WEED MODELS FOR INTEGRATED PEST MANAGEMENT OF LETTUCE

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN HORTICULTURE

MAY 1988

By

Glenn T. Sako

Thesis Committee:

Kent D. Kobayashi, Chairman
Roy K. Nishimoto
Wallace C. Mitchell

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

Chairman

This thesis is dedicated to my mother, Sadako Sako, and to the memory of my late father, Tokuma Sako. My special thanks go out to both of you for your patience and sacrifice that allowed me the opportunity to pursue this degree. Mom and Dad, thank you for your encouragement and support.

ACKNOWLEDGEMENTS

I would like to extend my sincerest thanks to Dr. Kent D. Kobayashi for his advice that guided this study through its course. His advice often extended beyond research and helped me to develop as a scientist and as a person. His positive attitude gave his graduate students life when it seemed darkest. I will miss our discussions on computer software, hardware, and scientific style.

I would like to thank the Integrated Pest Management principal investigators, Dr. Wallace C. Mitchell, Dr. John J. Cho, and Dr. Roy K. Nishimoto for extending to me the graduate assistantship to carry out this investigation. I would like to personally thank Dr. Mitchell and Dr. Nishimoto for serving on my committee and for their guidance.

My thanks of appreciation go to Lynne Horiuchi and the Horticulture Department staff, Herbert Omizu and the Waimanalo Experiment Station staff, Yukio Nakahira and the Poamoho Experimental Farm staff, and Yukio Otani and the Maui Branch Station staff, especially Bert Fujioka, for their assistance.

I would like to thank Dr. Duane Bartholomew for the use of his leaf area meter and Donald McDonald for designing my irrigation system.

My personal thanks go to Myrna De Vera, Kellie Murashige, Candace Yoshii, Vanepale Malofie, and Emily Fujii. Thank you for putting in those long hours to record my data and taking care of the experiments when I could not be there.

I would like to thank Osamu Kawabata and Dr. Haruyoshi Ikawa for sharing weather data with me, and thanks to Lee Yudin for sharing information with me on the behavior of the thrips on my weeds.

The ARCS Foundation deserves special recognition for their interest in promoting research and for awarding me scholarships in 1985 and 1986. A portion of the awards

were used to complete this investigation and to prepare this thesis. Part of my work was also supported by the USDA Special Grants Program for Tropical and Subtropical Agriculture Agreement No. 83-CRSR-2-2290.

My special thanks go out to the members of the Mac Nuts. I want to thank all of you for helping me with the Macintosh microcomputer and software. This thesis would not have been possible without the help of Sandi Kunimoto, Catherine G. Cavaletto, Kent D. Kobayashi, Harry "Skip" Bittenbender, and especially Charles L. Murdoch, who let me print this thesis with his LaserWriter Plus.

I would like to thank Karen Oda for her support and understanding during the hard times I put both of us through while working on this thesis. Thank you for your patience and for encouraging me to find the "trend."

And finally, I would like to thank my siblings, Rachael, Byron, and Esther for their moral support and enthusiasm for my work. My special thanks go out to my brother-in-law Andrew Nagao and my sister Rachael for allowing me the use of their home while I pursued this degree.

It's finished, and I couldn't have done it without all of you. Thank you.

ABSTRACT

Spanish needle (*Bidens pilosa* L.) and cheeseweed (*Malva parviflora* L.) are reservoir hosts of tomato spotted wilt virus (TSWV). Thrips are attracted to their flowers, and the larvae acquire the virus while feeding on them. Massive migrations of infected thrips from the reservoir hosts into the lettuce fields have resulted in severe crop losses. In an integrated pest management program, knowing the flowering patterns of spanish needle and cheeseweed will aid in the prediction of thrips migrations and control the incidence of disease by TSWV. The objective of this study was to develop statistical models to predict the time to first flower (T50) and the time to the flower peak of these 2 weed species.

Spanish needle plants were observed from the 5-node stage for the opening of the first flower and until the flower peak occurred. Increasing temperature and rainfall shortened the T50 and the time to the flower peak. Weather data were used to develop models to predict T50 and peak flowering time. Growing degree days was included in the analysis using a base temperature of 5 ^{o}C. The model to predict T50 was $T50 = -0.57(MAXT) - 0.31(MINT) + 0.05(GDD) + 21.61$ where T50 is the time to 50% of the plants flowered (days), MAXT is the average maximum air temperature (^{o}C) from the 5-node stage to T50, MINT is the average minimum air temperature (^{o}C) from the 5-node stage to T50, and GDD is the sum of growing degree days from the 5-node stage to T50. The coefficient of multiple determination (R^2) was 0.99 ***. Validation of the model resulted in predicted values that were within 1 day for 2 of 3 locations. The model to predict peak flowering was $WKS = -0.46(MAXT) - 0.32(EVAP) + 13.33$ where WKS is the number of weeks from the 5-node stage to the flowering peak and EVAP is the summation of evaporation (cm) from the 5-node stage to peak flower. The

R^2 was 0.82 **. Validation of the model indicated that the model predicted peak flowering to within 1 week of the actual peak time.

Cheeseweed plants were observed from the 4-leaf stage for the opening of the first flower and until peak flower. Increasing temperature and rainfall shortened the T50 and time to peak flower. Weather data were used to develop models to predict T50 and peak flowering time. Growing degree days was included in the analysis using a base temperature of 6 ^{o}C. The model to predict T50 was T50 = 0.05(GDD) + 7.3 where T50 is the time to 50% of the plants flowered (days), and GDD is the sum of growing degree days from the 4-leaf stage to T50. The R^2 was 0.86 ***. Validation of the model showed that it predicted T50 values that were within an average of 4 days from the actual values. The model to predict the time to the flower peak was WKS = -0.5(MAXT) + 0.007(GDD) + 15.6 where WKS is the number of weeks from the 4-leaf stage to the flowering peak, and MAXT is the average air maximum temperature (^{o}C) from the 4-leaf stage to peak flower. The R^2 was 0.96 ***. Validation of the model indicated that it predicted the observed peak flowering time. These models can be used to help time control measures to control thrips and TSWV.

TABLE OF CONTENTS

LIST OF TABLES

Table (con't) Page

CHAPTER I

INTRODUCTION

The lettuce industry on the island of Maui suffers high losses to tomato spotted wilt virus (TSWV) during hot, dry periods. The western flower thrips (*Frankliniella occidentalis* Pergande) is the major vector of TSWV in Hawaii. It acquires the virus only by feeding on an infected plant as a larva, but it can transmit the virus in the larval and adult stages (Samuel and Bald, 1931; Smith, 1932).

Spanish needle (*Bidens pilosa* L.) and cheeseweed (*Malva parviflora* L.) are two weeds of 25 species of plants in Hawaii that were confirmed reservoir hosts of TSWV by enzyme-linked immuno-absorbent assay (ELISA) (Cho et al., 1986). Spanish needle is from tropical America and is common throughout Hawaii. Cheeseweed is from Europe and is found in certain farming areas of Hawaii. ELISA tests indicate that 55% of the spanish needle and 33% of the cheeseweed population in Hawaii could be reservoir hosts of TSWV (Cho et al., 1986). Thrips are attracted to flowering spanish needle and cheeseweed (Yudin et al. 1988). The plants may become reservoir hosts of TSWV if a viruliferous thrips feeds upon it. As reservoir hosts, they may attract thrips to their flowers and infect thrips larvae feeding on the plants. When the plants desiccate or die, the thrips may migrate (Bailey, 1933) into the lettuce fields and infect the lettuce. An infected plant will die in about 2 weeks.

An integrated pest management (IPM) strategy is being developed to reduce the crop losses to TSWV and reduce the pesticide applications. A goal is to predict when large numbers of thrips will leave the reservoir weed hosts and infest the lettuce. Many useful models have been developed to predict the behavior of weeds and their impact on crops. A model to predict itchgrass (*Rottboellia exaltata* L.) competition in corn (*Zea*

mays L.) and soybean (*Glycine max* L.) helps farmers to evaluate the potential reduction in yield by the weed (Patterson and Flint, 1979). SETSIM, a model which simulates robust foxtail (*Setaria viridis* Schreiber) growth and development, predicts the period of highest susceptibility to a selective postemergence herbicide (Orwick et al., 1978). Patterson et al. (1979) developed a model to predict the growth performance of itchgrass in a new area. This model and SETSIM can both help to evaluate a potential weed problem before it develops. The objectives of this study were 1) to observe the growth and development of spanish needle and cheeseweed, and 2) to develop statistical models to predict time to first flower (T50) and time to the flower peak of spanish needle and cheeseweed.

CHAPTER II

REVIEW OF LITERATURE

INTEGRATED PEST MANAGEMENT

Introduction

Today, among the agricultural and ecological sciences, the term "Integrated Pest Management" (IPM) is becoming more commonplace than a decade ago. What is IPM? "Integrated pest management is the intelligent selection and use of crop protection measures that will ensure favorable economic, environmental and sociological results" (Knake and Downs, 1978). The objective of IPM is to develop an effective, long-term solution for pest problems through an understanding of the actions, reactions, and interactions of components of crops or other ecosystems to be protected. Long-term crop protection can be effective by integrating all the control practices for the pests into a cohesive system. The pest control system must be compatible with the overall management and economies of the farm (Bottrell and Smith, 1982). IPM is unique as a national program in that program determination is controlled at the local level by the farmers and other users (Blair and Edwards, 1980).

Need for IPM

Most solutions for pest problems recommend chemical control without considering other options to control the pests. For most of us, chemical control is viewed as an inexpensive, fast, and effective solution to the problem of pest control. This superficial thinking has created more problems than was anticipated. The American agricultural system has high potential for havoc from pests because of our highly

mechanized agricultural system. The repeated use of land for the same crops and the continued refinement of seed varieties have increased the energy requirements for maintaining stability in the field and achieving the crops' genetic potential for yield (Allen and Bath, 1980).

The need for IPM can be attributed to economic, social, agricultural, and public health reasons (Breidenbach, 1978; Allen and Bath, 1980):

1) Petroleum-based pesticides have become expensive, and this cost will be passed on to the consumer.

2) Our society is dependent on petroleum-based products. An "energy crisis" is a real problem so we must reduce our dependence and consumption of petroleum.

3) There is an increasing awareness of the effects of toxic chemicals on human health and environment. These are problems that pesticides can pose over long periods of time. Entomologists and other agricultural scientists are given the tasks of developing pest management techniques that protect the production of food and fiber and at the same time reduce adverse environmental effects (Breidenbach, 1978).

4) Finally, the ability of pests to develop resistance to chemicals continues to be a counter-productive side effect of conventional pesticide use. We are suffering heavy crop losses despite tremendous pesticide use. No single method will always give permanent control. The proof is the insect evolution of resistance to pesticides. A single control method may also allow a minor pest to develop into a major pest, creating another problem to be dealt with (Bottrell and Smith, 1982). We have become entranced with the thinking that chemical control is the answer to our problems. This is not so. We are

captives of the "pesticide treadmill" (Smythe, 1979). This is a sequence of increasing pest resistance to chemical controls. As resistance to pesticides increases, crop losses increase. We increase pesticide use to overcome the pest's resistance, and this results in further pest resistance and/or the development of another pest species as a major pest problem and so forth (Smythe, 1979).

Interdisciplinary Requirement

The key term in integrated pest management is "integrated". it has several meanings:

1) Multidisciplinary approach. The various disciplines of science will jointly consider ail classes of pests and their relationships. The pests include arthropods, nematodes, plant pathogens, weeds, vertebrates, and other organisms.

2) It requires that all available management tactics be coordinated into a unified program. The goal is the optimal management strategy.

3) Crop protection is treated as only one aspect of the total management program of the agroecosystem.

4) IPM recognizes the need of addressing economic, ecological, and social concerns. These factors are considered when developing the program strategy (Allen and Bath, 1980).

An integrated program will require cooperation and utilize the services of weed scientists, plant pathologists, horticulturists, entomologists, pest control specialists, ecologists, agronomists, economists, sociologists, and system scientists. Working

together, these disciplines are needed to collect the information, formulate the IPM strategy, execute the strategy, and evaluate the results (Bottrell and Smith, 1982; Shaw, 1982).

For maximum effectiveness, this interdisciplinary team must integrate their activities completely from the initial research through implementation and evaluation of the IPM strategy. This "systems approach" will integrate the crop protection and production disciplines in order to present a coherent plant protection approach. This will prevent interference and conflict with another discipline's recommendation (Allen and Bath, 1980).

IPM programs have resulted in the reduction of many institutional barriers that may have previously prevented cooperation (Blair and Edwards, 1980).

IPM Techniques

IPM is a distinctive control strategy that is not bent on the total exclusion of a pest from a geographical area, but allows a manageable pest population to exist in the crop production area. It consists of the following elements:

1) Acceptance of a pest population below an economic or environmental threshold that has been determined to be significant.

2) First use of nonchemical defenses against pests before altering the environment with chemical pesticides. Emphasis on the use of natural or biological controls such as parasites, predators, hormones, or diseases where such a practice is cost-effective. By proper timing, selective pesticides, or avoiding chemical control, the chances of pesticides contacting non-target organisms is reduced. This helps to maintain a healthy predator

level in the crop and also allows other non-destructive organisms to compete against the pests for space.

3) Use of genetically resistant or tolerant varieties of crops or other desired species that still provide the desired production or aesthetic benefits.

4) Ecosystems modification to increase the effectiveness of the elements and/or to otherwise disrupt the pests' life cycle. Modifications such as crop rotation, soil tillage, improved building construction design, or product storage are all intended to reduce the pests' population below the economic threshold of significance (Allen and Bath, 1980; Blair and Edwards, 1980; Shaw, 1982).

Some of the effective nonchemical techniques of elements 2, 3, and 4 were used before World War II. They provided reasonable control despite the absence of insecticides. When the war ended, these techniques were de-emphasized as effective chemicals became available (Bottrell and Smith, 1982). Chemical pesticides are still important to IPM, but the strategy calls for the judicious use of chemical pesticides. Continuous monitoring of pest populations and careful education of farmers and other users on the judicious use of chemicals will greatly enhance the pesticides' effectiveness (Allen and Bath, 1980).

There are some promising developments and techniques that will help to bolster the IPM arsenal of control tactics some of them are already used on a small scale. These are (Nielson, 1978; Bottrell and Smith, 1982):

- insect attractant and repellent chemicals
- weed, insect, and disease agents
- insect growth regulators (hormones)

- new survey methods
- predator-prey ratios
- pest prediction models
- plant growth models.

The use of weeds to interfere with pest establishment has been promoted by William (1981). Pest populations can be reduced or avoided by visual, chemical, decoys, and physical habitat interference. This would be accomplished by selective weeds on specific pests.

It is difficult to establish absolute guidelines for a specific IPM program because it depends on the pest complex, the resources to be protected, economic values, and the availability of personnel. It is a flexible system that offers a variety of options to increase its diversity. It holds the promise of alleviating pest control problems while still maintaining agricultural production.

Economic Viewpoint and Advantages of IPM

The possible benefits of IPM must be presented to the farmer in the most attractive package to convince him to utilize it. Profit is the chief motivator, and IPM programs in a cost-benefit analyses (Bottrell and Smith, 1982) show:

1) *Reduction in pesticide use.* This can be achieved by proper timing of those chemical applications that are needed. By monitoring pest levels, pesticides would be applied only when pest populations exceed the economic threshold level (Blair and Edwards, 1980).

2) *Increased profit for users over conventional spray program.* Reducing costly pesticide use and passes over the fields in tractors saves money from supplies, fuel, labor, and maintenance.

3) *Savings in energy cost.* Reduction of tractor or spray machinery use is only part of the energy savings. Reduction in pesticide transport must be considered, too (Bottrell and Smith, 1982).

4) *No reduction in crop yield or quality of the crop.* Many demonstration fields have consistently shown that implementation of IPM programs do not affect yield and quality. For a farmer to produce crops with less inputs but recover the same yield and quality as with a conventional spray program translates into higher profits (Breidenbach, 1978).

