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WEED ECOLOGY AND ECONOMIC IMPORTANCE OF *Emilia javanica* (Burm.) Rob. AND *E. sonchifolia* (L.) DC.

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WEED ECOLOGY AND ECONOMIC IMPORTANCE OF *Emilia javanica* (Burm.) Rob. AND *E. sonchifolia* (L.) DC

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ABSTRACT

The Emilia species and types in Hawaii were studied with respect to their taxonomy and life history, importance as disease reservoirs for the tomato spotted wilt virus, and as a weed competitor with crop plants like lettuce (Lactuca sativa L.), mustard cabbage (Brassica juncea Czern. & Coss.), sweet corn (Zea mays L.) and transplanted tomato (Lycopersicon esculentum L.).

Of the four Emilia species reported in Hawaii, only E. javanica (Burm.) Rob. and E. sonchifolia (L.) DC were found on the islands of Oahu and Kauai, while on Lanai only the Red and Orange types of E. javanica were observed. The E. javanica type Purple was found only in limited areas on Oahu and Kauai. The E. javanica types, particularly the Red type, which were referred to as E. sonchifolia or E. sagittata (Vahl) DC by other workers, are the most predominant types on Oahu, Kauai and Lanai. The similarities in vegetative and floral morphology of the different color types of E. javanica, in addition to their ability to interbreed indicate that they belong to the same species.

Plant height, capitulum size, number of achenes (seeds) per capitulum, number of capitula per plant were influenced by fertilizer and shading treatments. The E. javanica types were taller (50 to 62 cm) than E. sonchifolia (19 to 30 cm) at flowering. Fertilized Emilias under 55% shade were tallest while unfertilized plants under full sunlight were shortest. The total length of the capitulum of the E. javanica types ranged from 12.5 to 13 mm compared to E. sonchifolia with 10.5 to 11 mm. When fertilized with N-P-K and grown in full sun-

light, the Orange, Red and Purple types of E. javanica had 70, 64 and 57 seeds per capitulum, respectively, while E. sonchifolia had 60. Among the Emilias, the E. javanica type Purple produced the greatest number of capitula per plant. The earliest to mature (seed to seed) was the Purple type of E. javanica (48 ± 2 days), followed by the Red (51 ± 1 days), Orange (52 ± 1 days), and E. sonchifolia (53 ± 3 days) was the latest.

Seed germination studies showed that seeds of E. javanica matured earlier than E. sonchifolia. However, viable seeds were formed in both species before the capitula were ready to dehisce. All Emilias examined produced both light and dark colored seeds. The seeds of the Emilia species and types required light for germination up to a period of 4 weeks after harvest. Germination and dormancy varied with seed color, species, and types. Newly harvested seeds of E. sonchifolia germinated better under a wider temperature regime (15 to 35 C) than the E. javanica types (25 to 35 C).

Flowering response of the Emilia species and types were day neutral with respect to photoperiod. Observed differences in the time of flowering were due to differential rates of inflorescence development than to differential initiation of the floral primordium. Plants grew taller as the photoperiod was lengthened.

Transmission studies by sap inoculation of the tomato spotted wilt virus (TSWV) showed that all the types of E. javanica (Orange, Red and Purple) and E. sonchifolia harbored and transmitted the TSWV to tomato 'Tropic' and lettuce 'Anuenue'. The two species of Emilia differed with respect to infection with TSWV. E. sonchifolia gave a lethal reaction

while the E. javanica types tolerated infection of the virus. The TSWV from tomato and lettuce were re-transmitted back to the Emilias.

Pure stands of E. javanica type Red grown at specific densities with lettuce 'Anuenue', mustard cabbage 'Waianae', sweet corn 'H-68', and transplanted tomato 'N-52' demonstrated that the effects of Emilia on crop growth and yield varied with crop species. For example, full season competition of Emilia at 11 weeds per crop plant decreased the dry weights of lettuce and mustard cabbage by 70 to 30%, respectively. Sweet corn fodder was not affected even with 150 weeds per crop plant, while transplanted tomato fruit yield was reduced 18% by 80 to 126 weeds per crop plant. Because non-limiting irrigation was supplied, differences in response to Emilia competition depended on the crop plant's ability to compete for light and nutrients.

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PREFACE

About 20 Emilia species are known at present (Koyama, 1969). Among these, E. sonchifolia (L.) DC is the most widely distributed. In Hawaii, Fosberg (1948) reported four species: E. coccinea (Sims) Sweet, E. sonchifolia (L.) DC, E. javanica (Burm.) Rob. and an unnamed species. However, E. coccinea is considered by other workers (Robinson, 1908; Backer and Bakhuizen van den Brink, 1965) as a synonym for E. javanica. Most workers describe E. sonchifolia as having florets about equal or shorter than the involucre (Backer and Bakhuizen van den Brink, 1965; Fosberg, 1948; Koyama, 1969; Small, 1933), however, some taxonomic publications that illustrate E. sonchifolia show a plant with the florets longer than the involucre which appears to be E. javanica (Cardenas, Reyes and Doll, 1972; Haselwood and Motter, 1966; Neal, 1965; St. John and Hosaka, 1932). There is therefore a need to correctly identify the Emilia species and/or types found in the Hawaiian islands.

