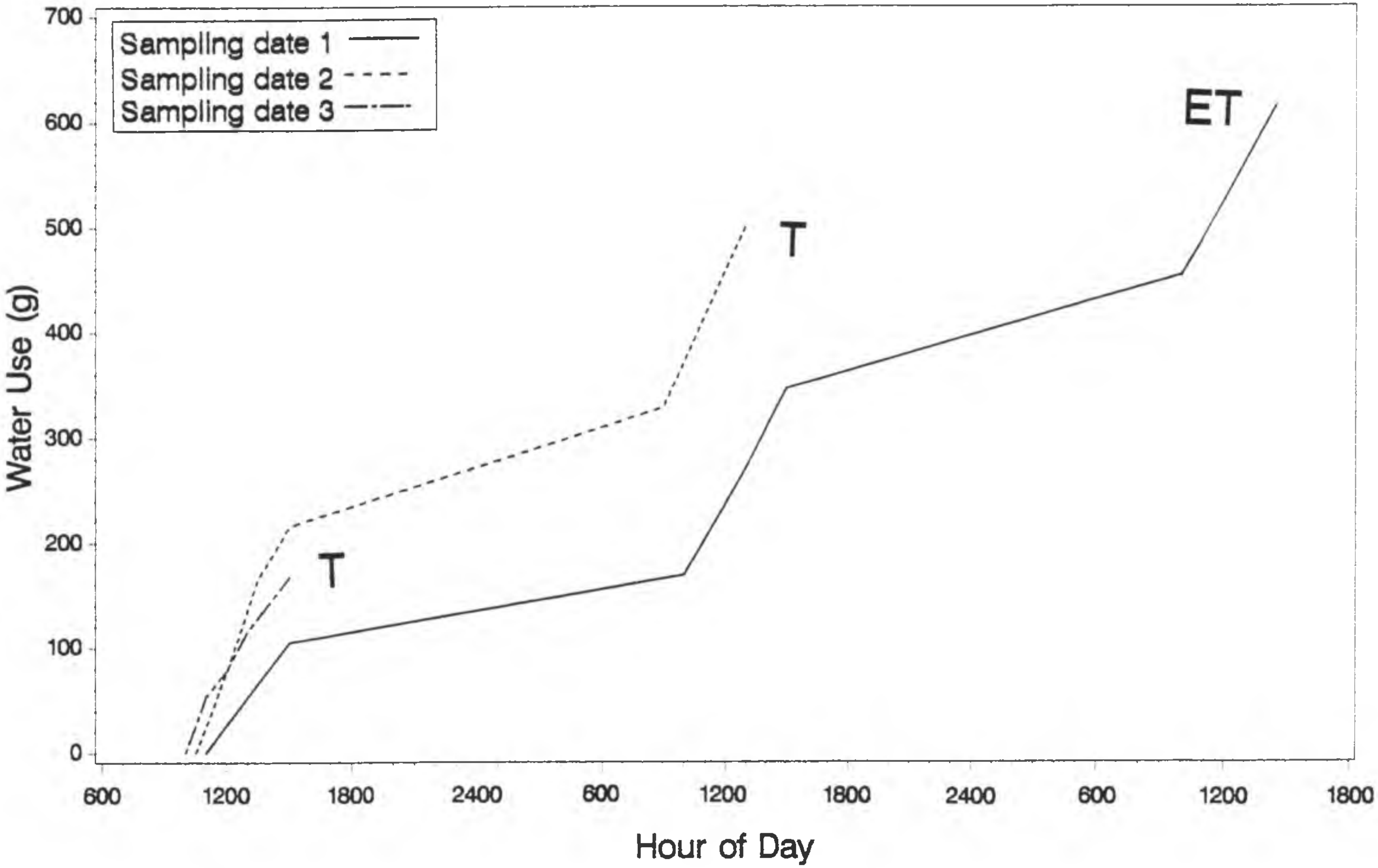


Figure 6.13

Cumulative water use by small weighing lysimeters for ET sampling date 1 (10 August 1993 and thereafter); and transpiration only for sampling dates 2 & 3 (18 and thereafter & 25 August 1993 and thereafter), n= 7-8.

significant for the number of shoots and the circumference lengths for the entire clumps (Table 6.4).

The means ± SDs value for number of shoots and total leaf area of the subsample pooled across all replications and all cultivars were 24.3 ± 8.6 and 2.10 ± 0.76 m^2 respectively. Therefore, total leaf area for the entire clump for all three cultivars was calculated by multiplying the number of shoots for the entire clump by the total leaf area in the subsample and then dividing by 24.3 (Table 6.4). LAI was calculated in two different ways: using the clump area as the ground area, and using the field area (Table 6.4).

The K_C ± SD for red ginger using the clump area was 4.2 ± 1.1 with n=3. Using the field area, the K_C ± SD for red ginger was 0.5 ± 0.1 with n=3 (Table 6.5).

Stomatal Conductance

After 1 PM stomatal conductance of the leaves on the shoots in the lysimeters appeared to reach its minimum and level off (Fig. 6.14). At 12 noon the stomatal conductance reached its maximum; this would correlate to when water use was highest (Fig. 6.13).

Discussion

Stomatal conductance on the last expanded leaves of the red ginger shoots in the lysimeters showed a rapid decrease

Table 6.4

Cultivar means for the number of shoots, circumference lengths, and leaf area index based on the perimeter at the ground surface and total field ground area for the three *Alpinia purpurata* cultivars across all irrigation treatment replicates for 22 June 1993.[z]

Cultivar	# Shoots	Circumference (m)	Clump Leaf Area (m^2)	Clump Ground Area (m^2)	Clump Area LAI	Field Ground Area (m^2)	Field Area LAI
Red ginger	112.8 a	3.57 a	9.75	0.81	12.0	7.2	1.3
Ginoza	110.8 a	3.84 ab	9.58	1.05	9.1	7.2	1.4
'Eileen McDonald'	168.4 b	4.14 b	14.55	1.44	10.1	7.2	2.0

[z] Means with the same letter are not significantly different as shown by the Waller-Duncan mean separation K-ratio=100 t test

Table 6.5

Comparison of all 6 lysimeters to pan evaporation for 3 daily periods of water use for the same time period from the first 2 sampling dates for red ginger. Two different LAI's based on the perimeter at the ground surface and on the field area were used to calculate two different K_c's.

Time periods	(1) Mean water loss/ shoot (g)	(2) Mean total leaf area/ shoot (cm^2)	(3) Pan evap. (cm)	(4) (1/2) Mean water loss/ shoot area (g/cm^2)	(5) Clump area LAI	(6) (4*5) Mean water loss/ ground area (g/cm^2)	(6* Density water) Mean water loss (cm)	(7) (6/3) Clump-basis Crop coeff. K_c
1^a	187.8	1612.5	0.45	0.117	12.0	1.40	1.40	3.1
2^b	284.6	1612.5	0.40	0.177	12.0	2.12	2.12	5.3
3^c	322.5	1771.4	0.52	0.182	12.0	2.19	2.19	4.2

Time periods	Field area LAI			Field-basis Crop coeff. K_c
1^a	1.3	0.15	0.15	0.3
2^b	1.3	0.23	0.23	0.6
3^c	1.3	0.24	0.24	0.5

[a] 10 August, 11:00 am to 11 August 1993, 10:20 am
[b] 11 August, 10:20 am to 12 August 1993, 10:00 am
[c] 18 August, 10:30 am to 19 August 1993, 9:05 am