Besides economic advantages, IPM will reduce soil erosion by reducing machinery use in the fields and increase job opportunities in the community. Students can work throughout the year as part-time scouts to monitor pest levels. It does not require a lot of training, and this job is suited for those who love the outdoors. Professional advisors are needed by private consulting firms and cooperatives. IPM specialists can also find jobs as area or county agents. Although farmers will have to pay for some of these services, their total cost of the program will be offset by increased efficiency and reduced pest control costs achieved by users (Ledbetter et al., 1979).

IPM Limitations and Needs

Clearly, there are many advantages and reasons for switching to the IPM strategy, but why does the agricultural community resist the change to IPM? The lack of interest or trust in IPM stems from farmers growing up during the time that IPM

techniques were downplayed and chemical control was emphasized. This occurred from the late 1920s to the late 1960s. During this period (Blair and Edwards, 1980), there were:

1) No widespread environmental concerns.

2) Sporadic incidences of insecticide resistance problems.

3) Inexpensive and readily available insecticides.

4) Lack of adequate money for IPM program development and personnel in both research and extension obstructed the communication of IPM principles.

There were no incentives for the development of IPM programs because their problems were not like the problems we face today. Even with pest control problems evident, farmers still are reluctant to change. It is difficult to sell the idea to farmers who are accustomed to the simpler chemical control strategy. To avoid this erroneous strategy, it must be proven to the farmer that IPM will control pests at a lower cost than that for chemical control (Breidenbach, 1978).

Education plays a major role in the acceptance of IPM. There is a widespread lack of understanding and support for multidisciplinary IPM research projects and companion educational and demonstration programs at public institutions. Those who really understand the concept and are well versed in ecology and applied biological sciences are members of a minority (Breidenbach, 1978).

Everyone must be educated in the concepts of IPM. Research scientists, extension agents, government regulators, elected officials, and farmers. It is difficult to translate IPM advantages and necessity to farmers and others, who are still bound by their faith in chemical control. Because their income is based on the crop's performance, farmers perceive the risk from pest damage to be much higher than it is and use pesticides on a

preventative schedule rather than based on actual need. They must be taught how to acquire and apply information necessary for IPM implementation rather than someone suggesting when to take action (Breidenbach, 1978; Knake and Downs, 1978; Allen and Bath, 1980).

Another obstacle to the acceptance of IPM is that the technology has not been adequately researched and developed. The economic thresholds are known only for a few pests. It is a multidisciplinary strategy, and it has gotten off to a slow start. To coordinate all of the disciplines to prepare a master plan is difficult and a slow process.

Status of IPM

Where does IPM stand now? Unfortunately, implementation of IPM has been slow. Adoption of IPM strategy has occurred basically in agricultural areas where high levels of insecticide resistance have developed in insect pests. This has forced farmers to seek alternative solutions to control their pest problems (Breidenbach, 1978). To convince the farmer to change his pest control tactics from conventional spraying, because of resistance problems, is not the desired situation. Adoption of new pest management techniques would be speeded up if the relative profitability of IPM is presented in a manner such that farmers would be willing to try it (Nielson, 1978).

IPM may have caught the interest of farmers for there is some evidence of success (Blair and Edwards, 1980; Bottrell and Smith, 1982):

1) There is an upsurge in the acreage being monitored by IPM scouts.

2) The continued increase in the number of states with demonstration programs.

3) The expansion of programs to include more commodities.

4) Movement from single- to multi-disciplinary programs.

5) Development of IPM producer organizations.

6) Growth in the number of IPM consulting firms.

7) The continued increase in producer support are indicative of the success of this program.

Nearly every crop used to demonstrate IPM has shown that pesticide use can be reduced significantly without a sacrifice in yield or quality and with increased profit to the farmer.

Conclusion

IPM is needed now to provide practical, effective, and energy-efficient solutions to significant pest problems in agriculture, forestry, and other sectors. If the public is not educated in the IPM concept and the requirement for discipline in holding to the strategy, we face many grave problems that threaten not only our agriculture, but our wildlife and health. IPM will minimize the potential hazards to humans, our food supply, possessions, and the environment.

WESTERN FLOWER THRIPS

Introduction

Frankliniella occidentalis (Pergande), commonly called the western flower thrips, is a member of the order Thysanoptera (thrips). Thrips are minute, agile insects rarely longer than 1.5 mm. They live and feed in flowers and other parts of the plant, except the roots. They pose serious problems to fruits, vegetables, flowers, and

field crops as vectors of tomato spotted wilt virus (TSWV) and because of the mechanical damage they inflict upon leaves and buds. *F. occidentalis* is a major vector for TSWV which is a severe problem in lettuce. *F. schultzei* and *F. tabaci* are vectors of TSWV, too, but their populations in Hawaii are small.

F. occidentalis is quite a complex species with pale and dark colored forms that can interbreed to produce intermediate colored forms. This has presented taxonomists with problems of categorization. On the continental USA, *F. occidentalis* and *F. moultoni* (Hood) are often confused because they share the same hosts and both vary in color from light yellow to light brown (Bryan and Smith, 1956).

Life History

In 1955, Bryan and Smith (1956) investigated the development of *F. occidentalis*. The adult female thrips inserts opaque, reniform (kidney-shaped) eggs into the parenchyma cells of leaves, flower parts, and fruits. The eggs have little protection from desiccation, and high loss is common. The eggs hatch in about 4 days at 26.7°C and 13 days at 15°C.

The first instar larva starts feeding immediately. The first molt occurs within 1-3 days at 26.7°C and after 7 days at 15°C. The second instar larva is golden yellow. It moves rapidly and prefers to feed in enclosures such as leaf folds. Development requires 3 days at 26.7°C and 12 days at 15oC.

The next stage is the quiescent stage. The second instar larva becomes progressively more sluggish, molts, and transforms into the early pseudopupa. At this stage, the wingpads appear, and the antennae shorten and become erect. This stage lasts 1 day at 26.7°C and 4 days at 15°C. When the early pseudopupa stage ends, the antennae lay back over the head. The pseudopupa then enters the late pseudopupal stage. During

this stage, the pseudopupa is reluctant to move. Its wings continue to grow, and adult setal patterns form. The adult will emerge 2-9 days later, depending on the temperature.

The effect of temperature on development of *F. occidentalis* was investigated by Lublinkhof and Foster (1977). Under laboratory conditions, all life stages of *F. occidentalis* develop more rapidly at higher temperatures between 15°C to 30°C.

Starting from eggs, the lapse time from hatching to the final molt averages 22.5, 12.6, and 8.4 days at 15°, 20°, and 30°C, respectively (Bryan and Smith, 1956; Lublinkhof and Foster, 1977). The preoviposition period requires 10.4 days at 15°C and 2.4 days at 20° and 30°C. The life span of the adult female shortens as the temperature increases. The adult female has a life expectancy of 40 days and the males about 20 days under laboratory conditions (Bryan and Smith, 1956). Optimal temperature for reproduction is around 20°C, whereas 15° and 30°C appear to be inhibitory on reproduction.

Temperature is a very important factor affecting population density of *F. occidentalis*. The relatively short life cycle at 20°C coupled with the high reproductive potential provides an ideal situation for population build up. The decreased reproductivity at 15°C and 30°C suggests normal early season and summer temperatures may dampen the population numbers. However, warm periods in early spring and cool summer weather may trigger a population build up. Conditions that favor an increase in flower population will increase thrips population because thrips depend on flowers and flowering plants for food, shelter, and breeding material.

The importance of precipitation in relation to population fluctuations of *F. occidentalis* is greatest in its effects upon the host plants. The rate or distribution of rainfall may be more important than the total amount. Heavy rains of short duration

probably limit the increase in population by delaying oviposition and larval development. Lighter rains with intervening periods of warmth provides good conditions for flowers which provides shelter and food for the thrips (Bryan and Smith, 1956).

Reproduction

The majority of the members of the family Thripidae, to which *F. occidentalis* belongs, is oviparous. Oviposition normally begins 3 days after emergence and continues intermittently throughout adulthood (Lublinkhof and Foster, 1977).

Reproduction in Thysanoptera is sexual, parthenogenetic, or both. Normal parthenogenesis is common among the thrips and may be classified as obligatory or facultative. Thrips commonly undergo constant obligatory parthenogenesis. Most Thysanoptera are facultatively parthenogenetic, that is, in the same parent, the egg may be either fertilized or develop parthenogenetically. A diploid female results if the egg is fertilized, and a haploid male occurs if no fertilization occurs. Both male and female progeny may be produced by a single mated female in which case the males are of eggs that are of parthenogenetic origin. This type of reproduction is always facultative and arrhenotokous (Suomalainen, 1950; Bryan and Smith, 1956).

A genetic analysis was conducted on the inheritance of body color by *F. occidentalis* using the various color forms the thrips are found in. It was found that (Bryan and Smith, 1956):

1) Pale and dark forms readily interbreed to produce an intermediate color.

2) Coloration is sex-limited. It is expressed phenotypically only by the females, and all males are homozygous and pale in color.

3) Pale coloration is dominant, and dark coloration is recessive. Males cannot be dark colored because they are haploid.

Thrips Vector Relationship with TSWV

Thrips are vectors of phytopathogenic bacteria, fungi, and TSWV. This IPM project is concerned with their role as vectors of TSWV. A good virus source is plants supplying good nutrition for the larvae, non-necrotic reaction from infection, and systematic, prolonged infection with high virus titer (Sakimura, 1961). *Emelia fosbergiii* (Compositae) is widely distributed and appears to be the most suitable host plant for several thrips species. *Malva parviflora* (Malvaceae) and *Bidens pilosa* (Compositae) have also been identified as hosts of TSWV (Cho et al., 1986).

The thrips mouth parts are suited for rasping-sucking, and they affect only the mesophyll tissues, not the vascular tissues. There are two basic types of feeding: the shallow type, restricted to epidermal tissues or a few layers of the mesophyll and the penetrating type, going into the deeper mesophyll tissues (Lewis, 1973).

The common characteristics in the virus vector relationships for the thrips vector species are (Samuel and Bald, 1931; Linford, 1932; Smith, 1932; Sakimura, 1963):

1) The inabiiity of adults to acquire the virus.

2) A well defined latent period ranging from 4-12 days.

3) A long retention period.

Studies directed at understanding the thrips larvae's ability to pick up the virus and the adult's inability to acquire the virus have been fruitless. The virus must be picked up in the larval stage because TSWV is not transmitted through the egg stage in thrips serving as vectors (Samuel et al., 1930). An investigation of *F. fusca*, a vector of TSWV, found virus-like particles in all tissues except the nervous, respiratory, and

male reproductive systems (Paliwal, 1979). The virus is transmitted in a persistent manner by the thrips, but there is no evidence for its multiplication in the thrips vector (Sakimura, 1963). There is some evidence showing that vector transmissibility of TSWV can decline if the virus is not periodically passed through the thrips (Paliwal, 1976).

Another investigation was conducted by Day and Irzykiewicz (1954) on *Thrips tabaci* to determine if the anatomy of the thrips would provide clues on the acquisition and retention of TSWV. The investigation was directed at:

1) Comparison of oxidation-reduction potential and pH of the midgut of larval and adult thrips.

2) Tracheal impregnation of the midgut.

3) Quantity of the infected plant material ingested.

4) The midgut permeability for the ability of TSWV to be absorbed into the midgut.

There was no evidence to show that larval and adult thrips in any of these investigations have any internal conditions suitable for the acquisition and maintenance of TSWV. The amount of infected plant material ingested does not make a difference in the virus acquisition or retention.

It is suggested that ingested virus may survive in an infectious state in thrips and be circulated in the body of the thrips. This would allow for the transmission of the virus in a persistent manner. The scattered virus particles would be difficult to detect by electron microscopy.

Due to the different color forms of *F. occidentalis* there was interest to see if there were any differences between the ability to transmit TSWV of the 3 color forms.

Comparing the light and dark forms, there are no differences between the males' and females' ability, of both color forms, to transmit the virus (Sakimura, 1962). The hybrid intermediate form does not produce any conclusive evidence on its transmission efficiency (Sakimura, 1962).

Color Preference of *F. occidentalis*

A rapid assessment of the adult thrips population is necessary in controlling the spread of TSWV. Sticky traps are easy to use, but require a color attractant that is more attractive to *F. occidentalis* than to the other thrips species. Thrips are attracted to yellow and white. Using white and yellow sticky traps, Moffitt (1964) found white traps caught 90% of the *F. occidentalis* compared to the yellow traps. It appears white is a stronger attractant than yellow, and this agrees with results of Yudin et al. (1987).

TOMATO SPOTTED WILT VIRUS

Introduction

In 1915, in Australia, Brittlebank (1919) and Osborn (1919) observed symptoms of a disease that was later shown to be caused by a virus (Samuel et al., 1930). This was the first description of tomato spotted wilt virus (TSWV). TSWV is very important because it is a serious disease in crops, has a wide reservoir host range, is only transmitted by thrips, and has the ability to recombine its genes readily (Best, 1954a,b, Best and Gallus, 1955; Best, 1961; Best, 1968; Smith, 1972).

An interesting relationship exists between TSWV and its thrips vector. The adult thrips can transmit the virus only if it has fed on a virus-infected plant when it was in

the larval stage (Samuel et al., 1930; Samuel and Bald, 1931; Smith, 1932; Linford, 1932). With *F. occidentalis*, infectivity can be retained for 30 days (Best, 1968). The virus infectivity can be retained by the larvae through pupation, but the embryo cannot pick up infectivity through the egg wall.

Symptoms and Hosts

TSWV has world-wide distribution due to its wide host range of 166 species (mostly dicotyledons) from 34 families (Ananthakrishnan, 1980). In Hawaii, at least 25 species of plants have been identified as reservoir hosts of TSWV (Cho et al., 1986). The two of interest in my thesis are:

Spanish needle ... *Bidens pilosa* L.

Cheeseweed ..... *Malva parviflora* L.

The general symptoms of the TSWV are initially rings or circular necrotic lesions, followed by mosaic and/or necrotic lesions (Smith, 1932). Symptoms are affected by (Best, 1968; Francki and Hatta, 1981):

1) The species of the host plant

2) The virulence of the virus, which is affected by the temperature, age, nutritional status of the host, and environmental factors.

3) The proportion of each strain present in the host.

The families Solanaceae, Compositae, and Leguminosae account for over 60% of the recorded hosts of TSWV in Hawaii. Within Compositae, lettuce (*Lactuca sativa* L.) is the most important crop affected by TSWV.

The symptoms of TSWV on lettuce are varied due to the many factors affecting the expression of the virus. Typically, the symptoms are necrotic lesions (primary and

systematic), necrotic ring spotting and/or non necrotic ring spotting, vein or net necrosis, non necrotic vein clearing, yellowing, and chlorotic mottling. The infection may start on one side of the plant which becomes chlorotic with brown patches. The discolorations extend to the heart tissues, and cessation of growth on one side of the plant occurs. Apparently, no vascular tissue is involved (Best, 1968; Ananthakrishnan, 1980).

Morphology

Chemical analysis and electron microscopy have been used to determine the composition and morphology of TSWV to aid in its identification. Chemically, TSWV is a RNA virus. It is composed of 20% lipids, 7% carbohydrates, and 73% ribose of RNA and is thus a pleomorphic myxovirus (Best, 1968). It is the first plant virus shown to contain lipid which exists as a membrane envelope (Best and Katekar, 1964).

Morphologically, TSWV is enveloped, roughly spherical particles about 85 nm in diameter (Francki and Hatta, 1981). It is extremely unstable in plant extracts. It is most stable at pH 7, and its stability decreases rapidly when the pH is less than 5 and greater than 10 (Best and Samuel, 1936). This is quite puzzling because the gut of the thrips vector has a pH of 5.0-5.6 which would provide a hostile environment for the virus (Best, 1968).

Control of TSWV

Three avenues under investigation to control the infection and spread of TSWV in the field are the control of the vectors, control of the reservoir hosts, and protection of the crop. Controlling the spread of TSWV by controlling the thrips vectors has been unsuccessful in Hawaii. Insecticides registered for lettuce are successful in reducing

thrips populations, but the spread of TSWV is not controlled. The insecticides do not ward off the thrips, and the thrips feed upon the lettuce and lay eggs. Although the thrips may be killed by the insecticide, infection has already taken place. When the insecticide loses its toxicity, the infected plant serves as a source of TSWV inoculum. Biological control of the thrips vector has not been extensively researched to be considered at this point.