Collections of Emilia plants that differed from each other in floral and vegetative morphology were made on the islands of Oahu, Kauai and Lanai where the four species of Emilia have been reported to exist (Fosberg, 1948).

Preliminary plantings of the collected materials were made and later experiments were designed to deduce the taxonomy of the weeds and also to study the life history of the weeds as affected by environmental factors.

An interesting characteristic of the Emilias is flower color. Various hues of red, orange and purple have been observed in the field. Because distinct populations of Emilia exhibiting various color types

existed, representative color types were studied to determine if they differed in growth habits or floral and vegetative morphology.

Among the important weed characteristics studied in the laboratory were seed germination and dormancy, and response to photoperiod. Knowledge about these characteristics can provide insight into the survival, persistence and geographical distribution of the Emilia species and/or types. Differences in physiological characteristics may also be used as supplementary information in determining the taxonomic status of the different color types.

An important aspect in this study is the economic importance of the Emilias. E. javanica, previously referred to as E. sonchifolia or E. sagittata, came into prominence in Hawaii in 1932 when it was discovered to be a preferred host for both the pineapple yellow spot virus (PYSV) and its insect vector, Thrips tabaci (Lind.) (Linford, 1932; Sakimura, 1932, 1938). The PYSV is now known as the tomato spotted wilt virus (Parris, 1940; Sakimura, 1940). Only members of the Thripidae family, of which there are four known species, transmit the virus in nature (Sakimura, 1962). Since only the red flowered type of E. javanica has been mentioned in the earlier virus transmission work (Linford, 1931), it would be useful to know whether all the other flower color types of E. javanica and E. sonchifolia can also harbor the TSWV and transmit it to host other plants.

In Hawaii, E. javanica infests vegetable, field, and orchard crops. Although Emilia has not been considered a serious crop competitor, the weed has shown tolerance to herbicides such as CDAA (N.N-diallyl-2-chloroacetamide) (Tanaka, Romanowski, Sakuoka and Crozier, 1974), DCPA

(dimethyltetrachloroterephthalate) (Osgood and Romanowski, 1969), DCMU [3-(3,4-chlorophenyl)-1,1-dimethyl urea] (Romanowski and Nakagawa, 1969) and CMU (3-(p-chlorophenyl-)-1,1-dimethyl urea) (Gowing and Lange, 1962). It is therefore possible that Emilia can predominate as a major weed species under some conditions. Thus far, there has been no published report on the effect of Emilia as a crop competitor on any crop.

The broad objectives of this dissertation, therefore, were to: 1) clarify the taxonomy and conduct some life history studies on the Emilia species and/or types in Hawaii; 2) determine if all the Emilia species and/or types can harbor and transmit the tomato spotted wilt virus to other crop plants; 3) and evaluate the effects of specific densities of pure stands of Emilia on the growth and yield of some vegetable crops.

Each objective will constitute a chapter which will be dealt separately from the others.

CHAPTER I

TAXONOMY AND LIFE HISTORY OF *Emilia javanica* (Burm.) Rob. AND E. *sonchifolia* (L.) DC

INTRODUCTION

Emilia javanica (burm.) Rob. (Figure 1.1A), previously referred to as *E. sonchifolia* (L.) DC or *E. sagittata* (Vahl) DC, attained prominence as an important weed in Hawaii when it was established that it was the favored host of the pineapple yellow spot virus (Linford, 1932) now known as the tomato spotted wilt virus (TSWV) (Parris, 1940; Sakimura, 1940). The plant was also a favored host of the TSWV insect vector, *Thrips tabaci* (Lind.) (Linford, 1932; Sakimura, 1932, 1938). *E. sonchifolia* (Figure 1.1B) is a distinct species having the widest range of distribution among the *Emilia* species (Bailey, 1909; Britton, 1918; Hooker, 1882; Koyama, 1969; Makino, 1948; Oliver, 1877; Ridley, 1923; Robinson, 1909; Small, 1933).