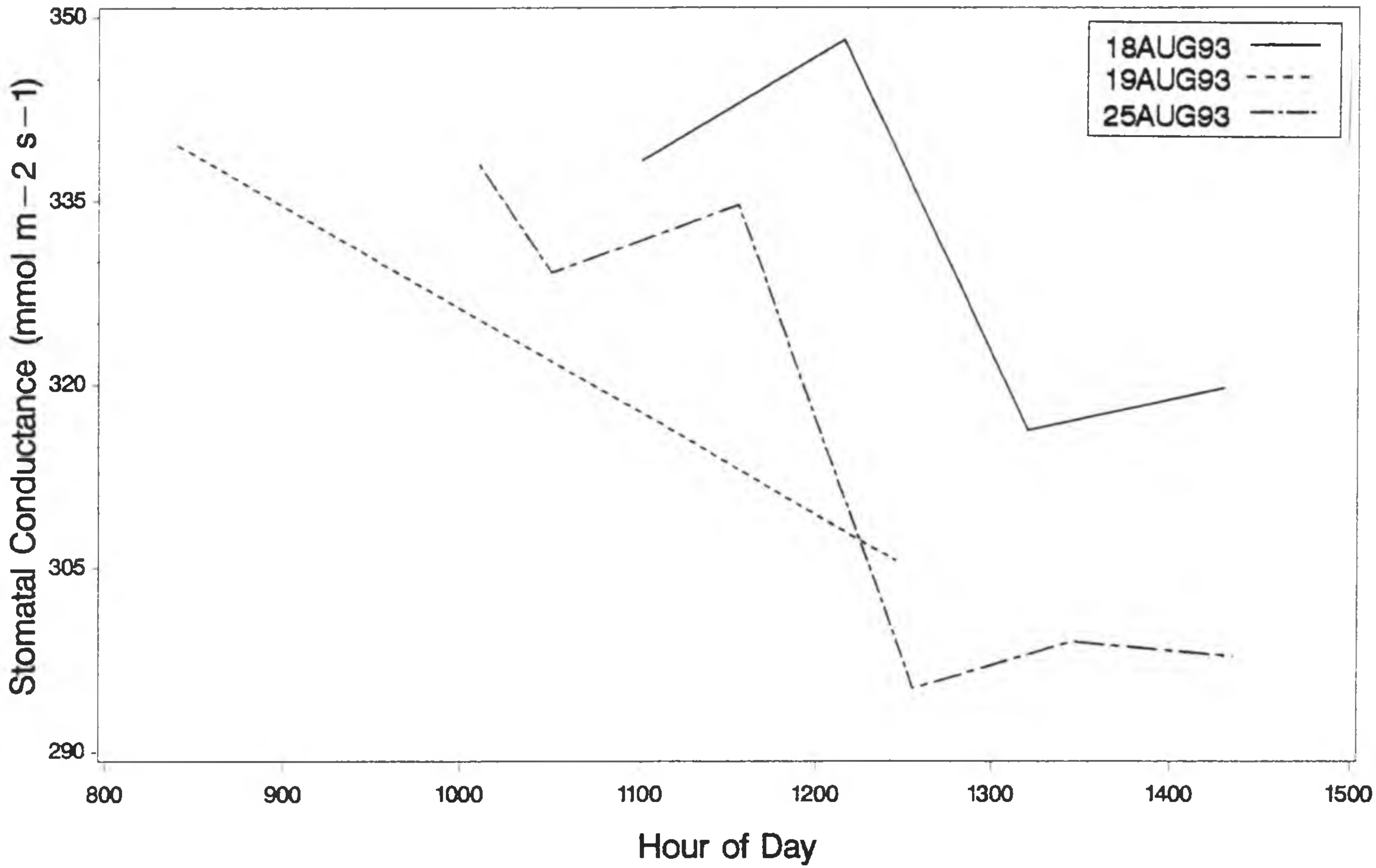


Figure 6.14

Stomatal conductance means for the last expanded leaves of the red ginger lysimeter shoots measured for 3 sampling dates, n=7 to 10 in stomatal conductance around noon (Fig. 6.14). For the field plants (Figs. 6.8 to 6.10) a rapid decrease occurred between 8 and 10 AM. The difference between the lysimeter conductance and field conductance pattern was probably because the lysimeter plants have more water and could keep their stomata open longer. Because the lysimeters were weighed between 10 AM and 3 PM, the peak water use rates between 10 and 12 when the stomata were open, were averaged with lower water use rates after 12.

The LAI values using the clump area ranged from 9.1 to 12.0 for the three cultivars are higher than the average LAI values for many other plants which range from 3 to 4. LAI values for sugarcane are about 8 and those for pineapple about 12 to 13 (F. Meinzer, telephone interview with author, January 1994). The LAI values using the field area, 1.3 to 2.0 for the three cultivars, was lower than the average LAI values for many other crops.

Both LAIs were used to produce K_Cs based on the two ground area bases. The LAI and K_C values were higher when the clump-area LAI was used compared to the K_C for the field-area LAI. The clump-area K_C could be applied to within well-watered clumps and the field-area K_C could be applied to fields where there is low transpiration between the clumps (bare, unirrigated soil). They are not for continuous plantings.

A K_C value of 1 would ordinarily represent a maximum which would occur when all radiant energy is used for ET, but higher values can occur when crops extract sensible heat from the air such as when wind blows through clumped crops. When plants are arranged in isolated clumps, edge effects are maximized and it is possible for warm air to be horizontally transported through the clumps from an area where sensible heat has been generated. When warm air circulates between the clumps, it is possible for actual ET to be greater than its potential. This is known as the clothesline effect (Rosenberg, 1983).

The K_c for *Alpinia purpurata* was higher than expected using the clump area, and lower than expected using the field area. K_c values for a related crop, banana, was 0.75 to 1.15; a crop of similar plant structure, sweet corn, was 0.95 to 1.10; and a crop which requires more water than most plants, rice, 1.10 (Hargreaves and Samani, 1991). The crop with the highest K_c was alfalfa with a range of 0.95 to 1.35. These crops are continuous plantings and not clumped, so the values over 1 are for regional advection and not the clothesline effect.

The pan factor treatments in this experiment are like clump-area K_cs. I feel my highest pan factor, 1.67, exceeded the actual clump K_c for well watered ginger and sufficient irrigation was applied. Therefore, a K_c of 4.2 for red ginger is higher than is expected for well-watered clumps, because the clothesline effect was exaggerated for the single plant in the lysimeter more than it would be for a typical clump. The K_c of 0.5 using the field area was lower than expected because the isolated plant is set in a field of arbitrarily large size. K_Cs need to be measured for real-sized well-watered clumps in a realistic sized field.

A measured value is not available for the field grown crop (no field lysimeters), but based on the water applied for the pan factor, the K_C's could have ranged from 0.3 to 1.67. The maximum proportion of this water which actually is transpirational would be about 0.3 to 1.0+; however our results suggest less of the water was transpirational because there is evidence of water stress for all treatments. The K_C from the lysimeters would be greater than a field value due to the isolated nature of the plant promoting sensible heat advection and additional ET than experienced by an isolated clump of plants in the field and due to the clearly well-watered conditions for the lysimeter which contrast with field conditions.

Objective 6: To explain the plant responses to the range of water application rates in terms of water availability in the water balance.

Subobjective 1: To determine the soil water holding capacity and other components of the water balance.

Results

A crop water balance includes all the additions and losses of water from the system: rain, irrigation, ET, deep drainage, conduction of water up into the root zone, water storage, and runon and runoff for a sloped site. This site was level so runoff and runon will not be considered. Measurements of rain and irrigation are available. Conduction of water up into the root zone is considered negligible (water table not present). There were no measurements of drainage but its importance can be inferred from the water balance residual. This discussion will focus on ET and water storage.

An investigation of the distribution of roots for *Alpinia purpurata* indicated that surface roots were present at the perimeter and the interior of the clump. Deeper roots were found away from the perimeter and towards the middle of the clump. Most of the roots reached to 30 to 50 cm from the soil surface. Roots were found as deep as 65 cm towards the middle of the clump and the digging was terminated at 75 cm. The pattern of the roots resembled an inverted cone. Approximately 85 to 95% of the roots occurred in this inverted cone from 0 to 75 cm with some roots moving laterally away from the perimeter of the clump.

The available soil water content of the Waialua clay variant at the Waimanalo experiment station is 0.13 to 0.15 mm of water per mm of soil (Soil Conservation Service, 1972). This root zone is thus able to hold 105 mm of water

(750 mm of soil rooting depth * 0.14 mm of water/mm of soil).

Laboratory data of the Waialua clay variant at the Waimanalo Experiment Station showed the 15-bar gravimetric water content to be 0.27 from 0 to 38 cm deep (Ikawa et al., 1985). The mean bulk density at the same depth was 1.2 g/cc therefore, the 15-bar volumetric water content is 0.33. A graduate student determined one-third-bar volumetric water content during his soil chemistry laboratory at the University of Hawaii at Manoa (R. Martinez, telephone interview with author, July 1994). For the Waialua soil, this value was 0.25. One-third-bar volumetric water content for the Waialua soil was approximately 0.38 (Mapa et al., 1986, their Fig. 4b.). The available water content using this data therefore, is approximately 0.05 which is lower than the available water content, 0.14, given by the Soil Conservation Service. The 0.14 value will be used here.

The water balance for the drip irrigated field at Waimanalo includes water application by rain and irrigation, and water losses by ET and deep drainage. Table 6.6 shows a sample calculation for the experimental site beginning following a large rain which refilled the root zone. A K_C of 1 will be used for all treatments to approximate ET although the treatment would affect ET especially with a pan factor of 0.33 and 0.67.

The water balance showed an increasing water content differential in the root zone between the irrigation

Table 6.6

Water balance for the drip irrigated field in Waimanalo for 20 days. The water balance was begun on 15 October 1991 when it was assumed that this large rain (126 mm) completely recharged the soil's water holding capacity to 105 mm on Day 1. All values are in mm.

Root Zone Water Storage

		Days					
		1	2-10[b]	11	12	13	14
Pan factors	Daily Additions & Withdrawls	+126 rai[a] - 21 deep drainage	-3.7 ET[c]	-3.3 ET	-4.3 ET +8.5 irr[d]	-3.1 ET	-3.0 ET +8.5 irr
0.33		105	71.7	68.4	66.9	63.8	63.6
0.67		105	71.7	68.4	69.8	66.7	69.4
1.00		105	71.7	68.4	72.6	69.5	75.0
1.67		105	71.7	68.4	78.3	75.2	86.4

	Days							
	15	16	17	18	19	20	21	22
	-3.0 ET	-5.1 ET +8.5 irr	-3.0 ET	-3.6 ET	-3.7 ET +8.3 irr	-1.1 ET	-3.1 ET +8.3 irr	-1.7 ET
0.33	60.6	58.3	47.5	43.9	42.9	41.8	41.4	39.7
0.67	66.4	67.0	64.0	60.4	62.3	61.2	63.7	62.0
1.00	72.0	75.4	72.4	68.8	73.4	72.3	77.5	75.8
1.67	83.4	92.5	89.5	85.9	96.1	95.0	105.0	103.3

[a] rai = Rainfall

[b] No irrigations were applied during this time because of the heavy rain on Day 1.

[c] ET = ET which is determined by daily pan evaporation (includes precipitation) * K_C (1.0)

[d] irr = Previous week's pan evaporation divided by the # of irrigations during the week (3) * PF. The PF is hidden until the daily balance is calculated.

treatments with time after the root zone was completely recharged. On Day 22, the root zone contained 39.7 to 103.3 mm of plant available water for pan factors 0.33 to 1.67 respectively for a root zone that was completely filled with water 21 days earlier.

Using a water content at wilting point of 0.25, for this soil 39.7 to 103.3 mm corresponds to a volumetric soil water content of 0.30 [0.25 + (39.7/ 105) x 0.14] to 0.39 [0.25 + (103.3/ 105) x 0.14].

Discussion

The measured soil water contents did not show the large differentials of the calculated water balance (Table 6.6). Real differences in ET water losses among the treatments could have reduced the differential in soil water content measured in the field, although the similar stomatal conductances among the treatments suggested ET was relatively similar among the treatments. Differential drainage among the treatments is the other possible water balance component which more likely explains the lack of differential among the treatments.

The inverted cone distribution of the roots suggest a vertical water movement from the irrigation applications. Although the soil is high in clay, which might be expected to store water and the infrequency of heavy rains to keep the soil uniformly wet and to keep soil hydraulic conductivity high prevented horizontal water and root movement.