Eliminating the virus reservoirs on which the thrips feed is not practical due to the extensive host range of TSWV. Hawaii has at least 153 plants that serve as reservoir hosts. To control their populations is not practical, and neighbors who allow the hosts to grow on their property cannot be forced to control the weeds.

The major source of infield virus titer is the infected plants. Current practice is to rogue the infected plants, but roguing has not been successful in controlling the incidences of infection. However, to disregard roguing as a preventative method may result in higher losses. There is a definite pattern of initial random infection in the field followed by deliberate within-row spread of infection. Initially, migrating viruliferous thrips infect random plants. Then, viruliferous adults may fly or crawl and larvae may crawl to the adjacent plants and infect them. Roguing results in random infection by outside thrips, but without roguing, there is random infection and slow within-row spread of infection.

Protecting the crop with cross-protection or resistance has not been encouraging. Cross-protection with a mild strain of TSWV to prevent a severe strain infection was unsuccessful (Best, 1954a). The different strains of TSWV readily recombine to produce a strain of intermediate virulence. A "cross-protected" field may serve as a reservoir from which vectors could migrate and threaten a sensitive neighboring crop (Best, 1954a). Mild TSWV strains can be produced for use in cross-

protection. The anticipated development of monoclonal antibodies would also serve to develop cross-protection in tomatoes and peppers.

Work on breeding resistance into the crops has been slow and tedious. Resistant varieties have been bred, but yield and quality have been poor. Yield and fruit quality are not linked to resistance to TSWV (Best, 1968).

WEED HOSTS

There are 2 weeds of interest in my thesis project:

Spanish needle ... *Bidens pilosa* L.

Cheeseweed ..... *Malva parviflora* L.

These weeds play an important role in the interaction between thrips, tomato spotted wilt virus (TSWV), and lettuce. The weeds occur within poorly managed fields and along the border, where they are a source of viruliferous thrips from outside of the field. They are typically two of the three dominant weed species in cultivated lettuce fields on Maui.

Spanish needle and cheeseweed serve as reservoirs of TSWV (Cho et al., 1986). These weeds are commonly found in poorly managed and along the border of lettuce fields which results in a surge of viruliferous thrips entering the fields when the flowers die. Thrips are attracted to the flowering plants (Yudin et al., 1988), and the weed host may become infected by a viruliferous thrips feeding on the plant. Following the virus incubation period, the weed host becomes a reservoir host for TSWV, and thrips larvae feeding on it has the potential to become viruliferous.

Spanish Needle

Bidens pilosa (L.) is commonly called Spanish needle or Beggar tick. It is native to tropical America and a member of the family Compositae.

This annual plant grows erect to a height of 0.3 to 1 m, and its stems and leaves are covered with many white hairs. The leaves are opposite, simple, or trifoliate, with serrated margins, and may reach a length of 5 cm (Neal, 1965; Haselwood and Motter, 1983). The flower heads are yellow and located on long stems that originate from the branch tips.

The fruit is classified as an achene and may be straight or slightly curved (Haselwood and Motter, 1983). There are 30 to 50 4-angled black achenes per flower head. At the tip, there are 2 to 3 barbed awns that measure around one-fourth the length of the seed. This aids in the dispersal of the seeds by sticking to clothes or fur of animals. The seeds are also dispersed by water.

B. pilosa is one of the most abundant weed pests in Hawaii. A survey of the important TSWV hosts in Kula, Maui, found that 55% of the surveyed plants tested positive for TSWV (Cho et al., 1986). This weed can be found in cultivated areas and roadsides, and it is distributed in dry and moist regions from lowlands to 1220 m elevation (Haselwood and Motter, 1983).

Cheeseweed

Malva parviflora (L.), (synonym *M. rotundifolia* (L.)), a member of the family Malvaceae, is commonly called cheeseweed. A native of Europe, it was first collected in Hawaii in 1826-1827 (Haselwood and Motter, 1983). It may be an annual, biennial, or perennial (Fogg, 1945; Neal, 1965; Haselwood and Motter, 1983) and sends out a deep taproot with extensive secondary roots.

It is a vigorous plant that spreads widely and will reach a height of 0.3 to 1 m. The round stems are pubescent and become fibrous as it matures.

The leaves are alternate, simple with palmate veination (Muenscher, 1980), and are attached to slender petioles 7.5 to 15 cm long. They are 1 to 4 cm across, circular in shape, and will have from 5 to 9 toothed to scalloped lobes.

It has perfect flowers that may be single or clustered in the leaf axils, and surrounded by 3 bracts on long peduncles. The calyx has 5 fused sepals and is hairy. The corolla is twice the length of the calyx and has 5 separate notched petals that are white to pinkish in color. There are numerous stamens that are united more than half their length to form a column about the pistil. There may be as many as 15 pistils, with each pistil holding 10 to 20 hairy carpels, which separate from the central axis when mature (Neal, 1965; Muenscher, 1980; Haselwood and Motter, 1983).

The fruit is an indehiscent capsule, with 1 seed per capsule, and about 15 capsules forming a ring. At maturity, the fruit will measure 2 cm in diameter, and appear light brown and slightly roughened with radiating ridges. The seeds within the capsule is reddish brown and about 1.5 mm (Neal, 1965; Muenscher, 1980; Haselwood and Motter, 1983).

This weed is found throughout the U.S. in the lower and middle elevations. It infests cultivated fields, new lawns, farmyards, and waste places. In Kula, Maui, a survey of this TSWV reservoir host found that 33% of the surveyed plants had the virus (Cho et al., 1986).

MODELS

Introduction

Modeling is one of the many tools available to investigate plant physiology. It involves many disciplines including mathematics, computer science, biochemistry, and biology. With the development of computers and data recorders, modeling has become a useful tool for the researcher and farmer.

A model studies a system so that the system may be better understood. It resembles the system and may simulate its movements if the system is dynamic. The model's behavior is the same or simiiar to that of the system. It should be more fully understood or described than the system.

A conceptual model is a description of a model based on your experiences. A mathematical model translates the conceptual model into equations. The model quantitatively represents assumptions that have been made about the system. Solving the equation will produce values that predict the response of the system. The model is tested by comparing these values with actual measurements made on the real system (Thornley, 1976).

Value of a Model

According to Thornley (1976), a model's value depends upon the nature of the problem, the goals of the investigator, and the type of mathematical model selected. Models may provide (Reynolds, 1979; Thornley, 1975):

1) Hypotheses for quantitative understanding of plants and their response to the environment.

2) Help in pin-pointing areas where knowledge and data are lacking.

3) New ideas and experimental approaches to solve complex system problems.

4) Opportunity to reduce experimentation, but still help investigators to answer questions and discriminate between alternative hypotheses.

5) Better use of data. Data is increasing in precision, but becoming more expensive to obtain.

6) A unified picture of plant growth, and may provide a valuable stimulus to collaboration and teamwork.

7) A convenient data summary.

8) A method for interpolation, prediction, and sometimes extrapolation.

9) Help to make decisions on research and development and help crop managers to take decisions.

A mathematical model may be derived by a mechanistic or statistical approach. Both methods have proven their effectiveness and have unique purposes. A complex model may be composed of both mechanistic and statistical sub-models.

Mechanistic Modeling

The purpose of the mechanistic model is to help investigators understand the response of a system in terms of the mechanisms involved. The crop must be well researched and specific knowledge on the mechanisms involved must be available before building the model. The model is constructed before any experimentation by the investigator. The system structure is divided into components, and the system's behavior will be analyzed by the investigator in terms of the individual system components and their interaction with each other (Thornley, 1976).

Mechanistic modeling may be difficult and time consuming, but it is justified when basic understanding of the system is essential for progress or technology is sufficiently advanced to make a useful model easily available (Box et al., 1975). The mechanistic approach will contribute to scientific understanding, expose areas lacking in research, provide a basis for extrapolation, and provide a representation of the response function that is more concise than the one obtained statistically (Box et al., 1975; Thornley, 1976). It confirms that our scientific understanding has been verified by experimentation.

Statistical Modeling

Statistical models are based upon events in the crop's past. Experimental data collected on the crop is analyzed, and an intelligent guess is made to select the equation or equations that best fit the data. It is not concerned with the mechanism causing the response in the plant, instead, it deals with the whole plant response. Statistical models simplify the complex system of a crop and are quickly constructed (Thornley, 1976).

The statistical model must be used carefully and its limitations must be understood because (Nye et al., 1975; Thornley, 1976; Reynolds, 1979):

1) The model applies only to the particular range of conditions under which the experiments were conducted. Results cannot be extrapolated beyond their range with certainty.

2) Statistical correlations do not test any theories of the individual mechanisms involved. It does suggest where investigations are needed.

3) Relationship between growth and other relevant factors becomes extremely complex when growth depends nonlinearly on many factors.

4) More than one equation can fit the data.

5) A large data base is needed to build a reliable model.

6) Parameters of the model are usually not biologically significant.

Verification

Verification of the model checks that the functional relationships modeled are correct by comparing the historical data recorded for the real world systems with the output of the model. Verification is necessary for multiple regression analysis. In this step, the functional relationships may need to be corrected, or the coefficients may need to be calibrated (Peart and Barrett, 1979).

Verification is especially important for mechanistic models. A model that withstands a lot of testing confirms the scientific understanding of the system. This puts the scientist in a stronger position for recommending future investigations with greater certainty. Allowance for extrapolations is based on the wide application of the mechanism, and the mechanism is based on partial understanding of the system (Box et al., 1975).

According to Draper and Smith (1966), some points to be aware of in verifying the model are:

1) Parameters are stable over the sample system. Equations fitted to observations over a long time span can be tested for stability of the coefficients by fitting the model on shorter time spans and determining the pattern of successive estimates for the regression coefficients. The coefficients may be rejected if it appears that trends occur with the shorter intervals.

2) Be aware of a systematic lack of fit of the equation. Regression residuals should be examined in all possible ways to see if any patterns are discernable which indicate that important variables have been omitted.

3) The practical aspects of the model should be intact. Unreasonable coefficients should be examined. Check to see that they are directionally correct (positive or negative). The appropriate variable should be in the equation, and check if any obvious variables are missing. The model should be usable. If it does not fulfill the objective, then a complete reconsideration of the model may be necessary. The next step is validation.

Validation

Model validation is a confirmation that the model is an accurate representation of the system. The criticism of the model's results is the most difficult step, and the investigator must decide between simplicity versus accuracy. If a model is incorrectly validated, the investigator will often increase the complexity of the model. Gentil and Blake (1981) feel that this is incorrect and prefer a simplified model. They feel that this will lead to better validation.

The method of validation depends on the type of model. The purpose of statistical models is to predict events within conditions from which it was developed. It is validated at the level of prediction (Reynolds, 1979).

The mechanistic model can be validated at the level of prediction and assumption. Prediction in good agreement with the model does not constitute validation of the assumptions of the model. Experiments should be conducted to confirm that the assumptions are correct, but according to Reynolds (1979), validation of the

assumptions are impossible. Validation of the mechanistic model is a continuous cycle of alternative hypotheses and experimentation. A model should not be so complex that it is impossible to reject all of its options and not too general that it leads to no logical deduction.

CHAPTER III

PREDICTING FLOWERING OF SPANISH NEEDLE (*Bidens pilosa* L.)

ABSTRACT

Spanish needle (*Bidens pilosa* L.) is a reservoir host of tomato spotted wilt virus (TSWV). Thrips are attracted to the spanish needle flowers, and the larvae acquire the virus while feeding on the plant. Massive migrations of infected thrips from spanish needle into the lettuce fields have resulted in heavy losses. In an integrated pest management program knowing the flowering patterns of spanish needle will aid in the prediction of thrips migrations and aid in controlling the incidence of disease by TSWV. The objective of this experiment was to develop statistical models to predict the time to first flower (T50) and the time to the flower peak of spanish needle. Plants were observed from the 5-node stage for the opening of the first flower and until peak flower. Increasing temperatures and rainfall shortened the T50 and time to peak flower. Weather data were used to develop models to predict T50 and peak flowering time. Growing degree days was included in the analysis using a base temperature of 5^{o}C. The model to predict T50 was T50 = -0.57(MAXT) - 0.31(MINT) + 0.05(GDD) + 21.61 where T50 is the time to 50% of the plants flowered (days), MAXT is the average maximum air temperature (^{o}C) from the 5-node stage to T50, MINT is the average minimum air temperature (^{o}C) from the 5-node stage to T50, and GDD is the sum of growing degree days from the 5-node stage to T50. The coefficient of multiple determination (R^2) was 0.99 ***. Validation of the model resulted in predicted values that were within 1 day for 2 of 3 locations. The model to predict peak flowering was WKS = -0.46(MAXT) - 0.32(EVAP) + 13.33 where WKS is the number of weeks from

the 5-node stage to the flowering peak and EVAP is the summation of evaporation (cm) from the 5-node stage to peak flower. The R^2 was 0.82 **. Validation of the model indicated that it predicted peak flowering to within one week of the actual peak time. These models can be used to help time control measures to control thrips and TSWV.

INTRODUCTION

The lettuce industry on the island of Maui suffers high losses to tomato spotted wilt virus (TSWV) during hot, dry periods. The western flower thrips (*Frankliniella occidentalis* Pergande) is the major vector of TSWV in Hawaii. It acquires the virus only by feeding on an infected plant as a larva, but it can transmit the virus in the larval and adult stages (Samuel and Bald, 1931; Smith, 1932).

Spanish needle (*Bidens pilosa* L.) is an annual weed that is one of 25 species of plants in Hawaii that are reservoir hosts of TSWV (Cho et al., 1986). Enzyme-linked immuno-absorbent assay (ELISA) tests indicate that 55% of the spanish needle population in Hawaii could be reservoir hosts of TSWV (Cho et al., 1986). Thrips are attracted to the flowering plant (Yudin et al. 1988), and the plant may become a reservoir host of TSWV if a viruliferous thrips feeds on it. As a reservoir host, it may attract thrips to its flowers and infect thrips larvae feeding on the plant. When the plant desiccates or dies, the thrips may migrate (Bailey, 1933) into the lettuce fields and infect the lettuce.

An integrated pest management (IPM) strategy is being developed to reduce losses to TSWV. A goal is to predict when large numbers of thrips will leave the spanish needle and infest the lettuce. Many useful models have been developed to predict the behavior of

weeds and their impact on crops. A model to predict itchgrass (*Rottboellia exaltata* L.) competition in corn (*Zea mays* L.) and soybean (*Glycine max* L.) helps farmers to evaluate the potential reduction in yield by the weed (Patterson and Flint, 1979). SETSIM, a model which simulates robust foxtail (*Setaria viridis* Schreiber) growth and development, predicts the period of highest susceptibility to a selective postemergence herbicide (Orwick et al., 1978). Patterson et al. (1979) developed a model to predict the growth performance of itchgrass in a new area. This model and SETSIM can both help to evaluate a potentlal weed problem before it develops. The objectives of this study were 1) to observe the growth and development of spanish needle and 2) to develop statistical models to predict time to first flower (T50) and time to the flower peak of spanish needle.

MATERIALS AND METHODS

Experiments were initiated at 4 locatlons: on Oahu at the Waimanalo and Poamoho experiment stations (10 and 275 m elevation, respectively) and on Maui at the Pulehu field (450 m elevation) and the Kula field (Maui Branch Station) (750 m elevation). The weather data collected at all locations were solar radiation, rainfall, evaporation, and maximum/minimum air temperatures.

Irrigation Experiments on Oahu

At the Poamoho and Waimanalo experiment stations, experiments were initiated during the summer (summer1) on June 23 and 25, 1986, respectively, to observe the effect of sprinkler irrigation on flowering. Both fields were rotovated and fumigated

with methyl bromide. The field was fertilized with 16-16-16 fertilizer at 0.17 kg/m^2 and rotovated again. Seeds were collected from the campus of the University of Hawaii and planted in rows spaced 0.5 m apart. The field was irrigated for a week after planting and the seedlings were hand thinned to 1 plant per 0.5 m. Three irrigation treatments were used:

T0 - no irrigation,

T1 - 1x the water deficit, and

T2 - 2x the water deficit.