In Hawaii, *E. javanica* infests vegetable (Romanowski and Nakagawa, 1969), field (Anonymous, 1962; St. John and Hosaka, 1932; Tanaka, Romanowski, Sakuoka and Crozier, 1974) and orchard crops (Crozier and Romanowski, 1969). Although it is susceptible to herbicides like atrazine [2-chloro-4 (ethylamino)-6-(isopropylamino)-*S*-triazine], simazine [2-chloro-4,6-bis (ethlamino)-*S*-triazine] and CDEC [2-chloroallyl diethyldithiocarbamate] (Tanaka et al., 1974), it has shown tolerance to CDAA (Tanaka et al., 1974), DCPA (Osgood and Romanowski, 1969), diuron (Romanowski and Nakagawa, 1969) and monuron

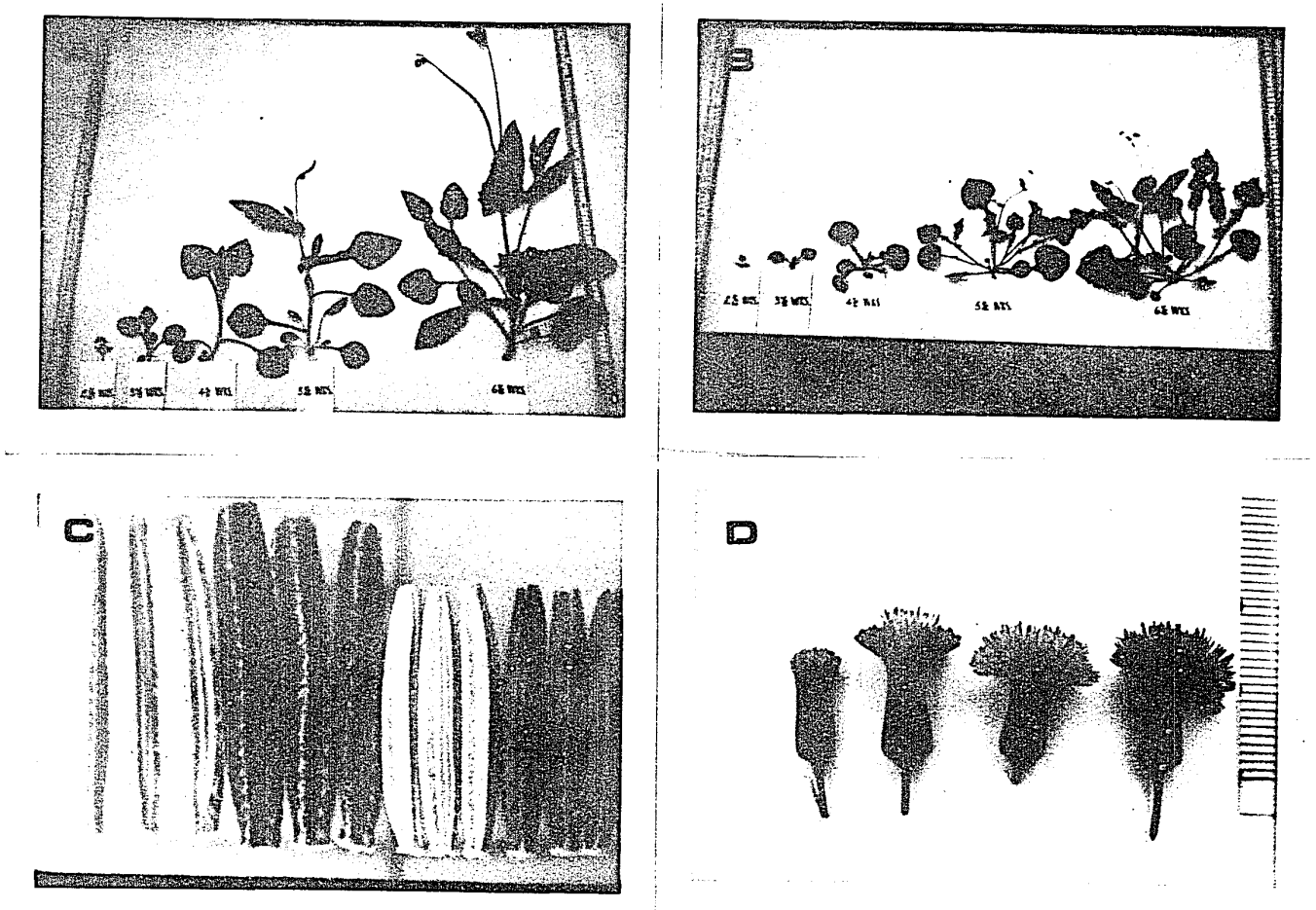


Figure 1.1. Vegetative and reproductive characteristics of E. javanica and E. sonchifolia. Morphology of plants of (A) E. javanica and (B) E. sonchifolia at different growth stages; (C) morphology of seeds of E. javanica (left), 4 mm long and grooved while that of E. sonchifolia (right) are 3 mm long with indistinct grooves; (D) floral morphology and color type(s) of (left to right) E. sonchifolia and the Purple (77B), Orange (29A) and Red (39A) types of E. javanica.

(Gowing and Lange, 1962). Therefore, in some situations, Emilia species can become a dominant weed. Furthermore, the importance of the Emilias as a virus disease reservoir requires that the weed be controlled in areas where TSWV is a problem.