From a comparison of the water balance and the measured soil water content, it is also quite evident that the irrigations were not effective in putting back into the root zone the water the plants were losing due to ET. Apparently the water was lost due to deep drainage. Even the treatment with the highest pan factor was not able to maintain the water content needed within the root zone although the treatment far exceeded ET.

Subobjective 2: To determine the soil wetting patterns by drip emitters.

Results

Bulk density is defined by the mass of oven dry soil (g) over the volume of soil (cm^3). Bulk density was determined in order to convert from gravimetric soil water content to volumetric. Bulk-density means were determined for the drip-irrigated field for two sampling dates in April and September 1993 (Table 6.7). Published data indicate similar values of bulk density, 1.01 and 1.17 Mg/m^3 for Waialua soil 8-cm deep before and after an irrigation (Mapa et al., 1986).

Table 6.7

Bulk density means ± SD determined at various depths for the Waialua clay variant from 2 sampling dates.

Depth (cm)	Bulk density (g/cm^3)	
	April 1993	Sept. 1993
2.5 - 15.0	0.84 ± 0.13	1.04 ± 0.04
15.0 - 24.0	1.13 ± 0.06	

The assumptions for the wetting patterns by drip irrigation based on volumetric soil water contents are:

1) Drier away from the emitter and

2) wetter next to the emitter.

The amount of moisture in the soil samples increased with depth. For the surface 15 cm of the soil, most of the samples were powdery dry. With depth, the color of the soil turned from a greyish-brown to darker red with the increasing water content. The soil texture also changed from powdery dry to sticky soil samples which retained the cylindrical form of the soil auger after the extraction. The deeper samples, usually 45 cm and deeper, were so sticky that the samples were sometimes difficult to remove from the soil auger bit. On occasions, samples taken below approximately 90 cm contained larger sized particles such as gravel or small stones.

Soil samples taken within the clumps contained more water than samples taken outside of the clumps. The centers of most of the clumps produced fewer shoots than their perimeters. Samples taken from the centers, 10 to 15 cm below the soil surface, were composed of decayed organic material with very little soil. Outside of the clumps, the samples were usually powdery dry as the soil was usually compact which made sampling difficult.

As might be expected, higher volumetric water content values were found next to the emitters on the perimeter of the clumps (Fig. 6.15). Values were slightly lower between two adjacent emitters on the perimeter of the clumps, but slightly smaller for the areas between two clumps within the rows, and between two clumps between the rows.

Wetting patterns as determined by volumetric soil water content samples at various depths revealed very little difference among irrigation treatments (Figs. 6.16 and 6.17). Soil samples at the perimeter of the clump contain more water than samples taken from the middle of the clump.

Discussion

The wetting front has extensive vertical movement without spreading horizontal through 120 cm (Fig. 6.16). Water movement was vertical rather than away from the emitters. It appears that deep drainage occurs as most of the roots for *Alpinia purpurata* reach to 75 cm. The very high water contents deep in the soil indicate where the irrigation water is ending up. The water table is not so high.

When the soil is newly wet after a heavy rain and the hydraulic conductivity of the soil is high, the drip irrigation spreads laterally, but as the soil dries the

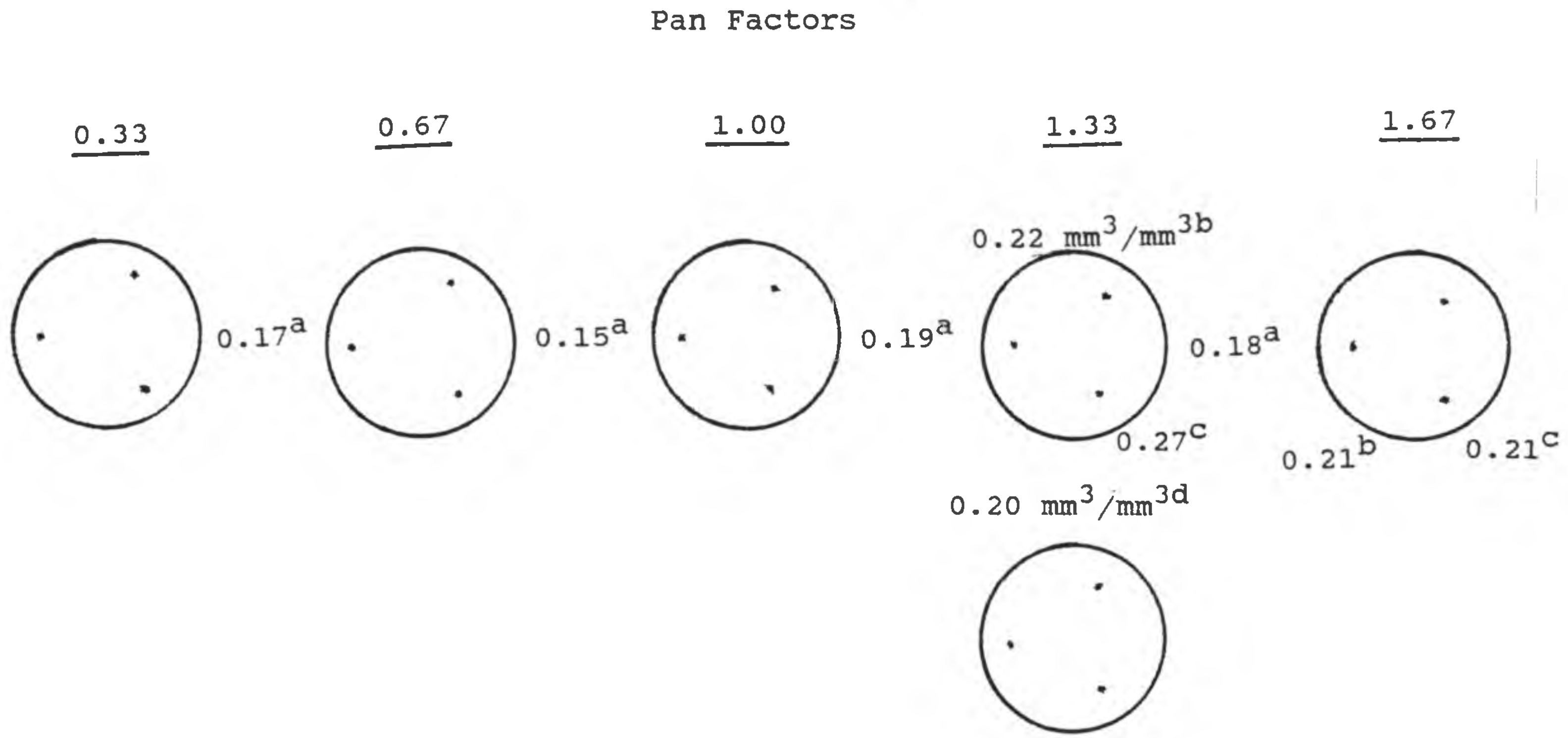


Figure 6.15

Mean volumetric soil water content between 0 to 15 cm deep sampled for over the entire drip irrigated field 1 day after irrigation on 09 April 1993. Samples were taken: a) between clumps within rows, b) on the perimeter of the clump between emitters, c) on the perimeter next to an emitter, and d) between rows.

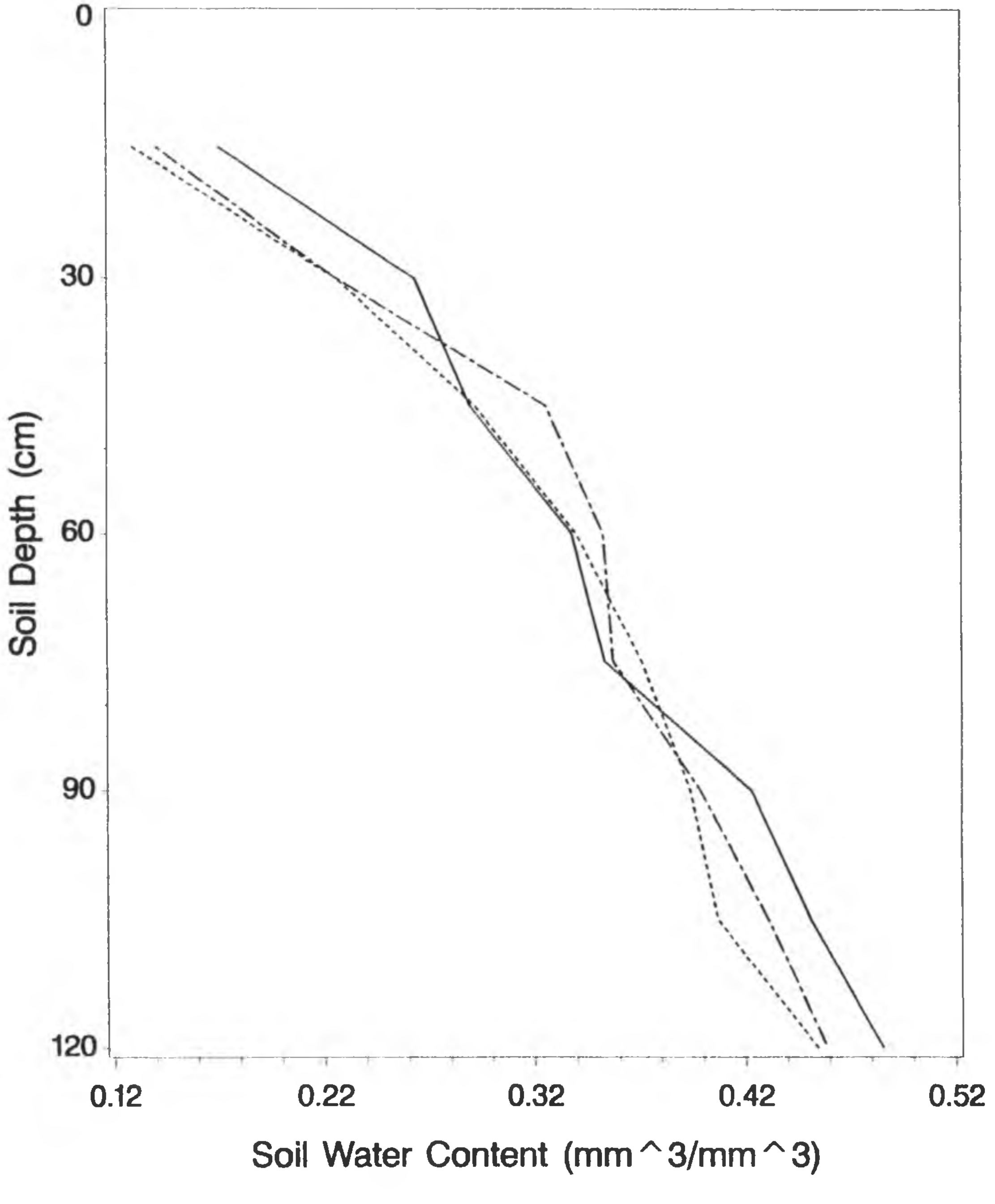


Figure 6.16

Mean volumetric soil water content for pan factors 0.33, 1.33, and 1.67 with depth sampled 1 day after irrigation next to the emitter on the perimeter of the clump for 25 May 1993, n=1 to 2