An irrigation schedule based on weekly rainfall and evaporation was set up. The weekly rainfall was subtracted from weekly evaporation. If rainfall was less than evaporation, a deficit occurred. If weekly rainfall were equal to or greater than weekly evaporation, no irrigation treatments were applied for that week. Ten weeks after the start of the experiment, the plants were side dressed with 16-16-16 fertilizer at 0.17 kg/m^2.

Time to First Flower

Plants were observed weekly from the 5-node stage. The cotyledons were counted as true leaves, and leaves were defined as opened if they were half unfolded. Flowering was defined as the opening of at least 1 orange floret bud. When the plants started to flower, observations of the appearance of the plant's first flower were taken every 2 days. Plants that flowered were marked and removed from field observations. When 50% of the test population had flowered, the experiment was completed. Treatment effects were analyzed by analysis of variance and Scheffe's F-test.

Flowering Cycle Peaks

Starting from the 5-node stage, sampling was done weekly. The plant was cut at ground level, and the soil was washed from the stems and leaves. Each sample was placed in a plastic bag and secured.

Data collected on each plant were height, number of nodes, number of flowers, leaf area of opened leaves, and stem and leaf dry weights. Plant height was measured from the basal cut to the node of the most-recently-opened leaf or flower bud on the longest stem. Preliminary observations on flower development indicated that it takes 5 to 7 days from the bud break stage to anthesis (Table 3.1). Since sampling was conducted weekly, the stages from bud break to full flower, inclusive, were defined as flowers. Leaf area was measured with a Li-cor Model 3100 area meter (Li-cor, Inc., Lincoln, Nebraska). The stems and leaves were oven-dried for 4 days at 77^{o}C before weighing.

Field Experiments

Experiments were initiated on Maui at Pulehu on August 20, 1986 (fall) and at Kula on September 9, 1986 (fall). Field preparation and the data taken was as previously described.

On Oahu at Waimanalo, experiments were initiated on November 12, 1986 (winter) and May 29, 1987 (summer2). The remaining plants were disked, and the field was fertilized at the previous rate and rotovated. The fields were irrigated, as needed, for 7-10 days to germinate the seed reservoir and no further irrigation was provided. For the first thinning of the seedlings, paper cups were placed over selected seedlings at 0.5 m intervals, and the remaining seedlings were sprayed with the herbicide glyphosate. The cups were removed, and a week later the seedlings were

thinned to 1 seedling per mound. Data taken was as previously described. These experiments were repeated at Poamoho on November 24, 1986 (winter) and June 15, 1987 (summer2). This experiment was also repeated at Pulehu on April 27, 1987 (spring) and at Kula on May 11, 1987 (spring).

Model Development

The statistical models to predict T50 and flower peaks were developed with stepwise multiple regression using Statistical Analysis System (SAS). Independent variables included in the analysis were weather data and growing degree days (GDD). Growing degree days were calculated using a base temperature of 5°C. Noguchi et al. (1981) determined that the base temperature of lettuce (*Lactuca sativa* L.), a relative of spanish needle, was 5°C. The Kula fall experiment was omitted from the flower peak model because of questionable data. Models were validated using weather data from the experiments of Waimanalo winter, Pulehu fall, and Kula spring.

RESULTS

T50

There were location and seasonal effects on T50, except for Pulehu (Table 3.2). Under summer conditions at Waimanalo T50 was not affected by irrigation. Both T0 and T1 took 12 days to reach T50, and T2 needed 15 days. At Poamoho, T0 and T2 were significantly different. T0 took only 7 days to reach T50, but T2 needed 15 days. There were no differences between T0 and T1 (9 days to T50), and between T1 and T2. The Poamoho summer1 T0 and T1 experiments were the shortest T50 observed. The winter

and summer2 experiments of Waimanalo and Poamoho had the longest T50s at those locations. The longest T50 of all the experiments was at the Kula spring experiment with 59 days.

T50 Model

A model to predict the T50 was developed with stepwise multiple regression analysis. The equation for T50 was:

$$T50 = -0.57(MAXT) - 0.31(MINT) + 0.05(GDD) + 21.61$$

where T50 is the time to 50% of the plants flowered (days), MAXT is the average maximum air temperature (^{o}C) from the 5-node stage to T50, MINT is the average minimum air temperature (^{o}C) from the 5-node stage to T50, and GDD is the sum of growing degree days from the 5-node stage to T50. The coefficient of multiple determination (R^2) was 0.99 ***. Validation of the model showed that it predicted values that were 1 day early for the Waimanalo winter and Pulehu fall experiments and 14 days early for the Kula spring experiment (Table 3.3).

Biodata at Flower Peak

The flower numbers were lowest in the summer2 experiments and the highest numbers occurred at the Poamoho location (Table 3.2). The summer2 experiments at Waimanalo had the lowest numbers with 28 flowers per plant, and Poamoho was second with 34 flowers at their peaks. The highest flower count was 204 flowers per plant at the Poamoho winter experiment. At Pulehu, the flower numbers were low for both the

fall and spring seasons. The fall experiment had 51 flowers, and the spring experiment had 43 flowers per plant. The Kula spring experiment had 68 flowers per plant.

Irrigation treatments did not affect flower numbers at Waimanalo, but there was an effect at Poamoho (Table 3.2). For the Waimanalo summer1 experiment, T0 had 79 flowers per plant, T1 had 71, and T2 had 85 flowers. At Poamoho, the increasing levels of irrigation resulted in increasing flower numbers. The Poamoho summer1 T0 experiment had 47 flowers per plant, T1 had 61 flowers, and T2 had 136 flowers.

The height of the plant and stem dry weight appeared to be related, except when the plants were irrigated (Table 3.2). The shortest plants were from the Waimanalo summer2 experiment and the Pulehu spring experiment. Waimanalo summer2 plants measured 50.4 cm and the stems weighed 13.1 g per plant. The Pulehu spring plants were 53.1 cm and 11.5 g per plant at the flowering peak. The Poamoho winter plants were the largest measuring 115.4 cm tall and its stems weighed 137.1 g per plant. Waimanalo summer1 T0 and T2 plants measured about 101 cm tall, but the T0 stem dry weight was only 70.5 g per plant and the T2 plants' stems weighed 83.2 g. The plants of the T1 experiment were 91 cm and weighed 65.3 g per plant. At the Poamoho summer1 experiment, the T0 plants were the shortest and the lightest at 77.8 cm and 39.3 g per plant. Both T1 and T2 plants measured 96.5 cm, but T1 weighed 72.5 g per plant while T2 plants weighed 110.6 g per plant.

The leaf nodes on the terminal of the plant ranged from 5-7, except for the 10 nodes per plant at the Poamoho summer2 experiment (Table 3.2). This experiment had the longest T50 on Oahu, but the flower and dry matter production was low.

As expected, leaf area and leaf dry weight were closely related (Table 3.2). The Waimanalo summer2 experiment had the lowest leaf area with 1,143 cm^2 per plant and a leaf dry weight of 5.4 g per plant. The Pulehu spring experiment also had low leaf area

with 1,667 cm^2 and 6.6 g leaf dry weight per plant. The Poamoho winter experiment had the highest leaf area with 12,413 cm^2 and a leaf weight of 31.2 g per plant, followed by Poamoho summer1 T2 with 11,196 cm^2 and 32.6 g per plant.

The size and weight of the plants seem to be indicative of flower production. Smaller, lighter plants produced the least flowers and the large, heavy plants produced the most flowers.

Time to Flower Peak

The time to the flower peak was shortest in middle and lower elevations of the spring and summer seasons, and longer in the cooler climate and in the winter season (Table 3.2). The shortest time to reach peak flowering was at the Pulehu spring experiment with 4 weeks and the Waimanalo summer2 experiment with 5 weeks. The Waimanalo winter experiment took the longest time to peak with 13 weeks, followed by the Kula spring experiment with 12 weeks, and the Poamoho winter experiment with 11 weeks.

Irrigation at Poamoho shortened the time to the flower peak, but there were no differences between irrigation treatments, whereas at Waimanalo only the high irrigation level shortened the time to the flower peak (Table 3.2). The Poamoho summer1 T0 experiment took 8 weeks to peak in contrast to the 7 weeks for the T1 and T2 experiments. At Waimanalo, the summer1 T2 experiment took only 6 weeks to reach the flower peak while the T0 and T1 experiments took 7 weeks.

Flower Peak Model

Stepwise multiple regression resulted in a 2-variable model to predict the flowering peak. The equation was:

$$WKS = -0.46(MAXT) - 0.32(EVAP) + 13.33$$

where WKS is the number of weeks from the 5-node stage to the flowering peak, MAXT is the average air maximum temperature (^{o}C) from the 5-node stage to peak flower,and EVAP is the summation of evaporation (cm) from the 5-node stage to peak flower. The R^2 was 0.82 **.

Validation of the model indicated that it predicted peak flowering one week early for the Waimanalo winter, Pulehu fall, and Kula spring experiments (Table 3.4).

DISCUSSION

T50

The T50 of spanish needle appears to be dependent on temperature and rainfall. Adkins et al. (1987) determined that development time of the temperate weed wild oats (*Avena fatua* L.) was inversely related to temperature and this agrees with work on the tropical weed, itchgrass (Patterson et al., 1979). This is supported in the irrigation experiments during summer1 on Oahu and at Kula Maui (Table 3.2). The summer2 seasons on Oahu did not decrease the T50 in response to increasing day temperatures, perhaps because temperatures may have gone beyond the optimum for growth and development . Corn, a C_4 plant, is reported to have an optimum temperature of 30.2^{o}C (Lehenbauer, 1914), and C_4 plants have an optimum temperature that is higher than that for C_3 plants (Raven et al., 1981). The summer1 and summer2 experiments started in the 28-29^{o}C range (data not shown).

The seasonal conditions in the fall or spring at Pulehu did not affect the T50. A model for this location may not be necessary. Instead, counting the days from the 5-node stage may be just as effective.

T50 Model

The model underpredicted T50 in 3 different seasons and locations. The Waimanalo winter and Pulehu fall experiments predicted T50 were very close to the observed T50, but the Kula spring was 14 days short. This model is driven by temperature variables and GDD. During the Kula spring experiment plants were subjected to.both extreme cool and dry conditions. Although rainfall was correlated to maximum temperature and GDD, the model was not developed with any data that were as extreme as the conditions during the Kula spring experiment. This may have caused the 14-day error.

The model accounted for most of the variation in T50 because the time to reach a level of flowering in the population was predicted instead of predicting the time for a given percentage flowering. Another reason for such a high R^2 was that the plots were very close in their T50 time. Many experiments had all of the replicates reaching T50 on the same day.

At the fields in Pulehu and on Oahu, the T50 of spanish needle that are on the field borders may be predicted accurately. This is assuming that irrigation does not extend beyond the crop. T50 of spanish needle growing within the field may not be predicted accurately because of the addition of water by irrigation. High levels of irrigation delays the T50.

This model may not predict T50 at very high elevations during dry periods. Although the R^2 value was high, caution should be used because of seasonal or yearly

weather differences. A weed growth degree-day model may predict growth well for one year, but different weather conditions the next year could reduce the predictive value of the model (Nussbaum et al., 1985). GDD models have achieved better accuracy when a correction for temperature beyond optimum is encountered (Gilmore and Rogers, 1958). This may be the case with spanish needle as growth seemed to be reduced at high temperatures, and the models underpredicted at all of the validation sites.

Another view to improving heat unit models is to adjust the base temperature. Wang and Bryson (1956, cited in Wang, 1960) argue that base temperatures of heat unit computations should not be regarded as constant through the life of the plant. Their work with pea (*Pisum sativum* L.) indicate that the optimum temperature during the various life stages changes, so the base temperature of the plant should be changed accordingly. The research to determine the optimum temperature of the various plant stages is expensive. Such work with spanish needle is not necessary since the models are quite accurate with the present methods.

Biodata at Flower Peak

Growing conditions that increased plant growth resulted in more flowers. These conditions produced axillary growth which increased flower bud production. Spanish needle is of a tropical origin so it was expected to do best on Oahu in warm, moist conditions. These conditions were met during the Poamoho winter experiment which produced the largest biomass and flower production per plant (Table 3.2). The upper elevation locations were expected to produce the smallest plants due to their cool temperatures. This was true except that Waimanalo summer2 also produced small plants (Table 3.2). Despite good rainfall, the temperatures were the highest experienced in the year, which were apparently too hot and some leaf drop occurred.

Time to Flower Peak

Delays in peak flowers in the Waimanalo and Poamoho winter experiments occurred in periods of declining temperatures with 1.5 and 1.9 cm of rainfall per week, respectively. These conditions increased vegetative growing time and delayed the peak. The Pulehu fall experiment was initiated during a period of declining temperatures, too, but with only 0.9 cm of rainfall per week, and its peak occurred in 7 weeks. During the Kula spring experiment temperatures were increasing, and maximum and minimum temperatures were not very different from the Pulehu spring experiment, but the flowering peak was delayed by dry conditions. At the time of its peak 12 weeks later, the Kula spring experiment had accumulated only 4.1 cm of rainfall for an average of 0.34 cm of rainfall per week. Cool and dry conditions delayed the flower peak. A technique of combining rainfall and temperature and preparing a weighted value for their influence on the crop's growth was described by Wang and Bryson (1956, cited by Wang, 1960). Such a technique may be useful to help explain plant behavior under conditions of varying rainfall and temperatures, especially when they are correlated but extreme conditions inhibit the development of the plant. A delayed T50 did not indicate a delay in the peak flower time.

Flower Peak Model

The variations in weeks to flower peak were accounted for very well in the model. This may be due to the broad definition of a flower since sampling was conducted weekly, and the prediction of the first major flower peak. The flower definition allowed for stages of flowering to be spread over a week (Table 3.1). This model was developed to predict the first (usually the only) flower peak of spanish needle, although there were occasions when another peak occurred later in the plants' life cycle. There was no

attempt to predict the secondary peak for it was felt that by this time, preventative measures to control the thrips and spread of TSWV would have been initiated.

Deviation of the predicted time to flower peak from the observed time to peaks may be due to some error in weather data collection. The evaporation data may be questionable at Kula and Pulehu because open air Class A stainless steel pans were used. These pans were not checked regularly and was subject to rain entering the reservoir. Error could have occurred if the pan overflowed during heavy rainfall. The different orifices of the rain gauge and pan reduces the confidence in evaporation data, obtained by subtracting the rain measurement from the pan measurement, after rainfall.

This model accurately predicted the peak at the Kula spring experiment, despite temperature data that was beyond those used to develop the model. The Kula spring temperature data started below the Pulehu temperatures, but the temperatures overlapped 4 weeks later. Evaporation data was within limits experienced at other locations.

The flower peak model can be used in the fields in Pulehu, Kula, and on Oahu. These models are accurate for weeds that are on the field borders, assuming that irrigation does not extend beyond the crop. Spanish needle within the field may not be predicted accurately because irrigation may cool the plants and shorten the time to the flower peak in hot weather and delay the peak in cool weather.

CONCLUSION

Models to predict the T50 and flower peak of spanish needle can be developed from field data and provide accurate results. Use of the models is limited to plants that

are on the border and not subjected to the farming practices of lettuce. The model can be used to help the farmers determine when to implement weed control practices and initiate preventative measures against the thrips. Needless pesticide applications could be be avoided to improve economic returns.

Table 3.1. Flowering stages of spanish needle.

Stage	Days from bud break	Description
Bud break	0	Bracts starting to withdraw.
Green	1 - 2	Bracts have withdrawn to expose green receptacular bracts.
Orange-tint	2 - 3	Floret bud (orange color) emerging from beneath the subtending bract. Buds on the edges emerge first.
Anthesis	3 - 4	Floret bud(s) are opened. Flowering progresses toward the center of the flower.
Full flower	6 - 7	All florets have opened. Senescence occurs with the florets along the edges first.

Table 3.2. Plant data collected at flowering peaks of spanish needle for locations on Oahu and Maui.