The strategy for effective control of weeds requires knowledge about the life history and environmental factors affecting the germination, growth and reproduction of a particular weed so that control measures can be directed toward its vulnerable growth stages (Shaw and Jansen, 1972). Life history studies have been worked out on a few weeds but none has been reported on Emilia species.

The objectives of this study of Emilias were to: 1) ascertain the number of Emilia species and/or types on Oahu, Kauai and Lanai; 2) determine the effects of fertilizer application and shading on their life history and morphology; 3) investigate the effects of light and temperature on seed germination; 4) and ascertain the effect of photoperiod on vegetative and floral development.

LITERATURE REVIEW

Taxonomy of the Emilia species

The genus Emilia (Family Compositae) is a small tropical genus described by Cassini. Members of the genus are characterized as follows (Koyama, 1969): "annual, biennial or perennial herbs, often glaucous, glabrous or hairy, leaves radical crowded petioled, the margin entire, toothed or lyrate-pinnatifid; cauline few, stem-clasping. Inflorescences solitary or loosely corymbose. Heads long peduncled, without bracteoles

at base, homogamous, discoid, yellow or reddish. Florets all hermaphrodite, fertile, tubular, narrow tube of corolla elongate, 5-lobed at apex. Anther bases truncate. The lower cells of upper part of filament are larger than the upper cells. Style branches long, truncate, hairy at tip. Achenes 5-ribbed or rarely terete, with soft, snow-white pappus."

There are about 20 species known at present (Koyama, 1969). According to Fosberg (1948), four species are present in Hawaii. The names and synonyms of his species are:

1) Emilia coccinea (Sims) Sweet
   = Cacalia coccinea Sims
   = Emilia flammea Cass
2) Emilia sonchifolia (L.) DC
   = Cacalia sonchifolia L.
3) Emilia javanica (Burm.) Rob.
   = Hieracium javanicum Burm.
   = Cacalia sagittata Vahl
   = Prenanthes javanica Willd.
   = Emilia sagittata (Vahl) DC
4) Emilia sp.

Fosberg distinguished the four species as follows:

A Florets with sub-equal involucre - E. sonchifolia

A' Florets exceeding the involucre - B

B Florets greatly exceeding the involucre which is practically as broad as high - E. coccinea

B' Florets somewhat exceeding the cylindrical involucre which is much higher

than broad - C

C Red, orange or magenta flowers; upper cauline leaves or bracts not laciniate sagittate - E. javanica

C' Lavender, purple or pink flowers; upper cauline leaves or bracts laciniate sagittate - Emilia sp.

However, one of his species, E. coccinea, is considered by Backer and Bakhuizen van den Brink (1965) and Robinson (1908) as a synonym of E. javanica. Although E. sonchifolia has been described by most workers as having florets about equal or subequal to the involucre (Backer and Bakhuizen van den Brink, 1965; Fosberg, 1948; Koyama, 1969; Small, 1933) some taxonomic publications that have illustrated E. sonchifolia show a plant with the florets much longer than the involucre which appears to be E. javanica (Cardenas, Reyes and Doll, 1972; Haselwood and Motter, 1966; Neal, 1965; St. John and Hosaka, 1932). According to Fosberg, Emilia sp. has "heads almost exactly as in E. javanica except that they are lavender or purple. The flowers exceed the involucres and the whole head is from 10 to 15 mm long." Fosberg (1948) suspects that this may be a polyploid form of E. sonchifolia and concluded that cytological evidence was needed before giving the plant nomenclatural recognition. Koyama (1969) stated that E. sonchifolia was a "variable species" and "various forms of these species were established according to habitats." This statement may be supported by the variable chromosome numbers reported for E. sonchifolia, 2n = 10 (Baldwin, 1946) and 2n = 20 (Arano, 1962; Koyama, 1967).

Most of the descriptions of the different Emilia species have been largely qualitative but that given by Backer and Bakhuizen van den Brink (1965) (Table 1.1) and Small 1933) include quantitative measurements. Small (1933) differed from Backer and Bakhuizen van den Brink by describing E. coccinea, a synonym of E. javanica, as having an involucre length of 10-12 mm, corolla 9-11 mm long and the achene, 4 mm long and E. sonchifolia with the involucre 8-10 mm long, corolla 708 mm long and the achene, 3 mm long (Figure 1.1C).

The preceding discussion on the taxonomy of the Emilias indicate the confusion on the proper identification of the Emilia species.

Germination and Dormancy

The germination characteristics of weed seeds are important in the spread and survival of a particular species. Germination is a critical factor in the establishment of weed infestations while seed dormancy is a characteristic that enables weed seeds to survive and persist in the soil (National Research Council, 1968). Dormancy is of particular significance since germination can be delayed until the environment is favorable for development of the seedlings (Crocker, 1948). This delayed time of emergence may also enable weed species to escape pre-emergence herbicidal control or early cultivation in crop production.