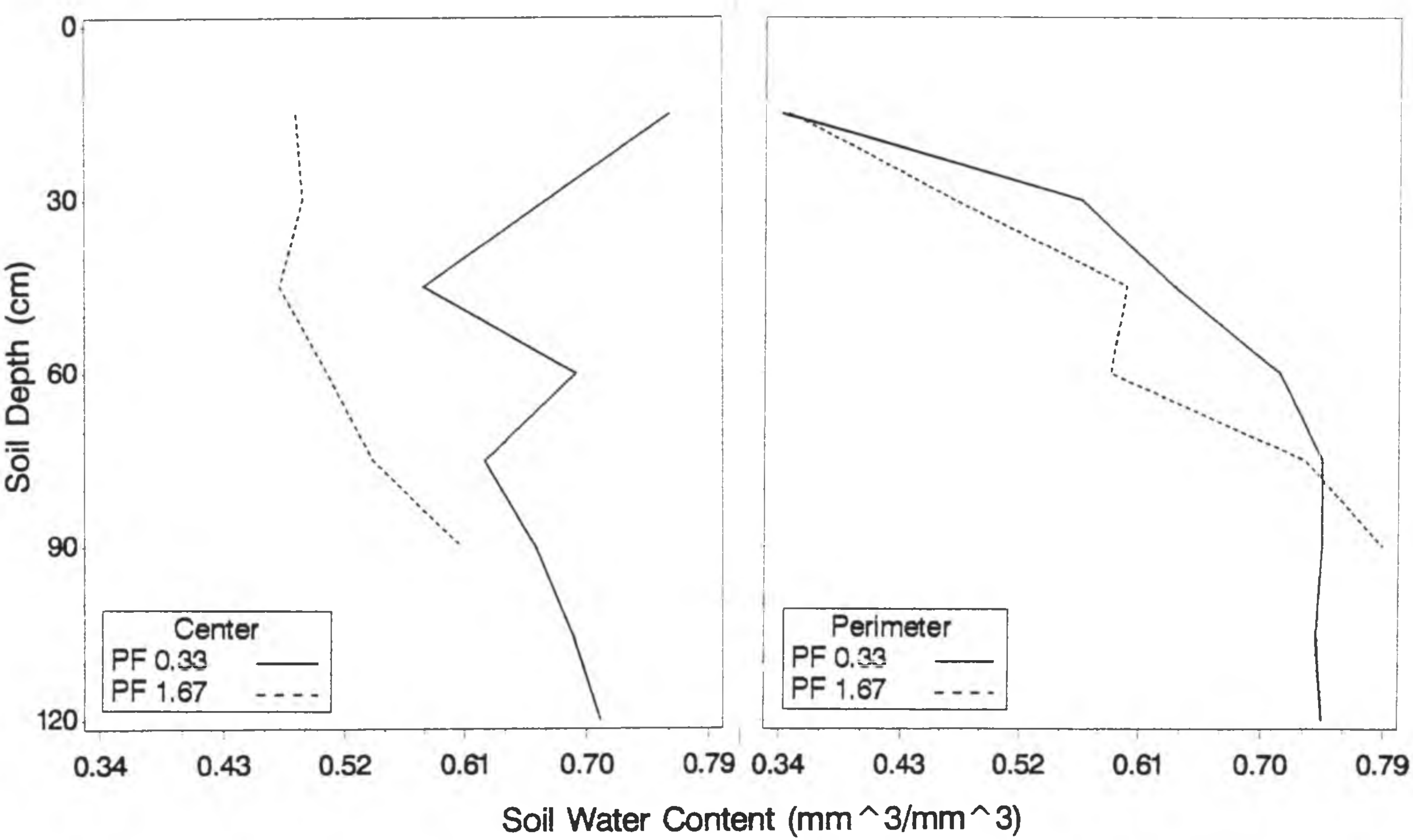


Figure 6.17

Volumetric soil water content for the center (Location 1), and perimeter next to the emitter of the clump (Location 2) for pan factors 0.33 and 1.67 with depth sampled 2 days after irrigation for 18 November 1993, n=1 hydraulic conductivity of the soil drops rapidly and the lateral spread from the drippers is reduced so much that it isn't reestablished by irrigation but only heavy rains.

Figure 6.18 represents volumetric water content contours of a Hawaiian soil, Molokai series, which shows a vertical movement of the water away from an emitter (Yabusaki, 1993). The Molokai series is a silty clay loam which is in the order Oxisols. At the time this data was taken this Molokai soil was experiencing more horizontal water movement and less vertical movement than the data in Fig. 6.17 indicates for the Waialua soil at the experimental site. The soil structure and initial water content at the time of irrigation are among the difference responsible for the different wetting patterns.

During the summer, May or June 1992, one vortex emitter was placed in an open area of bare soil, the timer was turned on for about one hour. After the hour, the wetting front was measured and it turned out to be 46 cm in diameter. This measurement was used to determine the amount of emitters to cover the area of the clumps. The mean length of the clump circumference was 2.4 m. Three circles, each 46 cm in diameter, were arranged in a triangular configuration with their perimeters slightly overlapping in order to fill as much of the clump area. Three emitters per clump were therefore chosen.

On 07 and 08 June 1993, data was taken to study the volumetric water content with distance and time from an

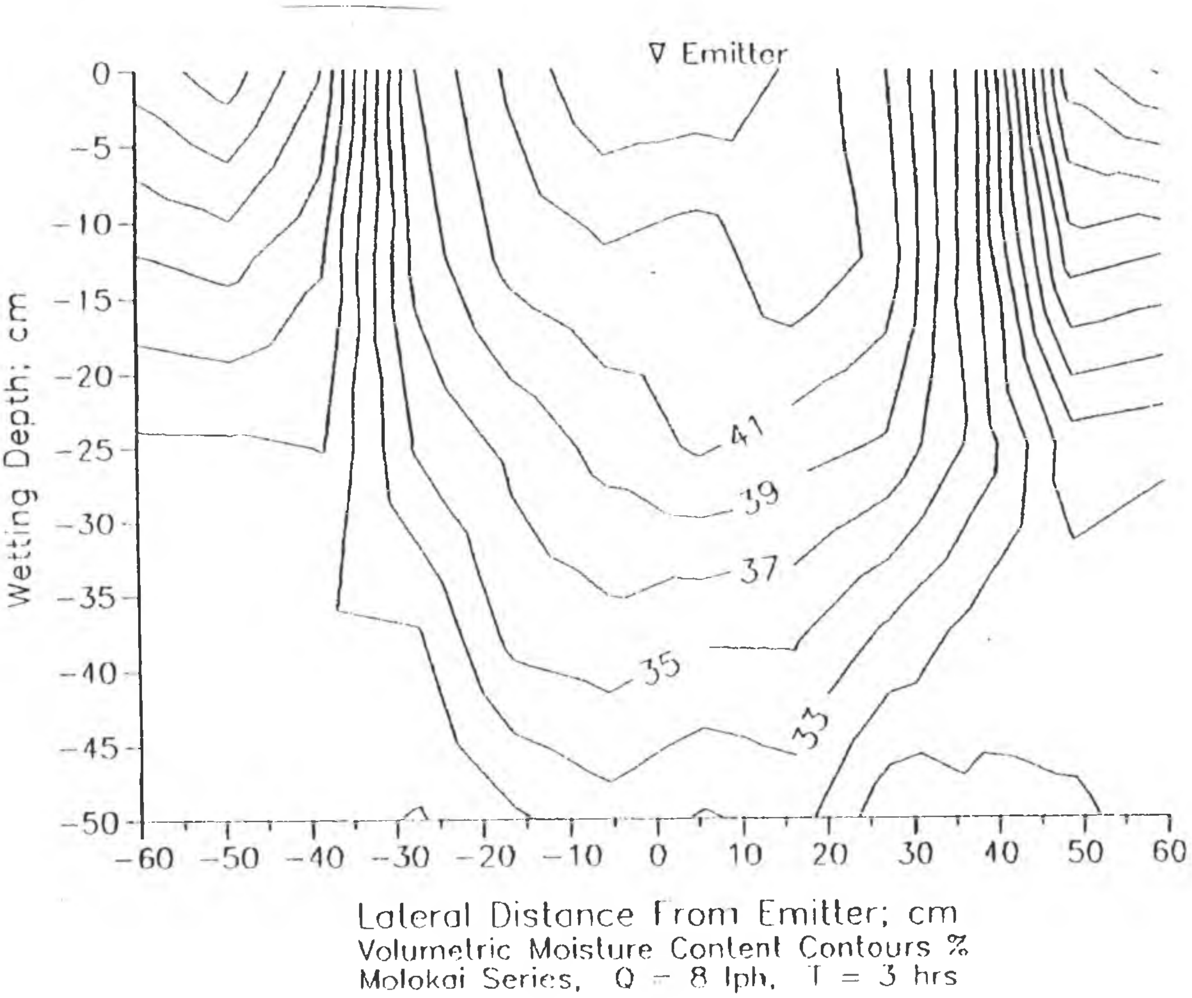


Figure 6.18

Volumetric soil water content contours for drip irrigation at 8 lph on Molokai Series[z]

[z] Figure was reproduced from Yabusaki K., "Incorporating Soil Hydraulic Properties into Drip System Design" (Ph D. dissertation, University of Hawaii, 1993).

emitter. Also the wetting fronts were recorded. The timers were left on overnight.