Location	Experiment	T50 (days)	Peak flowering (weeks)	Flowers	Height (cm)	Stem weight (g)	Nodes	Leaf area (cm^2)	Leaf weight (g)
Waimanalo	Summer1[z] T0[x]	12	7	79	100.5	70.5	7	6,116	21.7
	Summer1 T1	12	7	71	91.0	65.3	7	5,633	19.8
	Summer1 T2	15	6	85	101.0	83.2	7	7,924	23.7
	Winter	20	13	76	69.1	30.6	7	3,685	8.0
	Summer2[y]	18	5	28	50.4	13.1	7	1,143	5.4
Poamoho	Summer1 T0	7 a[w]	8	47	77.8	39.3	6	3,895	13.0
	Summer1 T1	9 ab	7	61	96.5	72.5	6	5,546	20.2
	Summer1 T2	15 b	7	136	96.5	110.6	5	11,196	32.6
	Winter	19	11	204	115.4	137.1	7	12,413	31.2
	Summer2	23	8	34	84.2	31.0	10	2,626	13.6
Pulehu	Fall	11	7	51	80.5	26.2	6	1,894	7.3
	Spring	13	4	43	53.1	11.5	7	1,667	6.6
Kula	Fall	23	- -	- -	- -	- -	- -	- -	- -
	Spring	59	12	68	69.3	29.0	5	2,402	9.0

[z]Summer1 is the summer of 1986.
[y]Summer2 is the summer of 1987.
[x]T0 = control, T1 = 1x the water deficit, T2 = 2x the water deficit.
[w]Means separated by Scheffe's multiple-comparison, 5 % level.

Table 3.3. Validation of the T50 model in predicting time to 50% flowering of spanish needle at 3 locations.

Location	Season	Observed T50[z] (days)	Predicted T50 (days)	Difference[y]
Waimanalo	Winter	20	19	- 1
Pulehu	Fall	11	10	- 1
Kula	Spring	59	45	-14

[z]T50 is the time to 50% flowering.
[y]Difference = Predicted T50 - Observed T50.

Table 3.4. Validation of the flower peak model of spanish needle at 3 locations.

Location	Season	Observed peak (weeks)	Predicted peak (weeks)	Difference[z]
Waimanalo	Winter	13	12	- 1
Pulehu	Fall	7	6	- 1
Kula	Spring	12	11	- 1

[z]Difference = Predicted peak - Observed peak.

CHAPTER NOTES

Adkins, S.W., M. Loewen, and S.J. Symons. 1987. Variation within pure lines of wild oats (*Avena fatua*) in relation to temperature of development. Weed Sci. 35:169-172.

Bailey, S.F. 1933. A contribution to the knowledge of the western flower thrips, *Frankliniella californica* (Moulton). J. Econ. Ent. 26:836-840.

Cho, J.J., R.F.L. Mau, D. Gonsalves, and W.C. Mitchell. 1986. Reservoir hosts of tomato spotted wilt virus. Plant Dis. 70:1014-1017.

Gilmore, E.C.Jr. and J.S. Rogers. 1958. Heat units as a method of measuring maturity in corn. Agron. J. 50:611-615.

Lehenbauer, P.A. 1914. Growth of maize seedlings in relation to temperature. Physiol. Res. 1:247-288.

Noguchi, M., K. Hoshino, and M. Kikkawa. 1981. Analysis of factors determining the vegetable crop yield effect of temperature on growth and dry matter production of lettuce at different growth stages. Bul. Veg. Ornamental. Crops Res. Sta. (9):47-62. [Hort. Abstr. 53(8):5851; 1983]

Nussbaum, E.S., A.F. Wiese, D.E. Crutchfield, E. W. Chenault, and D. Lavake. 1985. The effects of temperature and rainfall on emergence and growth of eight weeds. Weed Sci. 33:165-170.

Orwick, P.L., M.M. Schreiber, and D.A. Holt. 1978. Simulation of foxtail (*Setaria viridis* var. *robusta-alba*, *Setaria viridis* var. *robusta-purpurea*) growth: the development of SETSIM. Weed Sci. 26(6):691-699.

Patterson, D.T. and E.P. Fiint. 1979. Effects of simulated field temperatures and chilling on itchgrass (*Rottboellia exaltata*), corn (*Zea mays*), and soybean (*Glycine max*). Weed Sci. 27(6):645-650.

Patterson, D.T., C.R. Meyer, E.P. Flint, and P.C. Quimby, Jr. 1979. Temperature responses and potential distribution of itchgrass (*Rottboellia exaltata*) in the United States. Weed Sci. 27(1):77-82.

Raven, P.H., R.E. Evert, and H. Curtis. 1981. Biology of Plants. Worth Publishers, New York.

Samuel, G. and J.G. Bald. 1931. *Thrips tabaci* as a vector of plant virus disease. Nature. 128:494.

Smith, K.M. 1932. Studies on plant virus diseases. Ann. Applied Biol. 19:305-330.

Wang, J.Y. 1960. A critique of the heat unit approach to plant response studies. Ecology 41:785-790.

Wang, J.Y. and R.A. Bryson. 1956. A study of phytometeorological effects on the growth and development of peas. Dept. Meteorol., Univ. of Wisconsin.

Yudin, L.S., B.E. Tabashnik, J.J. Cho, and W.C. Mitchell. 1988. Colonization of weeds and lettuce by thrips (Thysanoptera: Thripidae). Env. Ent. (in press).

CHAPTER IV

PREDICTING FLOWERING OF CHEESEWEED (*Malva parviflora* L.)

ABSTRACT

Cheeseweed (*Malva parviflora* L.) is a reservoir host of tomato spotted wilt virus (TSWV). Thrips are attracted to the cheeseweed flowers, and the larvae acquire the virus while feeding on the plant. Massive migrations of infected thrips from cheeseweed into the lettuce fields have resulted in heavy losses. In an integrated pest management program knowing the flowering patterns of cheeseweed will aid in the prediction of thrips migrations and aid in controlling the incidence of disease by TSWV. The objective of this experiment was to develop statistical models to predict the time to first flower (T50) and the time to the flower peak of cheeseweed. Plants were observed from the 4-leaf stage for the opening of the first flower and until peak flower. Increasing temperatures and rainfall shortened the T50 and time to peak flower. Weather data were used to develop models to predict T50 and peak flowering time. Growing degree days was included in the analysis using a base temperature of 6^{o}C. The model to predict T50 was T50 = 0.05(GDD) + 7.3 where T50 is the time to 50% of the plants flowered (days), and GDD is the sum of growing degree days from the 4-leaf stage to T50. The coefficient of multiple determination (R^2) was 0.86 ***. Validation of the model showed that it predicted T50 values that were within an average of 4 days from the actual values. The model to predict the time to the flower peak was WKS = -0.5(MAXT) + 0.008(GDD) + 15.6 where WKS is the number of weeks from the 4-leaf stage to the flowering peak and MAXT is the average air maximum temperature (^{o}C) from the 4-leaf stage to peak flower. The R^2 was 0.96 ***. Validation of the model indicated that it predicted the

observed peak flowering time to within 1 week. These models can be used to help time control measures to control thrips and TSWV.

INTRODUCTION

The lettuce industry on the island of Maui suffers high losses to tomato spotted wilt virus (TSWV) during hot, dry periods. The western flower thrips (*Frankliniella occidentalis* Pergande) is the major vector of TSWV in Hawaii. It acquires the virus only by feeding on an infected plant as a larva, but it can transmit the virus in the larval and adult stages (Samuel and Bald, 1931; Smith, 1932).

Cheeseweed (*Malva parviflora L.*) is an annual weed that is one of 25 species of plants in Hawaii that are reservoir hosts of TSWV (Cho et al., 1986). Enzyme-linked immuno-absorbent assay (ELISA) tests indicate that 33% of the cheeseweed population in Hawaii are reservoir hosts of TSWV (Cho et al., 1986). Thrips are attracted to the flowering plant (Yudin et al. 1988), and the plant may become a reservoir host of TSWV if a viruliferous thrips feeds upon it. As a reservoir host, it may attract thrips to its flowers and infect thrips larvae feeding on the plant. When the plant desiccates or dies, the thrips (Bailey, 1933) may migrate into the lettuce fields and infect the lettuce.

An integrated pest management (IPM) strategy is being developed to reduce losses to TSWV. A goal is to predict when large numbers of thrips will leave the cheeseweed and infest the lettuce. Many useful models have been developed to predict the behavior of weeds and their impact on crops. A model to predict itchgrass (*Rottboellia exaltata* L.) competition in corn (*Zea mays* L.) and soybean (*Glycine max* L.) helps farmers to evaluate the potential reduction in yield by the weed (Patterson and Flint, 1979).

SETSIM, a model which simulates robust foxtail (*Setaria viridis* Schreiber) growth and development, predicts the period of highest susceptibility to a selective postemergence herbicide (Orwick et al., 1978). Patterson et al. (1979) developed a model to predict the growth performance of itchgrass in a new area. This model and SETSIM can both help to evaluate a potential weed problem before it develops. The objectives of this study were 1) to observe the growth and development of cheeseweed and 2) to develop statistical models to predict time to first flower (T50) and time to the flower peak of cheeseweed.

MATERIALS AND METHODS

Experiments were initiated at 4 locations: on Oahu at the Waimanalo and Poamoho experiment stations (10 and 275 m elevation, respectively) and on Maui at the Pulehu field (450 m elevation) and the Kula field (Maui Branch Station) (750 m elevation). The weather data collected at all locations were solar radiation, rainfall, evaporation, and maximum/minimum air temperatures.

Irrigation Experiments on Oahu

At the Poamoho and Waimanalo experiment stations, experiments were initiated during the summer (summer1) on July 7 and 30, 1986, respectively, to observe the effect of sprinkler irrigation on flowering. Both fields were rotovated and fumigated with methyl bromide. The field was fertilized with 16-16-16 fertilizer at 0.17 kg/m^2 and rotovated again. Seeds were collected from the Pulehu field on Maui. The seeds were scarified with 70% sulfuric acid, air dried, and planted in rows spaced 0.5 m apart. The

fields were irrigated for a week after planting, and the seedlings were thinned to 1 plant per 0.5 m. Three irrigation treatments were used:

T0 - no irrigation,

T1 - 1x the water deficit, and

T2 - 2x the water deficit.

An irrigation schedule based on weekly rainfall and evaporation was set up. The weekly rainfall was subtracted from weekly evaporation. If rainfall was less than evaporation, a deficit occurred. If weekly rainfall were equal to or greater than weekly evaporation, no irrigation treatments were applied for that week. Ten weeks after the start of the experiment, the plants were side dressed with 16-16-16 fertilizer at 0.17 kg/m^2.

Time to First Flower

Plants were observed weekly from the 4-leaf stage. The cotyledons were counted as true leaves, and leaves were defined as opened if they were half unfolded. Flowering was defined as the appearance of the white petals. When the plants started to flower, observations of the appearance of the plant's first flower were taken every 2 days. Plants that flowered were marked and removed from field observations. When 50% of the test population had flowered, the experiment was completed. Treatment effects were analyzed by analysis of variance and Scheffe's F-test.

Flowering Cycle Peaks

Starting from the 4-leaf stage, sampling was done weekly. The plant was cut at ground level, and the soil was washed from the stems and leaves. Each sample was placed in a plastic bag and secured.

Data collected on each plant were height, number of nodes on the terminal stem, number of flowers, leaf area of opened leaves, and stem and leaf dry weights. Plant height was measured from the basal cut to the node of the most-recently-opened leaf or flower bud on the terminal stem. Preliminary observations on flower development indicated that from the 3-mm bud stage it takes 2 to 4 days to anthesis and 5 to 7 days to reach the the green seed stage (Table 4.1). Since sampling was conducted weekly, the stages from 3-mm bud to green seed stage, inclusive, were defined as flowers (Table 4.1). Leaf area was measured with a Li-cor Model 3100 area meter (Li-cor, Inc., Lincoln, Nebraska). The stems and leaves were oven-dried for 4 days at 77°C before weighing.

Field Experiments

Experiments were initiated on Maui at Pulehu on August 8, 1986 (fall) and at Kula on September 9, 1986 (fall). Field preparation and the data taken was as previously described.

On Oahu at Poamoho, experiments were initiated on November 30, 1986 (winter) and June 3, 1987 (summer2) The remaining plants were disked, and the field was fertilized at the previous rate and rotovated. The fields were irrigated, as needed, for 7-10 days to germinate the seed reservoir. For the first thinning of the seedlings, paper cups were placed over selected seedlings at 0.5 m intervals, and the remaining seedlings were sprayed with the herbicide glyphosate. The cups were removed, and a week later the seedlings were thinned to 1 seedling per mound. Data taken was as previously described. These experiments were repeated at Waimanalo on January 26, 1987 (winter) and May 17, 1987 (summer2). This experiment was also repeated at Pulehu on April 10, 1987 (spring) and at Kula on April 21, 1987 (spring).

Model Development

The statistical models to predict T50 and flower peaks were developed with stepwise multiple regression using Statistical Analysis System (SAS). Independent variables included in the analysis were weather data and growing degree days (GDD). Growing degree days were calculated using a base temperature of 6^{o}C. Badr et al. (1984) determined that the base temperature of okra (*Abelmoscus esculentus* L.), a relative of cheeseweed, was 6^{o}C. The Kula fall experiment was omitted from the flower peak model because of unreliable data. Models were validated using weather and plant data from the experiments of Waimanalo winter, Pulehu fall, and Kula spring.

RESULTS

T50

There was location and seasonal effects on T50, except for Pulehu (Table 4.2). Under summer conditions at Waimanalo T50 was not affected by irrigation. T0 took 70 days and T1 took 71 to reach T50. T2 needed only 61 days for T50, but it was not significantly different. At Poamoho, T0 was significantly different from T1 and T2, but T1 and T2 were not significantly different. T0 took 32 days to reach T50, but T1 and T2 needed only 17 and 20 days, respectively. T2 had the shortest T50 observed for all experiments. The longest T50s were the Kula fall experiment with 64 days and the Waimanalo summer1 T2 experiment with 61 days.

T50 Model

A model to predict the T50 was developed with stepwise multiple regression analysis. The equation for T50 was:

$$T50 = 0.05(GDD) + 7.3$$

where T50 is the time to 50% of the plants flowered (days), and GDD is the sum of growing degree days from the 4-leaf stage to T50. The coefficient of multiple determination (R^2) was 0.86 ***. Validation of the model showed that it predicted T50 values that were 2 days early for the Waimanalo winter experiment, 2 days late for the Pulehu fall experiment, and 8 days early for the Kula spring experiment (Table 4.3).

Biodata at Flower Peak

Poamoho winter had the highest flower count with 2,058 per plant and Poamoho summer1 T2 had 495 flowers for the second highest count (Table 4.2). The lowest flower count was at Poamoho summer1 T0 with 45 flowers per plant. At Waimanalo, the winter experiment had 440 flowers per plant and the summer1 T2 had 331. The low flower count for Waimanalo was 121 for the summer1 T1 experiment. At Pulehu, the fall experiment produced 207 flowers per plant compared to 121 flowers per plant in the spring. The Kula spring experiment produced 324 flowers per plant.

The stem dry weight was not related to plant height. The only relationship between stem weight and height occurred with the shortest and tallest plants on Oahu. Poamoho summer1 T0 experiment had the shortest plants at 19.0 cm per plant and their stems weighed the least, with 3.0 g per plant (Table 4.2). The Poamoho winter experiment had the tallest plants with 133.9 cm per plant, and their stems weighed the

most with 492.3 g per plant. Kula spring experiment plants measured 61.7 cm per plant and weighed only 26.3 g per plant. This is in contrast to the Pulehu fall experiment plants which measured 45.5 cm per plant, but weighed 37.1 g per plant. At Poamoho, irrigation affected the plants' height and stem dry weight. T1 and T2 were much taller and had heavier stems than T0. At Waimanalo, the summer1 T2 experiment plants were taller than the plants of T0 and T1 with 57.5 cm for T2 in contrast to 37.8 and 33.3 cm for T0 and T1.