Various causes of seed dormancy have been recognized (Amen, 1968): 1) rudimentary embryos (orchids, gingko, holly), 2) physiologically immature embryos (inactive enzyme systems) (lettuce, barley, basswood), 3) mechanically resistant seed coats (many legumes), 4) impermeable seed coats (legumes), and 5) presence of germination inhibitors (mustard, coffee, tomato, cranberry, apple, cherry and cocklebur).

Table 1.1. Some important taxonomic characteristics distinguishing *E. javanica* from *E. sonchifolia* (Modified after Backer and Bakhuizen van den Brink, Jr., 1965. Flora of Java).

Characteristics	Species	
	E. javanica (Burm. f.) Merril α/	*E. sonchifolia* (L.) DC ex Wight β/
No. of florets/head	90	50-60
Capitulum size (mm)		
length	10-12	10-13
width	6-9	4-5
Involucre	Urceolate much shorter than florets 6-8 mm long	Cylindrical scarcely shorter than florets 9-12 mm long
No. of bracts	12-14	7-8 usually 8
Corolla	Orange or dark-purplish	Reddish-purple pink 8-10 mm long
Achene	3 mm long 5-6 broad, very prominent papillose ribs	3 mm long indistinct, glabrous ribs
Pappus	5 mm long	7 mm long

α/ Synonym: = *E. coccinea* (Sims) Sweet
= *E. flammea* Cass
= *E. sagittata* (Vahl) DC

β/ Synonym: = *Senecio sonchifolius* (L.) Moench

Among the factors affecting germination and dormancy, only light and temperature will be included in this review.

a) Light

Seeds of some species require light for germination or at least germinate better if light is supplied (Andersen, 1968). The response to light has been reported to be determined by: 1) wave lengths, 2) duration of exposure and intensity, and 3) the temperature of the seed, before, during and after exposure. Anderson (1968) stated that although interactions among these factors are often so complex general statements on the effect of light are seldom possible. However, some generalizations concerning responses to light have been made. Seeds must have imbibed water for light to be effective. The effect of light on seed germination is exerted through a phytochrome reaction, and red-light promotes and far-red light inhibits germination.

Germination of phytochrome-controlled seeds is prevented by increasing the ratio of Pr/Pfr. Taylorson and Borthwick (1969) have demonstrated that filtration of light by green leaves can alter its spectral quality so that much more of the incident red energy was absorbed than the far-red. According to them this phenomenon might be found under a canopy of foliage and could be an explanation why seed germination is largely suppressed once a crop-leaf canopy covers the soil.

Wesson and Wareing (1969) found that some weed species which appeared to be unaffected by light, prior to the burial in soil for 50 weeks, germinated only in the presence of light, suggesting the induction of light sensitivity. They also found that in species which showed

varying degrees of light sensitivity with freshly harvested seeds, following burial, were completely dependent upon exposure to light for germination. Holm and Miller (1972) also found that freshly harvested seeds of several common weeds which showed little or no promotion of germination by light became entirely dependent on exposure to light for germination after burial for 6 months.

Black and Wareing (1959) studied the effects of seed coat in relation to light sensitivity in Betula pubescens Ehrh. and found that in this species the inhibitory effect of the pericarp appears to be due partly to the presence of an inhibitor, the effect of which can be overcome by light. They observed that the coats also appeared to restrict gas exchange and speculated that dormancy control could be due to inhibitors and oxygen permeability.

b) Temperature

The effects of temperature has been investigated extensively in connection with germination (Went, 1953). There is a great variability of the temperature requirement among different species and within a species, depending on age, storage conditions and other factors (Toole et al., 1956).

Went (1953) reported that in many plants germination occurs only within a rather narrow range of temperatures, which have to be known if successful germination tests are to be carried out. In nature the establishment of plant communities can be determined by the temperature of germination (Went, 1948; 1949).

Chalnoky (1948, 1949) as cited by Went (1953) found that the optimum germination temperature of various seeds varied from 12 C for winter

germinators like Linum, Linaria and Delphinum, to 20 C for summer germinators (Perilla, Phlox, Tropaeolum), or even higher for tropical plants (Ageratum, Amaranthus, Coleus), whereas many weeds and grasses need a very wide daily range of temperature (12 to 33 C for Achilles, Physalis, Specularia, Viola). Most weed seeds germinate within the range of 20 C to 30 C (Steinbauer and Grigsby, 1957).

Some species require an initially high temperature for optimum germination. Barton (1945) found that when freshly harvested seeds of pigweed (Amaranthus retroflexus L.) was placed under moisture conditions which favor germination, the temperature determines the number of seedlings obtained. At 35 C germination was 90%, at 25 C to 30 C, 18% and no seed germinated at 20 C. Freshly harvested seeds of Brassica juncea Czern. and Coss. have a low initial temperature requirement of 10 C to 15 C. Its seeds germinated 95% at 10 to 15 C, 63% at 20 C and 8% at 25 C (Toole and Toole, 1939 as cited by Went, 1953).