For PF 1.00, the wetting front was 20 cm from the emitter. The wetting front was 30 cm from the emitter for PF 1.33, and 20 cm for PF 1.67. Apparently the soil near the dripper was drier on 7 to 8 June 1993 than May or June 1992 resulting in less horizontal spread. This indicates how the wet pattern is dependent on the soil water content.

Subobjective 3: To compare the water application rate and stomatal conductance of my best treatment with a commercial operation using a different irrigation method.

Results

The commercial operation which produces *Alpinia purpurata* cultivars is 3.8 ha with plants approximately 6 to 9 years old. The clumps were spaced 2.4 m within the rows and 3.0 m between the rows. The water source is from a reservoir that is pumped into 19 mm risers and emitted by RainBird^R impact sprinklers. Some of the risers are 1.5 to 1.8 m off the ground but most of them are about 0.6 m high. The water lines which run down the rows are 10.6 m apart; the distance between the risers is 10.6 m; and each sprinkler has a wetting range of approximately 9.1 m in diameter.

The irrigation frequency is three times a week. There are eight stations (approximately 24 sprinklers per station) that divides the farm therefore each station is manually irrigated for about one hour each watering day. The water bill is approximately $30 to $40 per month.

Two methods were used to determine the irrigation rate. Eight coffee cans were placed in the field in order to catch the water for one watering. Only two of the eight coffee cans collected water which averaged 12 mm in approximately one hour.

The second method involved collecting the water from one sprinkler into a plastic 19-l bucket for a given amount of time. The amount of water was 9.5 l over 30 seconds. The area covered by the emitter was 261.3 m^2 therefore, the irrigation rate was 4.3 mm/hr.

The mean bulk density ± SD was 0.85 ± 0.06 measured on 21 July 1993 after irrigation at 6.4 cm deep for 6 samples. The mean volumetric water content ± SD for the same 6 samples was 0.46 ± 0.05.

Stomatal conductance was monitored on 'Eileen McDonald' on leaves located above the canopy at approximately 1.8 m (Fig. 6.19). Stomatal conductance increased from 7 to 10 in the morning and decreased after 10 AM.

Discussion

The established shoots at the commercial field were much taller (from 2.4 up to 3.7 m) than my field (from 1.5

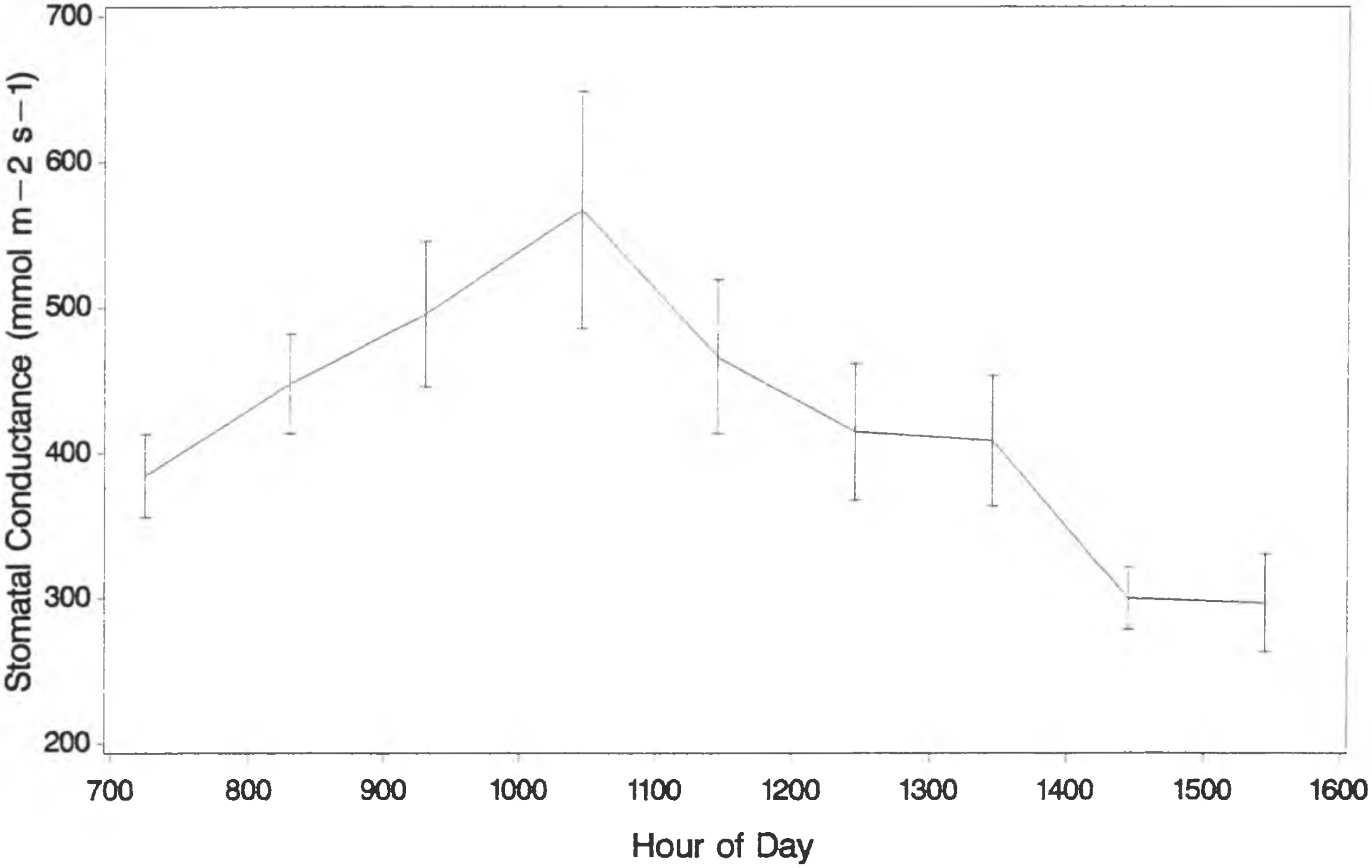


Figure 6.19

Stomatal conductance mean + SE on the last expanded leaf at the farm using overhaed impact sprinkler for 'Eileen McDonald' 1 day after irrigation on 24 June 1993, n=11 to 2.7 m). Although I did not measure the area occupied by the clumps, they appeared approximately 30 to over 100% larger than my field. The diameters at the base of the shoots were much thicker than my shoots, at times they appeared at least twice as thick. The areas between the clumps and between the rows were more shaded than my field due to the taller shoots which had larger leaves. I was not able to see the inflorescences on some shoots because they were shielded by the taller and larger leaves.

The ground was higher in moisture as I avoided the mud in many places. In contrast, the soil is usually powdery dry in my field. The difference is due to the different sprinklers along with the heavier shade.

Of particular interest was the observation of their irrigation. The older section of the farm, the 'Eileen McDonald' shoots from which I took stomatal conductance, was not spaced for individual clumps but rather a mass planting. The sprinklers were located above the plant canopy whereas the plantings of the newer sections were individually spaced which allowed for the sprinklers to be placed between the clumps 0.6 m off the ground. The idea was to avoid tearing the leaves by delivering a stream of water below them and using the splash off of the shoots and the resulting water running down the shoots to drip-irrigate the clumps.

Another major difference from my drip-irrigated field was the stomatal conductance which increased from 7 AM for the overhead irrigated field while the stomatal conductance decreased from 7 AM for the drip irrigated field (Fig. 6.20). The stomatal conductance also reached higher values of about 550 mmol m^{-2} s^{-1} instead of only 200 (3 days after irrigation) to 400 (1 day after irrigation), or 350 in the lysimeters (Fig. 6.14).

The rooting depth of the plants is essential to determine the available soil water reservoir. During the process of digging, the soil around the plant in my field was powdery dry. This supports the occurrence of water stress my plants must have been experiencing, and would probably explain why the stomata were shutting down in the morning hours even before noon. In contrast, the plants on the farm using overhead irrigation produced lower leaf temperatures compared to the leaves on my plants resulting in higher stomatal conductance data (Fig. 6.21). Having the sprinklers located above the plant canopy allows for wetting of the foliage thereby reducing leaf temperatures.

The farm using overhead irrigation applied water at a rate of approximately 4.3 mm three times a week. According to the water balance for the drip-irrigated field, Table 6.6, water was applied at 8.3 mm three times a week. It's interesting that the overhead-irrigation rate was one-half the drip-irrigation rate and because water is applied to the entire field, the soil of the overhead-irrigated field was wet compared to the powdery dry soil of the drip-irrigated field even the morning after an irrigation.