Leaf numbers on the terminal stem ranged from a low of 18 to a high of 47 (Table 4.2). The spring experiment plants at Pulehu and the Poamoho summer1 T0 experiment plants produced only 18 flowers per plant. This did relate to the lowest leaf area and leaf dry weight of all the locations. The Pulehu fall experiment plants had 31 nodes per plant and 2802 cm^2 leaf area that weighed 8.1 g , compared to the spring experiment whose plants had 18 nodes, 843 cm^2 leaf area, and 7.4 g of leaf dry weight. The Poamoho summer1 T0 experiment plants had the lowest leaf area and leaf dry weight with 504 cm^2 and 2.9 g per plant. Poamoho winter plants had the most nodes with 47 per plant. This experiment produced the highest leaf area of 51,322 cm^2 and leaf dry weight of 134.6 g per plant. The other experiments on Oahu had 20 to 35 nodes per plant, leaf area ranging from 1,240 to 4,625 cm^2, and leaf weights of 6.3 to 18.9 g per plant.

Time to Flower Peak

The shortest time to peak flower was observed at the Poamoho summer1 T0 and summer2 experiments with 5 weeks (Table 4.2). The longest time to peak flower was 14 weeks for the Poamoho winter experiment. At Waimanalo, irrigation reduced the peak flower time from 12 weeks for T0 to 10 and 8 weeks for T1 and T2, respectively.

At Poamoho, irrigation delayed the time to peak flowering from 5 weeks for T0 to 9 weeks for both T1 and T2. Between the Pulehu fall and spring experiments, there was a 2-week differential. The fall experiment took 9 weeks, and the spring experiment took 7 weeks. The Kula spring experiment took 8 weeks to peak.

Flower Peak Model

Stepwise multiple regression resulted in a 2-variable model to predict the flowering peak. The equation was:

$$WKS = -0.5(MAXT) + 0.007(GDD) + 15.6$$

where WKS is the number of weeks from the 4-leaf stage to the flowering peak, MAXT is the average air maximum temperature (^{o}C) from the 4-leaf stage to peak flower, and GDD is the sum of growing degree days from the 4-leaf stage to peak flower. The R^2 was 0.96***.

Validation of the model indicated that it predicted the observed peak flowering time for the Waimanalo winter experiment, the Pulehu fall, and the Kula spring experiments (Table 4.4).

DISCUSSION

T50

The T50 of the cheeseweed at Pulehu were not affected by the seasonal conditions of fall and spring (Table 4.2). A model to predict T50 at this location may not be needed. Counting the days from the 4-leaf stage may be adequate to predict T50.

The T50 at the other locations appeared to be affected by temperature, but a minimum temperature may be required to force flowering. This was shown by the long T50 of the Waimanalo irrigation experiments (Table 4.2). The seedlings germinated in high temperatures that may have kept the plants in a vegetative phase until the cooler fall temperatures occurred. The Poamoho summer1 Irrigation experiments showed how water with warm temperatures shortened the T50. Except for Pulehu, the fall and winter experiments had the longest T50 for their respective locations. These were periods of declining or low temperatures. This agrees with work on the temperate weed wild oats (*Avena fatu*a L.) and the tropical weed itchgrass that showed development time was lengthened with decreasing temperatures (Patterson et al., 1979; Adkins et al., 1987).

T50 Model

The T50 model overpredicted T50 for the mid-elevation experiment and underpredicted for the low and high elevation experiments. The Waimanalo and Poamoho predictions were close to the observed T50, but the Kula prediction was 8 days short (Table 4.3). The Kula experiment validated the model with weather data that was beyond the range used to develop the model. The model could not predict the delaying effect the very cold temperatures had on T50.

The model accounted for most of the variation in T50 because the time to reach a level of flowering in the population was predicted instead of predicting the time for a given percentage flowering. Another reason for such a high R^2 was that the plots were very close in their T50 time. Many experiments had most of the replicates reaching T50 on the same day.

The T50 model can be used in the fields in Pulehu and on Oahu. The model is accurate for weeds that are on the field borders, assuming that irrigation does not extend beyond the crop. Cheeseweed within the field may not be predicted accurately because of irrigation. Irrigation shortens the T50 during hot weather, and its cooling effect during the cool season may delay the flowering peak.

This model may not predict T50 at the high elevations of Kula. The model was accurate at Waimanalo and Pulehu, and the R^2 was high, but caution should be used because of seasonal or yearly weather differences. A weed growth degree-day model may predict growth well for one year, but different weather conditions the next year could reduce the predictive value of the model (Nussbaum et al., 1985).

Further work on determining the optimum temperature for cheeseweed may prove to be useful in improving the T50 models for cheeseweed. GDD models have achieved better accuracy when a correction for temperature beyond optimum is encountered (Gilmore and Rogers, 1958). High temperatures in the seedling stage seems to inhibit the flowering stage. The optimum temperature may have to be adjusted according to the stage of development of the plant, so the present base temperature may not be best suited for the seedling stage. Work with peas (*Pisum sativum* L.) found that the optimum temperature for growth of the seedling, vegetative, and flowering stages were different from each other (Wang and Bryson, 1956, cited by Wang, 1960).

Biodata at Flower Peak

Cheeseweed is originally from a temperate climate so it was expected to do better in warm day/cool night temperatures such as in the spring and fall seasons in Hawaii. The Kula spring experiment plants did quite well in flower and dry matter production as opposed to the Pulehu spring experiment, despite good rainfall at both locations, and Pulehu's warmer temperatures. On Oahu, the cooler seasons and irrigation resulted in more flower production (Table 4.2). The winter and T2 irrigation treatments, at all locations, always produced the most flowers. At Waimanalo, T0 and T1 produced more stem weight and/or leaf area and leaf dry weight, but did not produce as many flowers per plant. The number of flower clusters at each node was indeterminate so dry matter production was not indicative of the number of flowers to be produced under those weather conditions.

Stem weight was influenced by production of axillary stems near the base of the plant. There were usually 6-8 well-developed axillary stems near the base contributed to the flower bud production. Larger leaves were localized near the base of the older axillaries so this increased the leaf area and leaf dry weight.

Time to Flower Peak

Cheeseweed may have a minimum temperature threshold to be reached before flowering is initiated. Irrigation may substitute for the low temperature requirement in hot weather and reduce the time to the flower peak. In cooler weather, irrigation would delay the peak by inducing a prolonged vegetative stage. This was observed at the Waimanalo and Poamoho experiments (Table 4.2). At Waimanalo, irrigation treatments helped the plants to reach their peak faster. This experiment started with high temperatures and may have forced the plants to remain in a vegetative state. Irrigation

may have reduced the high temperature effect and initiated flowering. The Poamoho experiments did not experience the high temperatures of Waimanalo so the irrigation may have delayed the flower peak. The influence of cooler temperatures delaying the flowering peak was also observed at Pulehu, where the fall experiment's peak took longer to achieve than the spring experiment.

Plants of experiments that were started in rising moderate temperatures produced flowerlng peaks early. This occurred at the Pulehu spring, the Waimanalo and Poamoho summer2, and the Waimanalo winter experiments. The T50 did not give an indication of the time to flower peak.

Flower Peak Model

The variation in weeks to flower peak were accounted for very well in the model. This may be due to the broad definition of a flower since sampling was conducted weekly, and the prediction of the first major peak. The flower definition allowed for stages of flowering to be spread over a week (Table 4.1). This model was developed to predict the first (usually the only) flower peak of cheeseweed, although there were occasions when another peak occurred later in the plants' life cycle. There was no attempt to predict the secondary peak for it was felt that by this time, preventative measures to control the thrips and spread of TSWV would have been initiated.

The flower peak model accurately predicted the peak at the Kula spring experiment, despite temperature data that was beyond those used to develop the model. This model can be used in the fields in Pulehu, Kula, and on Oahu. These models are accurate for weeds that are on the field borders, assuming that irrigation does not extend beyond the crop. Cheeseweed within the field may not be predicted accurately because irrigation may cool the plants and shorten the time to the flower peak in hot weather and

delay the peak in cool weather. The base temperature used with the flower peak model is sufficient for these locations. Research to determine the optimum temperature for all stages of growth and development is not necessary.

CONCLUSION

Models to predict the T50 and flower peak of cheeseweed can be developed from field data and provide accurate results. Use of the models is limited to plants that are on the border and not subjected to the farming practices of lettuce. The model can be used to help the farmers determine when to implement weed control practices and initiate preventative measures against the thrips. Needless pesticide applications could be be avoided to improve economic returns.

Table 4.1. Flowering stages of cheeseweed.

Stage	Days from 3-mm bud	Description
3-mm bud	0	Bud enclosed by calyx. About 3 mm across at widest point.
Flower	1 - 3	Calyx split open and petals are pushing through up to fully opened flower.
Seed formation	3 - 5	Calyx closes around the flower. Petals wither and tips may be seen sticking out through the calyx. Bulging at flower base.
Green seed	5 - 7	1-2 of the sepals peel back and green seed husks within can be seen. No brown color on any of the seed husks.

Table 4.2. Plant data collected at flowering peak of cheeseweed for locations on Oahu and Maui.

Location	Experiment	T50 (days)	Peak flowering (weeks)	Flowers	Height (cm)	Stem weight (g)	Nodes	Leaf area (cm^2)	Leaf weight (g)
Waimanalo	Summer1[z] T0[x]	70	12	211	37.8	39.9	35	4,064	18.0
	Summer1 T1	71	10	121	33.3	34.9	30	4,588	18.9
	Summer1 T2	61	8	331	57.5	36.0	27	4,035	16.8
	Winter	37	8	440	40.5	27.1	20	2,998	10.2
	Summer2[y]	30	7	239	25.4	30.3	21	2,110	11.8
Poamoho	Summer1 T0	32 a[w]	5	45	19.0	3.0	18	504	2.9
	Summer1 T1	17 b	9	280	55.0	48.3	33	2,889	12.9
	Summer1 T2	20 b	9	495	60.7	50.7	33	4,625	18.3
	Winter	55	14	2,058	133.9	492.3	47	51,322	134.6
	Summer2	23	5	284	38.3	20.2	23	1,240	6.3
Pulehu	Fall	33	9	207	45.5	37.1	31	2,802	8.1
	Spring	34	7	121	38.2	9.4	18	843	3.8
Kula	Fall	64	- -	- -	- -	- -	- -	- -	- -
	Spring	31	8	324	61.7	26.3	21	1,883	7.4

[z]Summer1 is the summer of 1986.
[y]Summer2 is the summer of 1987.
[x]T0 = control, T1 = 1x the water deficit, T2 = 2x the water deficit.
[w]Means separated by Scheffe's multiple-comparison test, 5 % level.

Table 4.3. Validation of the T50 model in predicting time to 50% flowering of cheeseweed at 3 locations.

Location	Season	Observed T50[z] (days)	Predicted T50 (days)	Difference[y]
Waimanalo	Winter	37	35	- 2
Pulehu	Fall	33	35	2
Kula	Spring	31	23	- 8

[z]T50 is the time to 50% flowering.
[y]Difference = Predicted T50 - Observed T50.

Table 4.4. Validation of the flower peak model of cheeseweed at 3 locations.

Location	Season	Observed peak (weeks)	Predicted peak (weeks)	Difference[z]
Waimanalo	Winter	8	8	0
Pulehu	Fall	9	9	0
Kula	Spring	9	9	0

[z]Difference = Predicted peak - Observed peak.

CHAPTER NOTES

Adkins, S.W., M. Loewen, and S.J. Symons. 1987. Variation within pure lines of wild oats (*Avena fatua*) in relation to temperature of development. Weed Sci. 35:169-172.

Badr, H.M., A.M. El-Sharkawy, M.E. Kamar, M.A. El-Shal, and A.A. El-Sigeidi. 1984. The heat accumulation units required for flowering, fruit setting and fruit picking of okra. Ann. Agr. Sci., Moshtohor 21(3):913-917. [Hort. Abstr. 55(6):4459; 1985]

Bailey, S.F. 1933. A contribution to the knowledge of the western flower thrips, *Frankliniella californica* (Moulton). J. Econ. Ent. 26:836-840.

Cho, J.J., R.F.L. Mau, D. Gonsalves, and W.C. Mitchell. 1986. Reservoir hosts of tomato spotted wilt virus. Plant Dis. 70:1014-1017.

Gilmore, E.C.Jr. and J.S. Rogers. 1958. Heat units as a method of measuring maturity in corn. Agron. J. 50:611-615.

Lehenbauer, P.A. 1914. Growth of maize seedlings in relation to temperature. Physiol. Res. 1:247-288.

Neal, M.C. 1965. In Gardens of Hawaii. Bishop Museum Press, Honolulu.

Nussbaum, E.S., A.F. Wiese, D.E. Crutchfield, E. W. Chenault, and D. Lavake. 1985. The effects of temperature and rainfall on emergence and growth of eight weeds. Weed Sci. 33:165-170.

Orwick, P.L., M.M. Schreiber, and D.A. Holt. 1978. Simulation of foxtail (*Setaria viridis* var. *robusta-alba*, *Setaria viridis* var. *robusta-purpurea*) growth: the development of SETSIM. Weed Sci. 26(6):691-699.

Patterson, D.T. and E.P. Flint. 1979. Effects of simulated field temperatures and chilling on itchgrass (*Rottboellia exaltata*), corn (*Zea mays*), and soybean (*Glycine max*). Weed Sci. 27(6):645-650.

Patterson, D.T., C.R. Meyer, E.P. Flint, and P.C. Quimby, Jr. 1979. Temperature responses and potential distribution of itchgrass (*Rottboellia exaltata*) in the United States. Weed Sci. 27(1):77-82.

Raven, P.H., R.E. Evert, and H. Curtis. 1981. Biology of Plants. Worth Publishers, New York.

Samuel, G. and J.G. Bald. 1931. *Thrips tabaci* as a vector of plant virus disease. Nature. 128:494.

Smith, K.M. 1932. Studies on plant virus diseases. Ann. Applied Biol. 19:305-330.

Wang, J.Y. 1960. A critique of the heat unit approach to plant response studies. Ecology 41:785-790.

Wang, J.Y. and R.A. Bryson. 1956. A study of phytometeorological effects on the growth and development of peas. Dept. Meteorol., Univ. of Wisconsin.

Yudin, L.S., B.E. Tabashnik, J.J. Cho, and W.C. Mitchell. 1988. Colonization of weeds and lettuce by thrips (Thysanoptera: Thripidae). Env. Ent. (in press).

LITERATURE CITED

Adkins, S.W., M. Loewen, and S.J. Symons. 1987. Variation within pure lines of wild oats (*Avena fatua*) in relation to temperature of development. Weed Sci. 35:169-172.

Allen, G.E. and J.E. Bath. 1980. The conceptual and institutional aspects of integrated pest management. Bioscience 30(10):658-664.

Ananthakrishnan, T.N. 1980. Thrips, p. 149-164. In: K.F. Harris and K. Maramorosch (eds.). Vectors of plant pathogens. Acad. Press, Inc., New York.

Badr, H.M., A.M. El-Sharkawy, M.E. Kamar, M.A. El-Shal, and A.A. El-Sigeidi. 1984. The heat accumulation units required for flowering, fruit setting and fruit picking of okra. Ann. Agr. Sci., Moshtohor 21(3):913-917. [Hort. Abstr. 55(6):4459; 1985]

Bailey, S.F. 1933. A contribution to the knowledge of the western flower thrips, *Frankliniella californica* (Moulton). J. Econ. Ent. 26:836-840.

Best, R.J. 1954a. Cross protection by strains of tomato spotted wilt virus and a new theory to explain it. Australian J. Biol. Sci. 7:415-424.

Best, R.J. 1954b. The development and multiplication of viruses. J. Australian Inst. Agr. Sci. 20:36-40.

Best, R.J. 1961. Recombination experiments with strains A and E of tomato spotted wilt virus. Virology 15:327-339.

Best, R.J. 1968. Tomato spotted wilt virus, p. 65-146. In: K.M. Smith and M.A. Lauffer (eds.). Advances in virus research. Acad. Press, Inc., New York.

Best, R.J. and H.P.C. Gallus. 1955. Further evidence for the transfer of character-determinants (recombination) between strains of tomato spotted wilt virus. Enzymologia 17:207-221.

Best, R.J. and G.F. Katekar. 1964. Lipid in a purified preparation of tomato spotted wilt virus. Nature 203:671-672.

Best, R.J. and G. Samuel. 1936. The reaction of the viruses of tomato spotted wilt and tobacco mosaic to the pH value of media containing them. Ann. Applied Biol. 23:509-537.