In many cases where seeds do not germinate or germinate poorly when subjected to a constant temperature, best germination occurs when for 7 hours daily they are subjected to a much higher temperature than during the night (Went, 1953).

According to Amen (1968) the effects of temperature on seed dormancy and germination are inconsistent and the trigger mechanism is difficult to identify. He suggested that various enzyme systems are differentially sensitive to temperature wherein they are activated by a sequence of temperature regimes. However, evidence for such a scheme was meager.

Photoperiod and Flowering

Reviews on photoperiodism and the flowering process have been done by Doorenboos and Wellensiek (1959), Lockhart (1961), Salisbury (1961) and Naylor (1961). Books on the general subject of flowering have also been published (Hillman, 1962; Salisbury, 1963; Imamura, 1967; Evans, 1969; Bernier, 1970; Salisbury, 1971).

Because of the broad scope of the subject of flowering, only the effect of light on flower induction will be reviewed.

The leaf has been shown to be the site of photoreception for the induction of flowering (Knott, 1934), the most rapidly expanding leaf being the most sensitive to photoinduction (Hamner and Bonner, 1938).

Based on the response of plants to daylength with respect to flowering, Garner and Allard (1920) broadly categorized plants into short-day plants (SDP), long-day plants (LDP) and day-neutral plants (DNP). The SDP flower when the day is shorter than some maximum, while the LDP flower when the day is longer than some minimum. Since then several response types have been found (Salisbury, 1963).

A long dark period promotes flowering in SDP but inhibitory in LDP while short dark periods combined with short light periods inhibit flowering in SDP (Hamner and Bonner, 1938) and promote flowering in LDP (Allard and Garner, 1941).

The exact role of the dark period is not known but in SDP the floral stimulus is thought to be synthesized during this time. In the LDP the dark period may initiate the production of an inhibitor or annul the promotive effect of the light period. A light period of sufficient length should provide a long dark period to induce flowering in SDP

(Hamner, 1940). In plants requiring several inductive cycles (Glycine), an alteration of light and dark is necessary for induction but continuous darkness is non-promotive (Borthwick and Parker, 1938). In other plants (Kalanchoe), a few seconds of light per day are sufficient to induce flowering (Schwabe, 1969). If SDP are subjected to alternating long days and inductive cycles, flowering is also inhibited (Schwabe, 1959).

In LDP long light periods are favorable to flowering even when combined with long dark periods but short light periods combined with long dark periods are non-inductive (Naylor, 1941).

Two light reactions have been recognized in the photoperiod effect: reaction corresponding to phytochrome mediated reactions requiring low intensity light and the high irradiance reaction (HIR) (Mohr, Bienger and Lange, 1971).

Phytochrome responses are induced by brief exposures to low irradiance (as low as 0.18 lux) that are reversible by successive exposures to red and far-red light and have peak sensitivity at 660 and 730 mm.

In HIR, plants require extended periods of high intensity irradiation (above 10^4 ergs/cm^2/sec) given after the main light period for floral induction (Mohr, 1969). The HIR may be independent of phytochrome reaction and mediated by a separate pigment system (Siegelman and Hendricks, 1957; Mohr, 1962; Friend, 1968; Schneider and Stimson, 1971).

MATERIALS AND METHODS

Survey of Emilia species and types

Surveys were made on the islands of Oahu, Kauai and Lanai between January 1973 and December 1974. The survey was done by observing Emilia plants along roadsides, croplands, experimental farms and school sites accessible by road. Any plant having a different flower color hue or unusual plant morphology was noted. Flower color was described with the aid of a standard color chart (1966 colour chart of the Royal Horticultural Society, London), while plant morphology was described visually. Flower color was noted when all the florets were in full bloom which usually coincides with anther dehiscence. Mature seeds or flowering plant materials or both were collected.

Test for segregation

Individual capitula from plants having different flower colors and from different species of Emilia were selfed in the nursery and open-pollinated seeds (achenes) were collected from the field. Based on observations of earlier germination tests, seeds were stored for about a month to prevent any dormancy. To avoid contamination from Emilia from other sources, seeds from individual flower heads were first germinated in Petri dishes for 5 to 7 days and then transplanted, 15 seedlings to a flat.

The soil was fumigated with methyl bromide to kill most weed seeds present in the soil. Each flat containing 15 liters of soil was fertilized with 50 grams of 10-10-10. Insects were adequately controlled with sprays of diazinon [O,O-diethyl O-(2-isopropyl-4-methyl-6 pyrimidinyl)

phosphorothioate] and sevin (1-naphthyl-N-methylcarbamate).

The plants were observed at flowering for segregation. For each plant type, the number of progenies exhibiting a different color type and the total number of progenies were recorded.