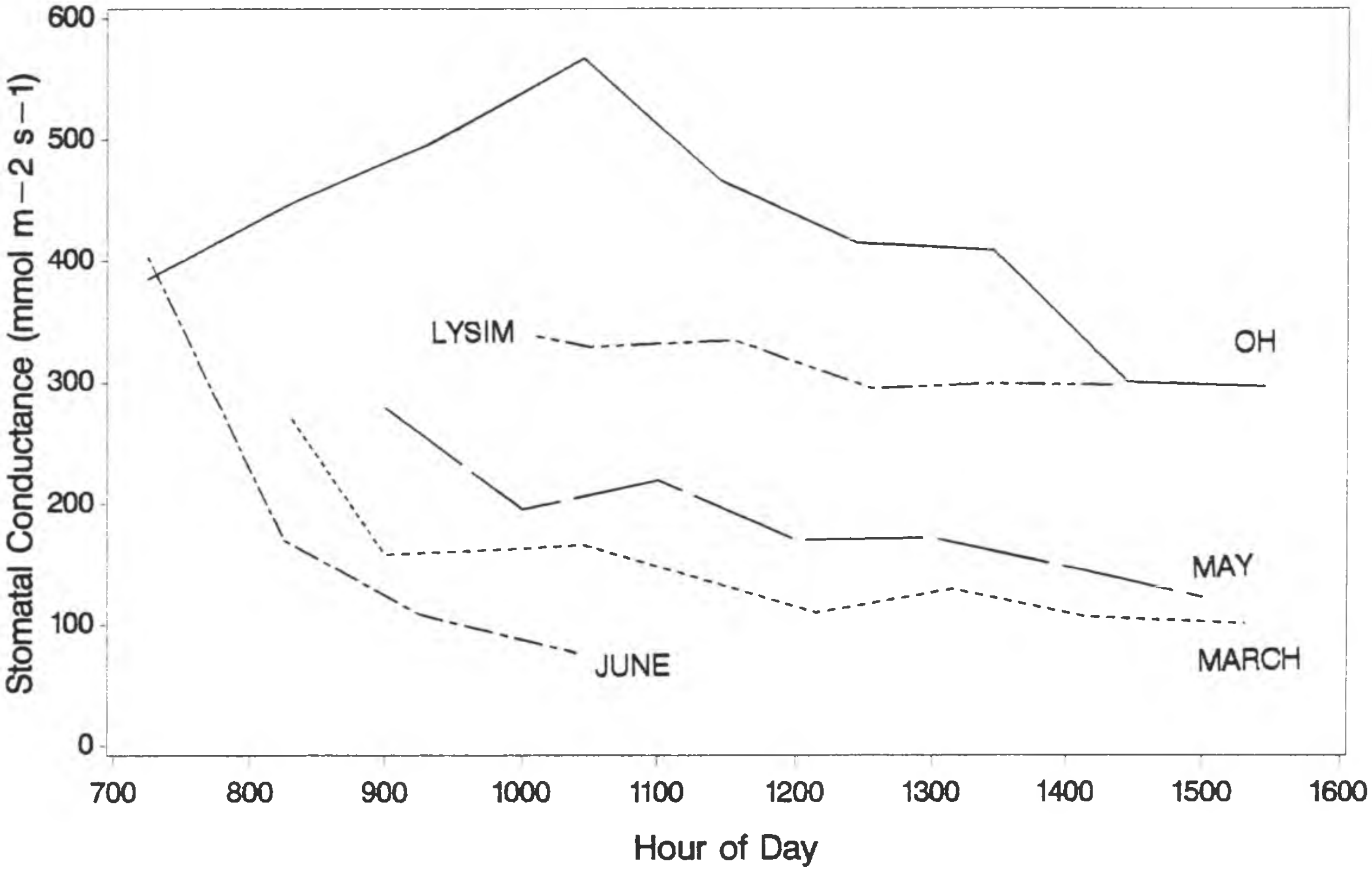


Figure 6.20

Mean stomatal conductances of the last expanded leaves for: pan factor 1.67 on 'Eileen McDonald' for 23 March 1993, 10 May 1993, and 15 June 1993; the red ginger shoots in the lysimeters; and on 'Eileen McDonald' at the farm using overhead sprinklers.

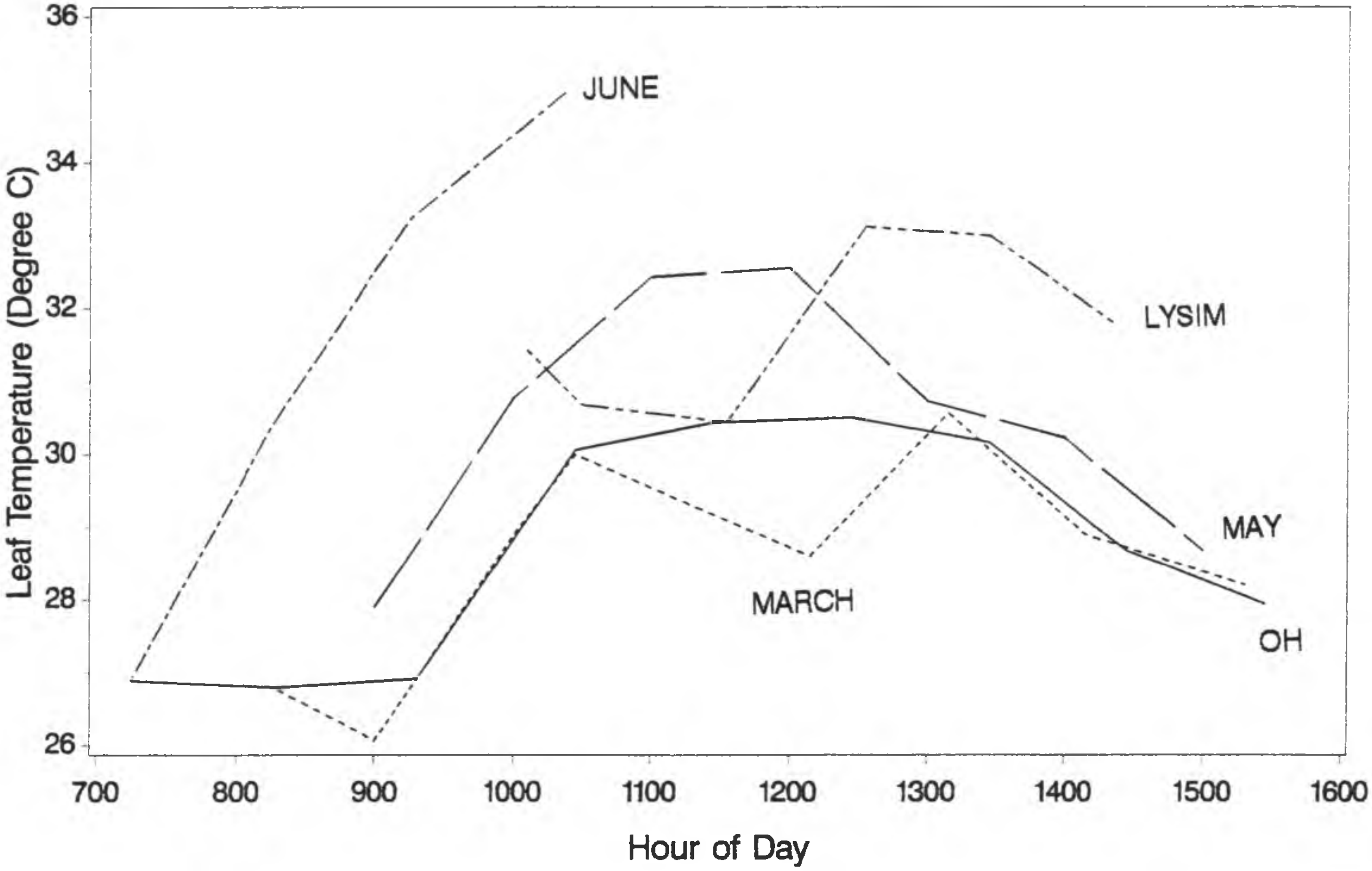


Figure 6.21

Mean leaf temperatures of the last expanded leaves for: pan factor 1.67 on 'Eileen McDonald' for 23 March 1993, 10 May 1993, and 15 June 1993; the red ginger shoots in the lysimeters; and on 'Eileen McDonald' at the farm using overhead sprinklers.

The appearance of the overhead-irrigated plants were tall shoots, shinny fully expanded turgid leaves with no indication of water stress. The drip-irrigated plants had dried edges on the leaves, matured leaves were curled, the color of the foliage wasn't as dark green as the overhead-irrigated plants, and the temperature in the overhead-irrigated field was cooler.

Chapter 7

To Evaluate the Results for Application by Commercial Growers

The cost of the water source is one of the main factors which will determine which type of irrigation system to use. Drip irrigation is not recommended for the production of *Alpinia purpurata* for the soil types available because it does not deliver the water to sufficiently cover the surface area of the clump. Water movement by drip irrigation was vertical rather than horizontal. *Alpinia purpurata* has a shallow root system and increases by rhizomes. This horizontal growth needs to be satisfied in order to produce high quality inflorescences.

My field observations were that the highest quality inflorescences usually were produced by the highest pan factor of the irrigation treatments, 1.67 times ET but the data indicated that even with the highest irrigation treatment, the ginger plants were not receiving enough water. The stomatal conductance for the plants in the lysimeters were greater than the conductance for the field plants. The stomatal conductance of the field plants were very low. The RWC of the last expanded leaves for the field plants were low. The distribution of the water to the soil was more vertical than horizontal according to the volumetric soil water content data. The surface was powdery dry while the subsurface water content increased with depth.

Growth and quality of the inflorescences and shoots did not peak at the highest irrigation levels as the graphs of the regression of the pan factors of the irrigation treatments on the yield variables were still in the limiting portion of the response curve. The final comparison was the plants on the farm that used overhead irrigation were less water stressed to the drip-irrigated plants.

The K_C calculated from the research for red ginger using the clump area was 4.2, and using the field area was 0.5 which suggests that the crops evapotranpirative demand was not met because of deep drainage which resulted in wasting water and stressing the plants. This was an inefficient means of irrigation. Overhead irrigation using impact sprinklers at a rate of 4.3 mm per hour for one hour three times a week, less during rainy periods, was a superior irrigation system.

Further Research Areas

A few of the areas which I could not answer were: inflorescence bract tip burn which may have been caused by the sun and/or wind. Growing plants under shade might answer this question. The pink-colored cultivars seemed to burn most easily.

The top end of the inflorescence sometimes results in the bracts not opening, producing a pointed-end inflorescence, a rat tail described by one grower. These rat tails results in inflorescences that are not marketable. He said that rat tails occur more in the summer months.