Blair, B.D. and C.R. Edwards. 1980. Development and status of extension integrated pest management programs in the United States. Ent. Soc. America 26(3):363-368.

Bottrell, D.G. and R.F. Smith. 1982. Integrated pest management. Env. Sci. Technol. 16(5):282A-288A.

Box, G.E.P., W.G. Hunter, and J.S. Hunter. 1978. Statistics for experimenters. Wiley, New York.

Breidenbach, A.W. 1978. Integrated pest management program. Ent. Soc. America Bul. 24(1):13-14.

Brittlebank, C.C. 1919. Tomato diseases. J. Agr. Victoria 17:231-235.

Bryan, D.E. and R.F. Smith. 1956. The *Frankliniella occidentalis* (Pergande) complex in California. (*Thysanoptera: Thripidae*). Univ. Calif. Pub. Ent. 10(6):359-410.

Cho, J.J., R.F.L. Mau, D. Gonsalves, and W.C. Mitchell. 1986. Reservoir hosts of tomato spotted wilt virus. Plant Dis. 70:1014-1017.

Day, M.F. and H. Irzykiewicz. 1954. Physiological studies on thrips in relation to transmission of tomato spotted wilt virus. Australian J. Biol. Sci. 7:274-281.

Draper, N.R. and H. Smith. 1966. Applied regression analysis. Wiley, New York.

Fogg, J.M. 1945. Weeds of Lawn and Garden. Univ. of Pa. Press, Philadelphia.

Francki, R.I.B. and T. Hatta. 1981. Tomato spotted wilt virus, p. 492-512. In: E. Kurstak (ed.). Handbook of plant virus infections and comparative diagnosis. Elsevier/North-Holland Biomedical Press, New York.

Gentil, S. and G. Blake. 1981. Validation of complex ecosystem models. Ecol. Modelling 14:21-38.

Gilmore, E.C.Jr. and J.S. Rogers. 1958. Heat units as a method of measuring maturity in corn. Agron. J. 50:611-615.

Haselwood, E.L. and G.G. Motter. 1983. Handbook of Hawaiian weeds. 2nd ed. Univ. of Hawaii Press, Honolulu.

Knake, E.L. and J.P. Downs. 1978. The role of the university in integrated pest management. N. Central Weed Control Conf. Proc. 33:124-126.

Ledbetter, R.J., A.D. Davison, E.E. Deal, E.H. Glass, J.M. Good, H.B. Petty, I.J. Thomason, L. Moore, F.L. Baldwin, J.A. Brittain, J.L. Crawford, C.S. Davis, R.A. Dunn, C.R. Edwards, R.E. Frisbie, D.H. Petersen, R.L. Robertson, R.E. Smith, E.W. Stroube, J.P. Tette, R.E. Hepp. 1979. Integrated pest management programs for the State Cooperative Extension Service. AL Coop. Ext. Serv., Auburn Univ., Auburn.

Lehenbauer, P.A. 1914. Growth of maize seedlings in relation to temperature. Physiol. Res. 1:247-288.

Lewis, T. 1973. Thrips: their biology, ecology and economic importance. Acad. Press, Inc., New York.

Linford, M.B. 1932. Transmission of the pineapple yellow-spot virus by *Thrips tabaci*. Phytopath. 22:301-324.

Lublinkhof, J. and D.E. Foster. 1977. Development and reproductive capacity of *Frankliniella occidentalis* (*Thysanoptera: Thripidae*) reared at three temperatures. Kan. Ent. Soc. 50(3):313-316.

Moffitt, H.R. 1964. A color preference of the western flower thrips, *Frankliniella occidentalis*. J. Econ. Ent. 57(4):604-605.

Muenscher, W.C. 1980. Weeds. 2nd ed. Cornell Univ. Press, Ithaca.

Neal, M.C. 1965. In Gardens of Hawaii. Bishop Museum Press, Honolulu.

Nielson, J. 1978. USDA's role in pest management programs. Ent. Soc. America Bul. 24(1):15-17.

Noguchi, M., K. Hoshino, and M. Kikkawa. 1981. Analysis of factors determining the vegetable crop yield effect of temperature on growth and dry matter production of lettuce at different growth stages. Bul. Veg. Ornamental. Crops Res. Sta. (9):47-62. [Hort. Abstr. 53(8):5851; 1983]

Nussbaum, E.S., A.F. Wiese, D.E. Crutchfield, E. W. Chenault, and D. Lavake. 1985. The effects of temperature and rainfall on emergence and growth of eight weeds. Weed Sci. 33:165-170.

Nye, P.H., J.L. Brewster, and K.K.S. Bhat. 1975. The possibiiity of predicting solute uptake and plant growth response from independently measured soil and plant characteristics. Plant and Soil 42:161-170.

Orwick, P.L., M.M. Schreiber, and D.A. Holt. 1978. Simulation of foxtail (*Setaria viridis* var. *robusta-alba*, *Setaria viridis* var. *robusta-purpurea*) growth: the development of SETSIM. Weed Sci. 26(6):691-699.

Osborn, T.G.B. 1919. Two serious new wilt diseases. J. Agr. S. Australia 23:437.

Paliwal, Y.C. 1976. Some characteristics of the thrip vector relationship of tomato spotted wilt virus in Canada. Canadian J. Bot. 54:402-405.

Paliwal, Y.C. 1979. Occurrence and localization of spherical virus-like particles in tissues of apparently healthy tobacco thrips, *Frankliniella fusca*, a vector of tomato spotted wilt virus. J. Invertebrate Pathol.33:307-315.

Patterson, D.T. and E.P. Flint. 1979. Effects of simulated field temperatures and chilling on itchgrass (*Rottboellia exaltata*), corn (*Zea mays*), and soybean (*Glycine max*). Weed Sci. 27(6):645-650.

Patterson, D.T., C.R. Meyer, E.P. Flint, and P.C. Quimby, Jr. 1979. Temperature responses and potential distribution of itchgrass (*Rottboellia exaltata*) in the United States. Weed Sci. 27(1):77-82.

Peart, R.M. and J.R. Barrett, Jr. 1979. The role of simulation, p. 467-480. In: B.J. Barfield and J.F. Gerber (eds.). Modification of the aerial environment of plants. Amer. Soc. Agr. Eng., St. Joseph, Mich.

Raven, P.H., R.E. Evert, and H. Curtis. 1981. Biology of Plants. Worth Publishers, New York.

Reynolds, J.F. 1979. Some misconceptions of mathematical modeling. What's New in Plant Physiol. 10(11):41-43.

Sakimura, K. 1961. Techniques for handling thrips in transmission experiments with the tomato spotted wilt virus. Plant Dis. Rptr. 45(10):766-771.

Sakimura, K. 1962. *Frankliniella occidentalis* (*Thysanoptera: Thripidae*), a vector of the tomato spotted wilt virus, with special reference to color forms. Ann. Ent. Soc. America 55:387-389.

Sakimura, K. 1963. *Frankliniella fusca,* an additional vector for the tomato spotted wilt virus. Phytopath. 53:412-415.

Samuel, G. and J.G. Bald. 1931. *Thrips tabaci* as a vector of plant virus disease. Nature. 128:494.

Samuel, G., J.G. Bald, and H.A. Pittman. 1930. Investigation on "spotted wilt" of tomatos. Australian Council Sci. Ind. Res. Bul. No. 44.

Shaw, W.C. 1982. Integrated weed management systems technology for pest management. Weed Sci. 30(supplement):2-12.

Smith, K.M. 1932. Studies on plant virus diseases. Ann. Applied Biol. 19:305-330.

Smith, K.M. 1972. A textbook of plant virus diseases. Longman, London.

Smythe, R.B. 1979. Integrated pest management -- Recent policy developments. Proc. Minutes 28th Annu. Meeting Agr. Res. Inst. p. 98-104.

Suomalainen, E. 1950. Parthenogenesis in animals. In: M. Demerec (ed.). Advances in genetics. Vol. III. Acad. Press, Inc., New York.

Thornley, J.H.M. 1975. Modelling as a tool in plant physiological research, p. 339-350. In: J.J. Landsberg and C.V. Cutting (eds.). Environmental effects on crop physiology: proceedings of a symposium held at Long Ashton Research Station, Univ. of Bristol, 13-16 April 1975. Acad. Press, Inc., New York.

Thornley, J.H.M. 1976. Mathematical models in plant physiology: a quantitative approach to problems in plant and crop physiology. Acad. Press, Inc. New York.

Wang, J.Y. 1960. A critique of the heat unit approach to plant response studies. Ecology 41:785-790.

Wang, J.Y. and R.A. Bryson. 1956. A study of phytometeorological effects on the growth and development of peas. Dept. Meteorol., Univ. of Wisconsin.

William, R.D. 1981. Complementary interactions between weeds, weed control practices and pests in horticultural cropping systems. Hortscience 16(4):508-513.

Yudin, L.S. W.C. Mitchell, and J.J. Cho. 1987. Color preference of thrips (*Thysanoptera: Thripidae*) with reference to aphids (*Homoptera: Aphididae*) and leafminers in Hawaiiand lettuce farms. J. Econ. Ent. 80:51-55.

Yudin, L.S., B.E. Tabashnik, J.J. Cho, and W.C. Mitchell. 1988. Colonization of weeds and lettuce by thrips (Thysanoptera: Thripidae). Env. Ent. (in press).

APPENDIX

Table A1. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Waimanalo summer1 T0 experiment. Started on June 25, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
July 2	124.31	28.1	23.4	0.2	-3.8	145.04
July 9	222.08	28.3	23.5	1.3	-6.6	271.84
July 16	315.36	28.4	23.3	2.2	-9.4	396.40
July 24	467.93	28.6	23.5	2.8	-13.3	588.84
July 31	583.21	28.6	23.6	8.5	-15.8	739.20
Aug. 6	716.58	28.7	23.7	9.8	-19.0	889.84
Aug. 12	814.14	28.8	23.8	10.3	-21.7	1043.00

[z]Average temperature from the 5-node stage.
[y]Class A stainless steel pan.
[x]Base temperature = 5^oC

Table A2. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Waimanalo summer1 T1 experiment. Started on June 25, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)[y]	Evaporation (cm)[x]	Growing degree days[w]
July 2	124.31	28.1	23.4	3.8	-3.8	145.04
July 9	222.08	28.3	23.5	6.6	-6.6	271.84
July 16	315.36	28.4	23.3	9.4	-9.4	396.40
July 24	467.93	28.6	23.5	13.3	-13.3	588.84
July 31	583.21	28.6	23.6	19.0[v]	-15.8	739.20
Aug. 6	716.58	28.7	23.7	21.8	-19.0	889.84
Aug. 12	814.14	28.8	23.8	24.1	-21.7	1043.00

[z]Average temperature from the 5-node stage.
[y]Irrigation added to natural rainfall total.
[x]Class A stainless steel pan.
[w]Base temperature = 5^oC
[v]No irrigation treatment this week; rainfall was greater than evaporation.

Table A3. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Waimanalo summer1 T2 experiment. Started on June 25, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)[y]	Evaporation (cm)[x]	Growing degree days[w]
July 2	124.31	28.1	23.4	7.7	-3.8	145.04
July 9	222.08	28.3	23.5	12.2	-6.6	271.84
July 16	315.36	28.4	23.3	18.6	-9.4	396.40
July 24	467.93	28.6	23.5	24.7	-13.3	588.84
July 31	583.21	28.6	23.6	30.3[v]	-15.8	739.20
Aug. 6	716.58	28.7	23.7	34.6	-19.0	889.84

[z]Average temperature from the 5-node stage.
[y]Irrigation added to natural rainfall total.
[x]Class A stainless steel pan.
[w]Base temperature = 5°C
[v]No irrigation treatment this week; rainfall was greater than evaporation.

Table A4. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Waimanalo winter experiment. Started on November 12, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
Nov. 18	56.70	27.5	23.4	0.8	-2.3	122.88
Nov. 25	122.59	27.7	23.3	1.4	-5.1	266.24
Dec. 2	181.41	27.0	22.5	2.5	-8.3	395.32
Dec. 9	267.34	26.5	21.3	5.7	-11.2	509.84
Dec. 16	329.11	26.5	21.5	6.4	-13.2	645.08
Dec. 22	394.08	26.5	21.3	7.3	-15.2	756.20
Dec. 29	478.63	26.5	21.0	9.6	-17.9	881.64
1987						
Jan 5	545.73	26.4	20.9	11.7	-20.0	1008.97
Jan. 12	624.04	26.4	20.6	13.0	-22.8	1130.97
Jan. 19	683.89	26.1	20.4	16.8	-25.1	1241.77
Jan. 26	747.64	26.0	20.2	17.8	-28.3	1356.77
Feb. 2	848.42	25.8	19.9	19.0	-31.3	1467.02
Feb. 9	945.11	25.8	19.7	19.0	-34.0	1580.57

[z]Average temperature from the 5-node stage.
[y]Class A stainless steel pan.
[x]Base temperature = 5°C

Table A5. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Waimanalo summer2 experiment. Started on May 29, 1987.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
June 8	204.63	28.9	21.0	2.3	-3.5	199.25
June 15	337.27	29.1	21.2	3.5	-6.1	342.85
June 22	469.70	29.2	21.3	5.1	-8.7	486.80
June 28	618.36	29.7	21.5	5.5	-11.0	617.65
July 4	754.54	29.9	21.6	6.1	-13.6	747.15

[z]Average temperature from the 5-node stage.
[y]Class A stainless steel pan.
[x]Base temperature = 5^oC

Table A6. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Poamoho summer1 T0 experiment. Started on June 23, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
June 30	156.65	28.9	21.3	0.4	-3.8	140.56
July 7	320.88	28.8	21.6	2.2	-7.6	282.52
July 14	471.29	28.6	21.9	2.7	-11.3	425.88
July 21	587.04	28.6	22.1	5.1	-14.4	569.52
July 28	683.44	28.6	22.2	12.9	-16.9	713.16
Aug. 4	841.92	28.6	22.1	13.4	-20.7	854.56
Aug. 11	954.04	28.7	22.2	14.0	-24.0	1002.68
Aug. 18	1039.81	28.6	22.3	14.9	-26.7	1144.64

[z]Average temperature from the 5-node stage.
[y]Class A stainless steel pan.
[x]Base temperature = 5°C

Table A7. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Poamoho summer1 T1 experiment. Started on June 23, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)[y]	Evaporation (cm)[x]	Growing degree days[w]
June 30	156.65	28.9	21.3	3.8	-3.8	140.56
July 7	320.88	28.8	21.6	7.6	-7.6	282.52
July 14	471.29	28.6	21.9	11.3	-11.3	425.88
July 21	587.04	28.6	22.1	14.4	-14.4	569.52
July 28	683.44	28.6	22.2	20.1[v]	-16.9	713.16
Aug. 4	841.92	28.6	22.1	23.9	-20.7	854.56
Aug. 11	954.04	28.7	22.2	27.2	-24.0	1002.68

[z]Average temperature from the 5-node stage.
[y]Irrigation added to natural rainfall total.
[x]Class A stainless steel pan.
[w]Base temperature = 5°C
[v]No irrigation treatment this week; rainfall was greater than evaporation.

Table A8. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Poamoho summer1 T2 experiment. Started on June 23, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)[y]	Evaporation (cm)[x]	Growing degree days[w]
June 30	156.65	28.9	21.3	7.5	-3.8	140.56
July 7	320.88	28.8	21.6	13.6	-7.6	282.52
July 14	471.29	28.6	21.9	20.5	-11.3	425.88
July 21	587.04	28.6	22.1	24.3	-14.4	569.52
July 28	683.44	28.6	22.2	29.9[v]	-16.9	713.16
Aug. 4	841.92	28.6	22.1	37.0	-20.7	854.56
Aug. 11	954.04	28.7	22.2	43.1	-24.0	1002.68

[z]Average temperature from the 5-node stage.
[y]Irrigation added to natural rainfall total.
[x]Class A stainless steel pan.
[w]Base temperature = 5°C
[v]No irrigation treatment this week; rainfall was greater than evaporation.