Effect of fertilizer application and shading on life history and morphology

Two sets of pot experiments were conducted in the nursery with three flower types of E. javanica [Orange (29A), Red (39A) and Purple (77B)] and E. sonchifolia (Figure 1.1D); each set grown under full sunlight and 55% shade. In each shading treatment, plants either received a basal and two topdress applications of N-P-K fertilizer or none at all. Shading was provided by a propylene mesh cloth that allows 45% of the sunlight to pass through. Fertilized plants were grown in 3.8-liter pots containing Waialua silty clay soil thoroughly mixed with 10 g of 10-10-10. These plants were later topdressed twice with 5 g of 10-10-10 per pot per application at two and three months after transplanting. To insure uniform establishment of plants, Emilia seeds were first germinated in Petri dishes and transplanted, 5 to 6 days later, at 2 plants per pot.

A split plot design was used with the fertilizer as the main plot and Emilia species and color types as the sub-plots. Each sub-plot consisted of eight pots. A pot was considered a replicate. Results of the full sunlight and 55% shade experiments were compared using Student's t-test. Phenological data were collected on each Emilia species and type. In addition plant height was measured at periodic intervals,

and data on capitulum size, number of seeds per capitulum and number of flower heads per plant were obtained.

Seed germination characteristics

Seed germination characteristics were based on a 100-seed sample. Unless otherwise stated seeds were germinated in a 9-cm Petri dish lined with filter paper and moistened with distilled water. Each treatment was replicated four times and each Petri dish represented a replicate. Light was supplied by cool white fluorescent lamps with an intensity of 9.29 lux. Dark conditions were simulated by wrapping the Petri dishes with two layers of aluminum foil. The dishes were then placed inside a four layered paper bag. Seeds germinated under dark conditions were counted in a darkroom with a 10-watt fluorescent tube covered with two layers of green cellophane.

a. Effect of stage of capitulum development on germination

Two Emilia species, E. javanica type Red and E. sonchifolia were used. A total of 80 capitula that were in full bloom were tagged for each species. Ten capitula of each species were collected at random from the tagged flowers starting on the third day after tagging. Capitula were collected daily thereafter until the 10th day when the capitula started to dehisce. After drying for 1 week, the seeds were sorted into filled and unfilled categories. The filled seeds were stored for 29 days after the last batch of flowers were harvested. Seeds were germinated in continuous light at 25 C. The germination percentage was based on the total number of seeds that germinated within 25 days.

b. Effect of length of storage, seed color and light on germination

Light and dark colored seeds of the different Emilia species and types were germinated in the laboratory under two light regimes (continuous light and continuous darkness) at different times (1 and 7 days; 4, 14 and 38 weeks) after harvest at a constant temperature of 25 C. The percentage germination was based on the total number of seeds that germinated within 3 weeks.

c. Effect of temperature on germination

Newly harvested light-colored seeds of E. javanica types (Red, Orange and Purple) and E. sonchifolia were germinated in the laboratory under alternate 12-hour light and 12-hour dark conditions at 5 to 45 C with 10 C increments. The percentage germination was based on the number of seeds that germinated within 3 weeks.

Effect of photoperiod on floral and vegetative development

Two photoperiod experiments were conducted in growth chambers. In the first experiment, three types of E. javanica (Orange, Red and Purple) and E. sonchifolia were grown under 8, 12 and 16 hours photoperiods and under natural day length from September 13 to October 24, 1974. Each growth chamber was set at the desired photoperiod with a constant day and night temperature of 27 C $\pm$ 3 C. The light source consisted of cool white fluorescent tubes and incandescent bulbs. The intensity was about 32.5 lux. Except for the plants grown under natural daylength, the plants grown at specific photoperiods were grown continuously in the growth chamber for the first 2 weeks and then were given about 7 to 7½ hours of natural sunlight daily in order that the plants

would photosynthesize normally.

Plants were grown in 1-liter plastic pots containing autoclaved soil fertilized with 10 grams of 10-10-10 per 3.8 liters of soil. Each pot containing two plants represented a replicate. Each treatment consisted of four replications.

Data were taken on the number of days after sowing (DAS) to the first appearance of flower buds, leaf numbers at the time the bud appeared and plant heights at 41 DAS.

The second experiment was conducted from March 10 to April 25, 1975. Only the E. javanica type Red was grown under the same photoperiod treatments and conditions as in the first experiment. The temperature was lowered to 25 C $\pm$ 2 C and the light source was incandescent bulbs only. Each treatment was composed of eight pots containing 2 plants per pot.

Two plants from each photoperiod treatment were dissected under a stereo microscope starting at 17 DAS and every two days thereafter until the flower initiation stage was determined. The reproductive apex was dome shaped while the vegetative growing point was more pointed.

Data on the number of days from sowing to floral initiation (FI), bud appearance (BA) and full bloom (FB); the leaf stage at FI and at BA; and plant heights at BA and FB were taken.