I would have liked to researched the use of different types of spray emitters rather than drip emitters. This may offer an alternative to the traditional overhead and flood irrigation. This type of system would be more efficient in the use of water especially when a more expensive, municipal, source of water is used.

Appendix A

List of Sampling Dates for Data Collection of the Research

Data	Number of sampling dates	Sampling dates
Objective 1		
1) Stages of growth & development	13	Nov. 1991 to Jan. 1993
2) Total leaf area per shoot	7	Jan. 1992 to Jan. 1993
3) Inflorescence initiation	5 1	July 1992 and June 1993 Sept. 1992
4) Clump area	5	Jan. 1992 to June 1993
Objectives 2 & 3		
1) Number of inflorescences/clump	18 mos.	Nov. 1991 to May 1993
Objective 4		
1) Last expanded leaf	12	Apr. 1993 to July 1993
2) RWC	1	June 1993
3) Stomatal conductance	4	Jan. 1992 to June 1993
Objective 5		
1) Lysimetry	3	1 (ET): 10 to 12 Aug. 1993 2 (T only): 18 to 19 Aug. 1993 3 (T only): 25 Aug. 1993

Appendix B

Regression Analyses Results for the Irrigation Treatment Effects on the Yield Variables for Each Cultivar

Cultivar	Y variable	Intercept	Slope	Pr.	R-square
Growth & Development					
'Eileen McDonald'	Shoot length	83.3	21.9	0.02	0.15
Ginoza	Shoot length	118.2	51.6	0.05	0.26
Red ginger	Shoot length				0.18
'Eileen McDonald'	Number of expanded leaves				0.13
Ginoza					0.54
Red ginger					0.35
'Eileen McDonald'	Inflorescence length	11.9	3.7	0.003	0.24
Ginoza					0.21
Red ginger					0.68
Total Leaf Area per Shoot					
'Eileen McDonald'	Total leaf area per shoot				0.24
Ginoza					0.31
Red ginger					0.07
Quality (Chapter 5)					
'Eileen McDonald'	Inflorescence diameter	4.5	0.15	0.001	0.03
Ginoza		4.8	0.30	0.0001	0.09
Red ginger		4.8	0.32	0.0001	0.06

Appendix B (continued)

Regression Analyses Results for the Irrigation Treatment Effects on the Yield Variables for Each Cultivar

Cultivar	Y variable	Intercept	Slope	Pr.	R-square
Quality (Chapter 5)					
'Eileen McDonald'	Shoot diameter	13.1	0.31	0.035	0.02
Ginoza		13.3	0.62	0.002	0.03
Red ginger		12.4	0.52	0.0002	0.05
'Eileen McDonald'	Inflorescence length	19.5	0.70	0.01	0.02
Ginoza		14.7	0.87	0.0001	0.08
Red ginger		19.0	0.89	0.0004	0.04
'Eileen McDonald'	Shoot length	98.7	11.6	0.0001	0.12
Ginoza		125.5	17.3	0.0001	0.11
Red ginger		100.0	18.2	0.0001	0.17
Water Relations (Chapter 6)					
'Eileen McDonald'	Inflorescence diameter	3.2	1.06	0.0001	0.69
Ginoza		4.0	1.03	0.0001	0.44
Red ginger		4.1	0.80	0.0001	0.46
'Eileen McDonald'	Shoot diameter	8.5	2.49	0.0001	0.71
Ginoza		9.8	2.23	0.0001	0.49
Red ginger		10.0	1.70	0.0001	0.42
'Eileen McDonald'	Inflorescence length	14.6	2.50	0.0001	0.36
Ginoza		11.2	3.37	0.0001	0.52
Red ginger		15.8	1.94	0.0001	0.42

Appendix B (continued)

Regression Analyses Results for the Irrigation Treatment Effects on the Yield Variables for Each Cultivar

Cultivar	Y variable	Intercept	Slope	Pr.	R-square
Water Relations (Chapter 6)					
'Eileen McDonald'	Shoot length	86.5	39.65	0.0001	0.74
Ginoza		124.2	41.12	0.0001	0.60
Red ginger		95.9	39.73	0.0001	0.58
'Eileen McDonald'	Fresh leaf weight	1.4	2.69	0.0001	0.72
Ginoza		3.0	3.08	0.0001	0.37
Red ginger		2.6	1.83	0.0001	0.35
'Eileen McDonald'	Last expanded leaf area	55.5	78.10	0.0001	0.63
Ginoza		123.6	86.13	0.0001	0.30
Red ginger		87.2	49.75	0.0001	0.29
'Eileen McDonald'	Dry leaf weight	0.4	0.79	0.0001	0.71
Ginoza		0.8	0.85	0.0001	0.37
Red ginger		0.7	0.52	0.0001	0.34

Appendix C

Mean Weekly Environmetal Data Collected by the Weather Station at the Waimanalo Experiment Station from January 1991 to December 1993

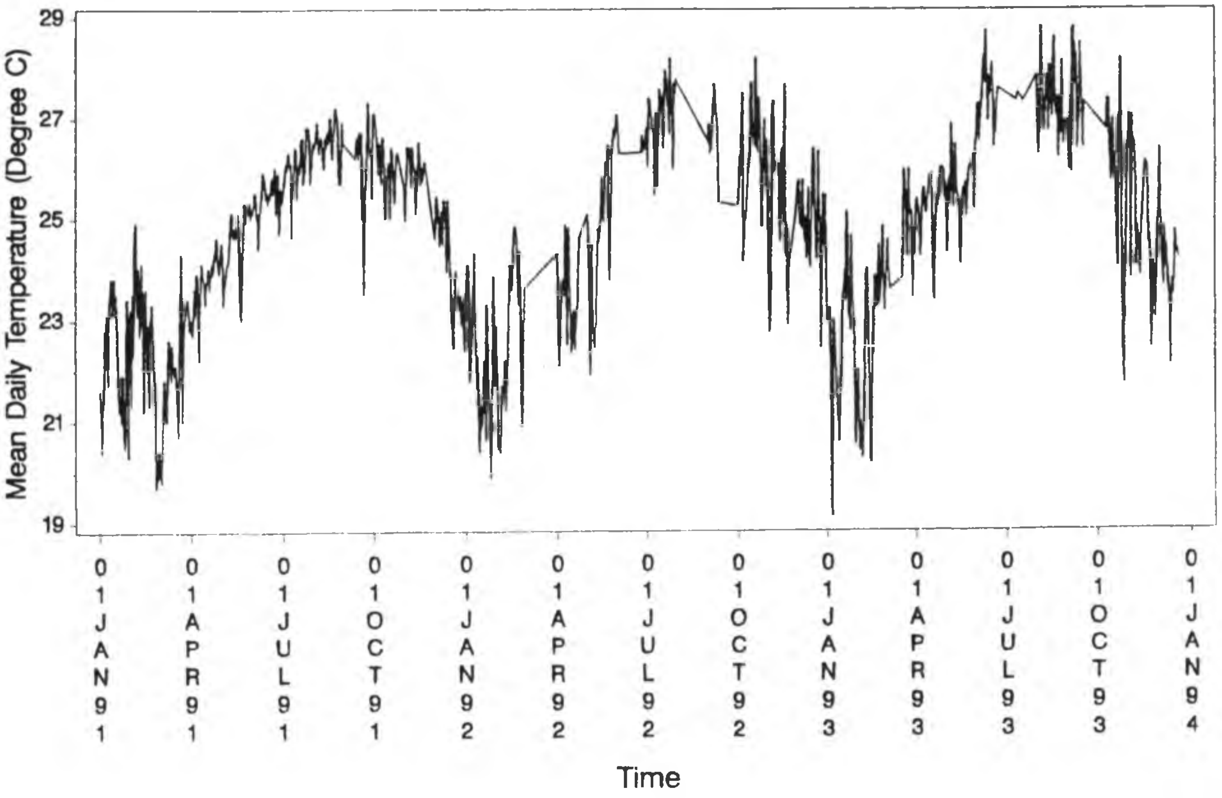


Figure C.1

The Mean Weekly Temperature for the Waimanalo Experiment Station From January 1991 to December 1993