Table A9. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Poamoho winter experiment. Started on November 24, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
Nov. 30	51.91	25.1	20.1	2.2	-1.8	105.52
Dec. 7	115.82	23.9	18.5	8.3	-4.0	210.52
Dec. 14	189.40	24.6	18.7	8.4	-6.1	332.60
Dec. 21	265.17	25.0	19.0	9.1	-8.1	458.04
Dec. 28	354.52	25.2	19.2	11.2	-10.5	583.20
1987						
Jan. 4	433.96	25.1	19.0	14.0	-12.4	699.40
Jan. 11	505.70	25.1	18.8	16.1	-14.3	813.36
Jan. 18	575.21	24.7	18.7	17.4	-16.4	916.96
Jan. 25	645.89	24.4	18.5	18.6	-18.7	1019.72
Feb. 1	724.63	24.3	18.3	22.5	-20.8	1124.72
Feb. 8	845.82	24.2	18.1	22.8	-23.5	1227.48

[z]Average temperature from the 5-node stage.
[y]Class A stainless steel pan.
[x]Base temperature = 5^oC

Table A10. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Poamoho summer2 experiment. Started on June 15, 1987.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
June 21	104.30	27.2	19.7	1.1	-2.8	110.56
June 28	231.36	28.1	20.1	1.6	-6.2	248.60
July.4	335.07	28.1	20.4	2.1	-9.0	366.44
July.12	473.47	28.3	20.7	2.9	-12.7	526.36
July.19	585.20	28.4	20.9	3.3	-16.3	668.60
July.28	726.46	28.7	21.2	6.2	-20.4	856.56
Aug. 2	792.70	28.6	21.3	6.4	-22.5	958.40
Aug. 9	912.97	28.7	21.3	6.5	-25.9	1100.92

[z]Average temperature from the 5-node stage.
[y]Class A stainless steel pan.
[x]Base temperature = 5^oC

Table A11. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Pulehu fall experiment. Started on August 20, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
Aug. 26	113.36	28.6	17.8	0.0	-2.0	109.13
Sep. 2	268.19	29.2	17.4	0.0	-3.8	237.82
Sep. 9	400.04	29.4	17.4	0.0	-9.7	367.69
Sep. 15	486.61	28.9	17.3	2.8	-11.2	470.51
Sep. 25	651.98	28.8	17.3	2.8	-15.2	649.58
Oct. 2	746.77	28.6	17.5	5.6	-16.5	775.66
Oct. 8	882.25	28.6	17.4	6.3	-18.8	881.95

[z]Average temperature from the 5-node stage.
[y]Class A stainless steel pan.
[x]Base temperature = 5^oC

Table A12. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Pulehu spring experiment. Started on April 27, 1987.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
May 4	133.66	24.4	12.8	0.4	-2.0	95.11
May 11	251.16	22.6	13.2	5.2	-3.3	181.15
May 18	390.10	23.1	13.2	5.3	-5.8	276.10
May 26	560.14	23.7	13.5	5.7	-8.4	394.19

[z]Average temperature from the 5-node stage.
[y]Class A stainless steel pan.
[x]Base temperature = 5^oC

Table A13. Sum of weekly weather data from 5-node stage to peak flowering of spanish needle for the Kula spring experiment. Started on May 11, 1987.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
May 18	109.73	20.9	12.3	0.1	-1.3	81.26
May 26	280.89	21.5	12.7	1.2	-3.3	181.72
June 1	418.95	22.1	13.2	1.2	-5.6	265.75
June 9	572.49	22.5	13.6	1.2	-8.9	378.19
June 15	696.05	22.7	13.6	1.3	-10.2	461.83
June 22	836.88	22.9	13.8	1.7	-12.7	560.49
June 29	960.61	23.1	14.0	1.7	-14.7	663.98
July 9	1176.33	23.4	14.1	1.7	-20.1	811.12
July 13	1251.52	23.5	14.2	1.9	-23.1	871.48
July 20	1386.08	23.6	14.3	3.5	-25.1	976.98
July 27	1487.90	23.7	14.5	3.6	-27.2	1084.49
Aug. 10	1620.29	23.8	14.6	4.1	-29.0	1192.97

[z]Average temperature from the 5-node stage.
[y]Class A stainless steel pan.
[x]Base temperature = 5^oC

Table A14. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Waimanalo summer1 T0 experiment. Started on July 30, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
Aug. 6	133.37	29.2	23.8	1.3	-2.8	143.64
Aug. 13	230.93	29.3	24.1	1.8	-5.5	289.80
Aug. 20	349.84	29.2	23.9	3.3	-7.9	431.20
Aug. 27	496.27	29.3	24.2	4.6	-11.2	581.00
Sep. 3	635.11	29.5	24.4	5.6	-14.2	733.32
Sep. 11	783.68	29.6	24.3	6.6	-17.1	900.36
Sep. 17	886.87	29.7	24.1	6.8	-19.6	1022.84
Sep. 23	989.62	29.7	23.9	7.5	-21.5	1143.36
Sep. 30	1078.80	29.7	23.9	13.5	-23.7	1290.36
Oct. 7	1191.92	29.7	24.0	15.1	-26.3	1437.08
Oct. 15	1335.55	29.6	23.8	17.2	-29.5	1593.76
Oct. 21	1418.29	29.6	23.8	19.7	-31.5	1716.24

[z]Average temperature from the 4-leaf stage.
[y]Class A stainless steel pan.
[x]Base temperature = 6^oC

Table A15. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Waimanalo summer1 T1 experiment. Started on July 30, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall[y] (cm)	Evaporation (cm)[x]	Growing degree days[w]
Aug. 6	133.37	29.2	23.8	2.8	-2.8	143.64
Aug. 13	230.93	29.3	24.1	5.5	-5.5	289.80
Aug. 20	349.84	29.2	23.9	7.9	-7.9	431.20
Aug. 27	496.27	29.3	24.2	11.2	-11.2	581.00
Sep. 3	635.11	29.5	24.4	14.2	-14.2	733.32
Sep. 11	783.68	29.6	24.3	17.1	-17.1	900.36
Sep. 17	886.87	29.7	24.1	19.6	-19.6	1022.84
Sep. 23	989.62	29.7	23.9	21.5	-21.5	1143.36
Sep. 30	1078.80	29.7	23.9	23.7	-23.7	1290.36
Oct. 7	1191.92	29.7	24.0	26.3	-26.3	1437.08

[z]Average temperature from the 4-leaf stage.
[y]Irrigation added to natural rainfall total.
[x]Class A stainless steel pan.
[w]Base temperature = 6^oC

Table A16. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Waimanalo summer1 T2 experiment. Started on July 30, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall[y] (cm)	Evaporation (cm)[x]	Growing degree days[w]
Aug. 6	133.37	29.2	23.8	4.3	-2.8	143.64
Aug. 13	230.93	29.3	24.1	8.3	-5.5	289.80
Aug. 20	349.84	29.2	23.9	12.5	-7.9	431.20
Aug. 27	496.27	29.3	24.2	17.8	-11.2	581.00
Sep. 3	635.11	29.5	24.4	21.8	-14.2	733.32
Sep. 11	783.68	29.6	24.3	27.0	-17.1	900.36
Sep. 17	886.87	29.7	24.1	32.6	-19.6	1022.84
Sep. 23	989.62	29.7	23.9	36.3	-21.5	1143.36

[z]Average temperature from the 4-leaf stage.
[y]Irrigation added to natural rainfall total.
[x]Class A stainless steel pan.
[w]Base temperature = 6^oC

Table A17. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Waimanalo winter experiment. Started on January 26, 1987.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
Feb. 2	100.78	24.7	16.8	1.2	-3.0	103.25
Feb. 9	197.47	25.3	16.7	1.2	-5.6	209.80
Feb. 16	260.08	24.8	17.0	11.5	-7.5	313.15
Feb. 23	356.80	25.1	17.1	12.2	-9.7	422.90
Mar. 2	459.22	25.3	16.5	13.8	-11.9	521.80
Mar. 9	570.14	25.4	16.3	14.1	-14.5	624.20
Mar. 15	674.74	25.8	16.8	14.2	-16.6	732.95
Mar. 21	793.67	26.2	17.1	15.0	-18.7	843.00

[z]Average temperature from the 4-leaf stage.
[y]Class A stainless steel pan.
[x]Base temperature = 6^oC

Table A18. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Waimanalo summer2 experiment. Started on May 17, 1987.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
May 23	103.47	26.5	19.2	1.4	-1.8	101.05
May 29	126.79	26.7	20.7	0.8	-2.7	106.25
June 8	331.42	28.1	20.9	3.0	-6.2	295.50
June 15	464.06	28.5	21.1	4.3	-8.8	432.10
June 22	596.49	28.7	21.2	5.8	-11.4	569.05
June 28	745.15	29.2	21.3	6.3	-13.7	693.90
July 4	881.33	29.5	21.5	6.8	-16.3	817.40

[z]Average temperature from the 4-leaf stage.
[y]Class A stainless steel pan.
[x]Base temperature = 6^oC

Table A19. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Poamoho summer1 T0 experiment. Started on July 7, 1986.

Date	Solar radiation (mi/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[w]
July 14	150.41	28.4	22.6	0.5	-3.7	136.36
July 21	266.16	28.4	22.6	2.9	-6.8	273.00
July 28	362.56	28.4	22.6	10.7	-9.3	409.64
Aug. 4	521.04	28.6	22.3	11.3	-13.1	544.04
Aug. 11	633.16	28.7	22.4	11.8	-16.4	685.16

[z]Average temperature from the 4-leaf stage.
[y]Class A stainless steel pan.
[w]Base temperature = 6^oC

Table A20. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Poamoho summer1 T1 experiment. Started on July 7, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)[y]	Evaporation (cm)[x]	Growing degree days[w]
July 14	150.41	28.4	22.6	3.7	-3.7	136.36
July 21	266.16	28.4	22.6	6.8	-6.8	273.00
July 28	362.56	28.4	22.6	9.3[v]	-9.3	409.64
Aug. 4	521.04	28.6	22.3	13.1	-13.1	544.04
Aug. 11	633.16	28.7	22.4	16.4	-16.4	685.16
Aug. 18	718.93	28.6	22.5	19.1	-19.1	820.12
Aug. 25	837.77	28.8	22.4	22.7	-22.7	959.84
Sep. 1	999.43	29.0	22.4	26.5	-26.5	1101.52
Sep. 7	1109.47	29.0	22.3	29.8	-29.8	1219.24

[z]Average temperature from the 4-leaf stage.
[y]Irrigation added to natural rainfall total.
[x]Class A stainless steel pan.
[w]Base temperature = 6°C
[v]No irrigation treatment this week; rainfall was greater than evaporation.

Table A21. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Poamoho summer1 T2 experiment. Started on July 7, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)[y]	Evaporation (cm)[x]	Growing degree days[w]
July 14	150.41	28.4	22.6	6.9	-3.7	136.36
July 21	266.16	28.4	22.6	10.7	-6.8	273.00
July 28	362.56	28.4	22.6	18.5[v]	-9.3	409.64
Aug. 4	521.04	28.6	22.3	25.5	-13.1	544.04
Aug. 11	633.16	28.7	22.4	31.6	-16.4	685.16
Aug. 18	718.93	28.6	22.5	34.9	-19.1	820.12
Aug. 25	837.77	28.8	22.4	40.6	-22.7	959.84
Sep. 1	999.43	29.0	22.4	48.1	-26.5	1101.52
Sep. 7	1109.47	29.0	22.3	54.6	-29.8	1219.24

[z]Average temperature from the 4-leaf stage.
[y]Irrigation added to natural rainfall total.
[x]Class A stainless steel pan.
[w]Base temperature = 6^oC
[v]No irrigation treatment this week; rainfall was greater than evaporation.

Table A22. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Poamoho winter experiment. Started on November 30, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
Dec. 7	63.90	22.8	17.2	6.0	-2.2	98.00
Dec. 15	147.57	24.5	18.3	6.1	-4.6	231.16
Dec. 22	218.49	24.8	18.7	8.1	-6.5	346.52
Dec. 29	307.66	25.0	19.0	10.6	-8.9	463.56
1987						
Jan. 4	382.05	25.1	18.8	11.8	-10.7	558.88
Jan. 11	453.79	25.1	18.7	13.8	-12.6	665.84
Jan. 18	523.29	24.6	18.5	15.2	-14.7	762.44
Jan. 25	593.97	24.3	18.3	16.4	-16.9	858.20
Feb. 1	672.71	24.2	18.2	20.2	-19.0	956.20
Feb. 8	793.91	24.1	18.0	20.6	-21.8	1051.96
Feb. 15	878.17	24.1	17.9	25.5	-23.9	1153.32
Feb. 22	966.55	23.9	17.8	28.5	-25.8	1249.92
Mar. 1	1084.35	23.9	17.5	29.8	-28.7	1340.36
Mar. 8	1202.84	23.9	17.5	30.4	-31.8	1439.76

[z]Average temperature from the 4-leaf stage.
[y]Class A stainless steel pan.
[x]Base temperature = 6°C

Table A23. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Poamoho summer2 experiment. Started on June 3, 1987.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
June 15	222.50	28.0	20.1	5.2	-6.0	216.40
June 21	104.30	27.2	19.7	1.1	-2.8	104.56
June 28	231.36	28.1	20.1	1.6	-6.2	235.60
July 4	335.07	28.1	20.4	2.1	-9.0	347.44
July 12	473.47	28.3	20.7	2.9	-12.7	499.36

[z]Average temperature from the 4-leaf stage.
[y]Class A stainless steel pan.
[x]Base temperature = 6^oC

Table A24. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Pulehu fall experiment. Started on August 8, 1986.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
Aug. 20	199.51	27.8	17.3	0.8	-3.8	199.00
Aug. 26	312.87	28.1	17.5	0.8	-5.8	302.13
Sep. 2	467.70	28.5	17.4	0.8	-7.6	423.82
Sep. 9	599.55	28.8	17.4	0.8	-13.5	546.69
Sep. 15	686.12	28.5	17.3	3.6	-15.0	643.51
Sep. 25	851.49	28.5	17.3	3.6	-19.1	812.58
Oct. 2	946.28	28.4	17.5	6.4	-20.3	931.66
Oct. 8	1081.76	28.5	17.4	7.1	-22.6	1031.95
Oct. 16	1240.65	28.5	17.2	7.1	-25.1	1163.86

[z]Average temperature from the 4-leaf stage.
[y]Class A stainless steel pan.
[x]Base temperature = 6^oC

Table A25. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Pulehu spring experiment. Started on April 10, 1987.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
Apr. 21	178.76	24.5	13.5	0.0	-2.8	142.81
Apr. 27	300.42	24.0	13.6	11.2	-4.1	218.01
May 4	434.08	24.1	13.4	11.6	-6.1	306.12
May 11	551.58	23.4	13.4	16.4	-7.4	385.16
May 18	690.52	23.5	13.4	16.5	-9.9	473.11
May 26	860.56	23.8	13.6	16.9	-12.4	583.20
June 1	1005.28	24.1	13.7	17.0	-15.5	672.01

[z]Average temperature from the 4-leaf stage.
[y]Class A stainless steel pan.
[x]Base temperature = 6°C

Table A26. Sum of weekly weather data from 4-leaf stage to peak flowering of cheeseweed for the Kula spring experiment. Started on April 21, 1987.

Date	Solar radiation (mj/m^2)	Maximum temperature (^oC)[z]	Minimum temperature (^oC)	Rainfall (cm)	Evaporation (cm)[y]	Growing degree days[x]
Apr. 27	114.74	21.1	12.7	12.2	-0.8	65.50
May 4	236.22	21.1	11.8	12.3	-2.3	138.69
May 11	361.41	20.1	12.0	20.2	-3.3	201.55
May 18	471.14	20.3	12.1	20.4	-4.6	275.81
May 26	642.30	20.7	12.3	21.4	-6.6	368.27
June 1	780.36	21.1	12.6	21.4	-8.9	446.30
June 9	933.90	21.5	12.9	21.5	-12.2	550.74
June 15	1057.46	21.8	13.1	21.6	-13.5	628.38

[z]Average temperature from the 4-leaf stage.
[y]Class A stainless steel pan.
[x]Base temperature = 6^oC