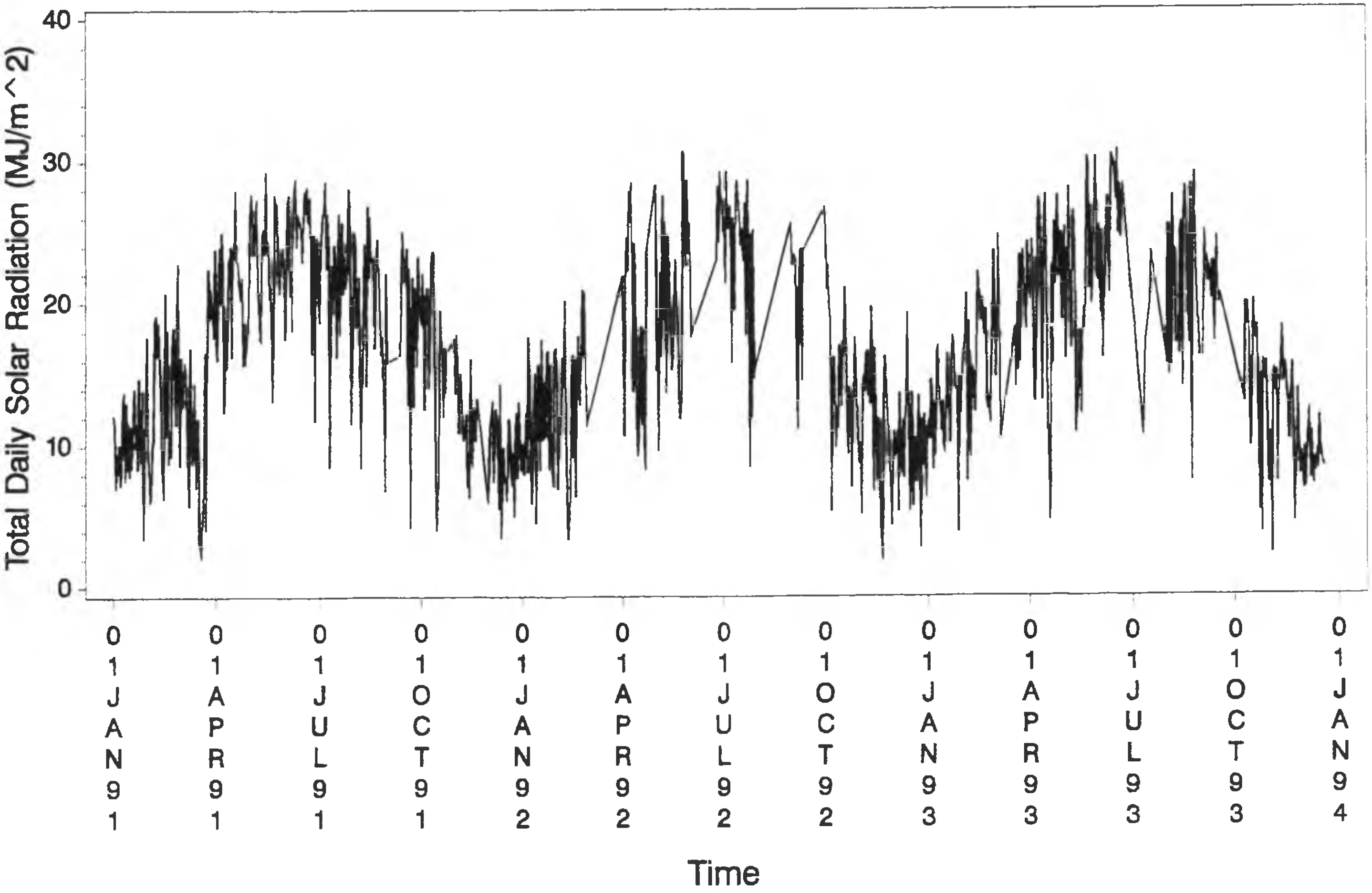


Figure C.2

The Total Weekly Solar Radiation for the Waimanalo Experiment Station From January 1991 to December 1993

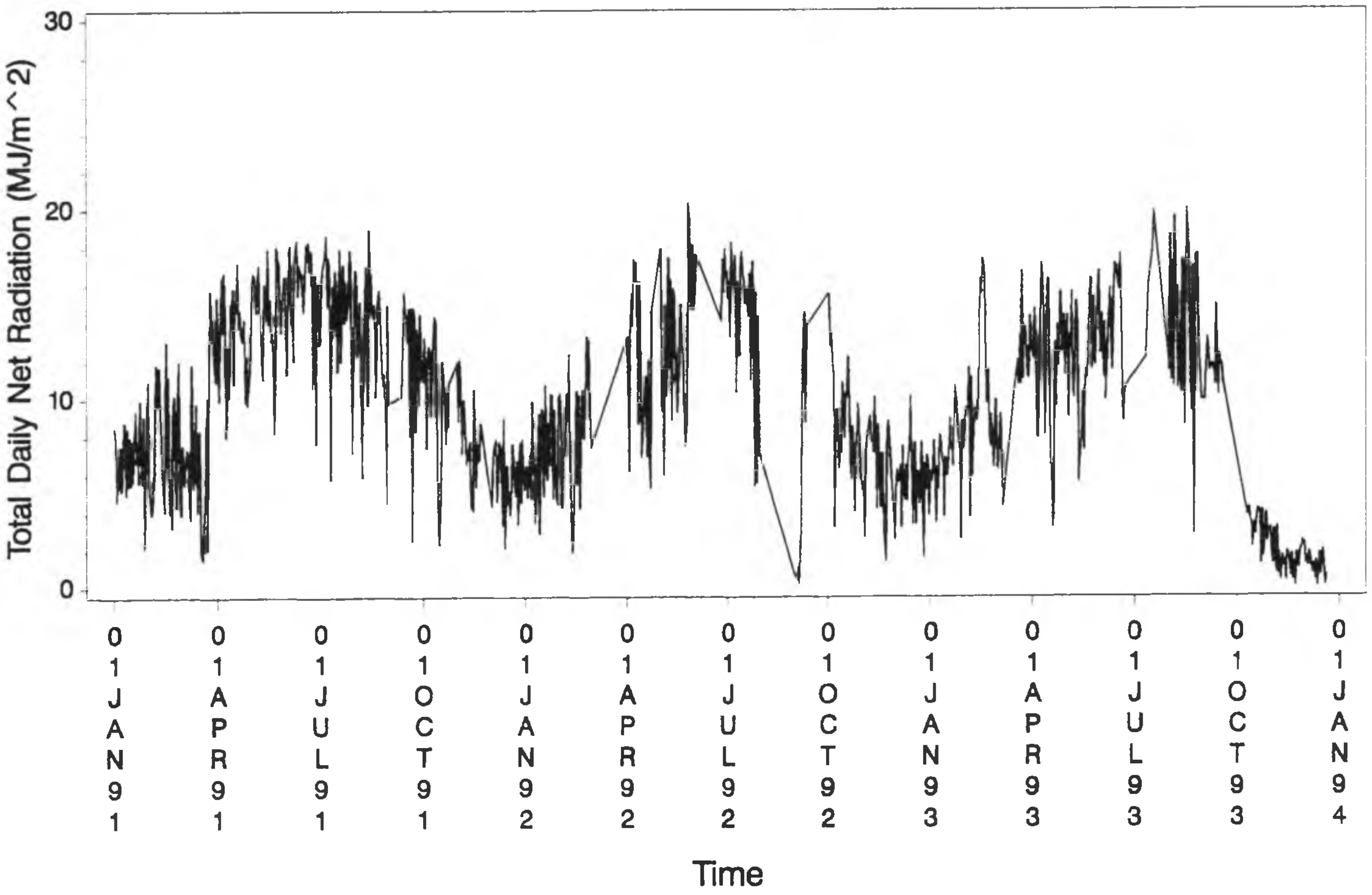


Figure C.3

The Total Weekly Net Radiation for the Waimanalo Experiment Station From January 1991 to December 1993

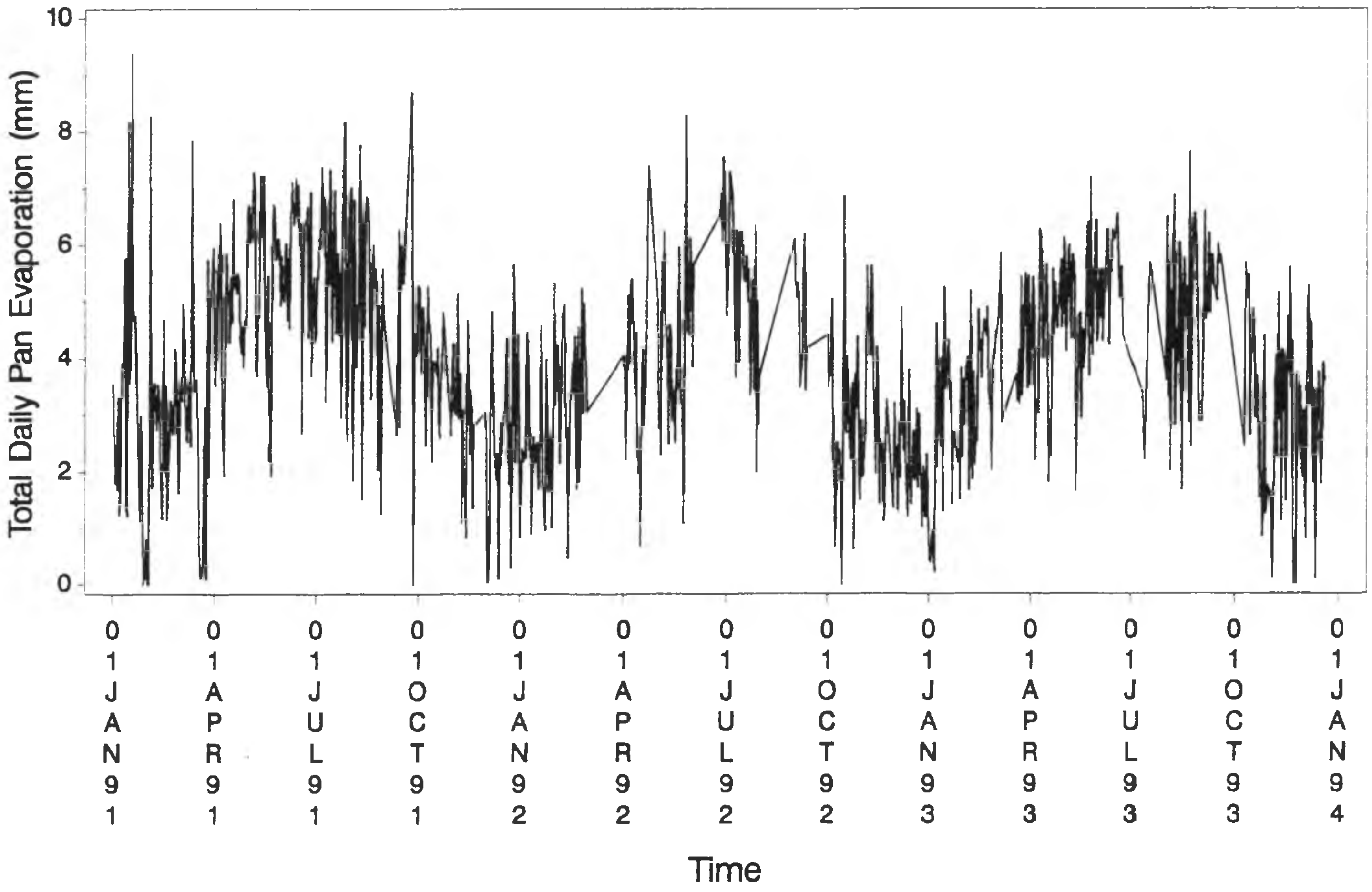


Figure C.4

The Total Weekly Pan Evaporation for the Waimanalo Experiment Station From January 1991 to December 1993

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