RESULTS AND DISCUSSION

Survey of Emilia species and types

Of the four Emilia species reported by Fosberg (1948) to be present in Hawaii, only E. javanica and E. sonchifolia were found (Table 1-2). Dr. Harold St. John (personal communication) concurred with me on the identity of these two species. E. sonchifolia was found only on Oahu and Kauai. The species described by Fosberg as E. coccinea which he reported to be abundant in Lanai was not found.

A spectrum of flower color types of E. javanica ranging from orange (24A) to purple (77B) were noted. The alphanumeric term in parenthesis refer to specific colors in the 1966 colour chart of the Royal Horticultural Society of London. Although the Red-purple type of E. javanica (62A) was not seen on Kauai, the greatest color variation in the Orange and Red types occurred there. Although no quantitative data were taken, it was observed that the population of the different types of E. javanica were more widespread on Kauai than Oahu and Lanai. It was also observed that the Red types were the most predominant among the E. javanica types. The Red types were found in large numbers on all three islands.

Test for Segregation

Observations of preliminary plantings of E. javanica types showed that some plants grown from seeds of a particular color type produced plants having more than one flower color. To ascertain whether some of the E. javanica types were segregating, selfed and open-pollinated seeds from the different Emilia species and types were planted. Segregation occurred only in some of the E. javanica types (Table 1.3). Among the

Table 1.2. Different species and types of Emilia found in a survey of the islands of Oahu, Kauai and Lanai α/.

Species and color group	Individual colors β/ found on		
	Oahu	Kauai	Lanai
Emilia javanica (Burm) Rob.			
Orange (24-29)	24A	24A	24A
	25A	25A, 25B	24A
	28B	28A, 28B	28B
	29A	29A	29A
Orange-red (30-35)	30C	30B	30C
	32A	30C	
		32A, 32C	
		33A, 33B	
Red (36-56)	39A	37A	39A
		39A, 39B	
	41A	41A, 41B	41A
		41C	
		44D	
		46C, 46D	
		50C	
		51A, 52A	
Red-purple (57-75)	62A	none	none
Purple (76-79)			
E. sonchifolia (L.) DC			
Purple (76-79)	77B	77B	none

α/ Emilia plants found along roadsides, croplands, experimental farms and school sites.

β/ Alphanumeric designation correspond to the type of color on the 1966 colour chart of the Royal Horticultural Society of London.

Table 1.3. Flower color types of progenies from selfed and open-pollinated flowers of E. javanica and E. sonchifolia α/.

Species, color group and type	Mode of Pollination	Progeny			Source
		color type	number	Total	
E. javanica					
Orange group (24-29)					
24A	open	24A	13	27	Oahu
		28B	14		
25B β/	selfed	25B	4	9	Kauai
		29A	5		
28A	open	28A	43	44	Kauai
		31A	1		
28B	open	28B	32	32	Kauai
28B	selfed	28B	58	58	Kauai
29A	open	29A	100	100	Kauai
29A	selfed	29A	120	120	Kauai
Orange-Red group (30-35)					
30C	open	30C	83		Kauai
		32C	1	85	
		33A	1		
30C γ/	open	25A	8	47	Kauai
		25B	5		
		28B	5		
		30C	9		
		32B	14		
		39A/B	5		
		47B	1		
Red group (36-56)					
39A	selfed	39A	61	61	Oahu
39A	selfed	39A	41	41	Kauai

Table 1.3. Flower color types of progenies from selfed and open-pollination flowers of E. javanica and E. sonchifolia α/. (continued)

Species, color group and type	Mode of Pollination	Progeny			Source
		color type	number	Total	
39A/B δ/	selfed	32A	42	85	Kauai
		39A/B	43		
39A	open	29A	2		Kauai
		30D	1	98	
		39A	95		
Red-Purple group (57-75)					
62A	selfed	62A	18	18	Oahu
Purple group (76-79)					
77B	selfed	77B	110	110	Kauai
77B	open	77B	95	95	Kauai
E. sonchifolia					
Purple group (76-79)					
77B ε/	open	77B	101	101	Kauai

α/ Alphanumeric designations correspond to the type of color on the 1966 colour chart of the Royal Horticultural Society of London.

β/ From plant growing with pure stands of 29A flower type.

γ/ From plant with both 30C and 23A flower types on the same plant.

δ/ From plant growing with pure stands of 77B flower type.

ε/ Plant with white pollen grains.

E. javanica types, the orange and red groups segregated and produced progenies that exhibited a different flower color hue from the same color group [24A (orange group) producing 24A and 28B, or 30C producing 30C, 32C and 33A], or gave rise to progenies with flower colors from a different color group [28A (orange group) producing 28A and 31A (orange-red group); 30C (orange-red) producing 25A (orange group), 30C, 47B (red group)]. No segregation in flower color was observed from the E. javanica Purple type (77B) and E. sonchifolia.

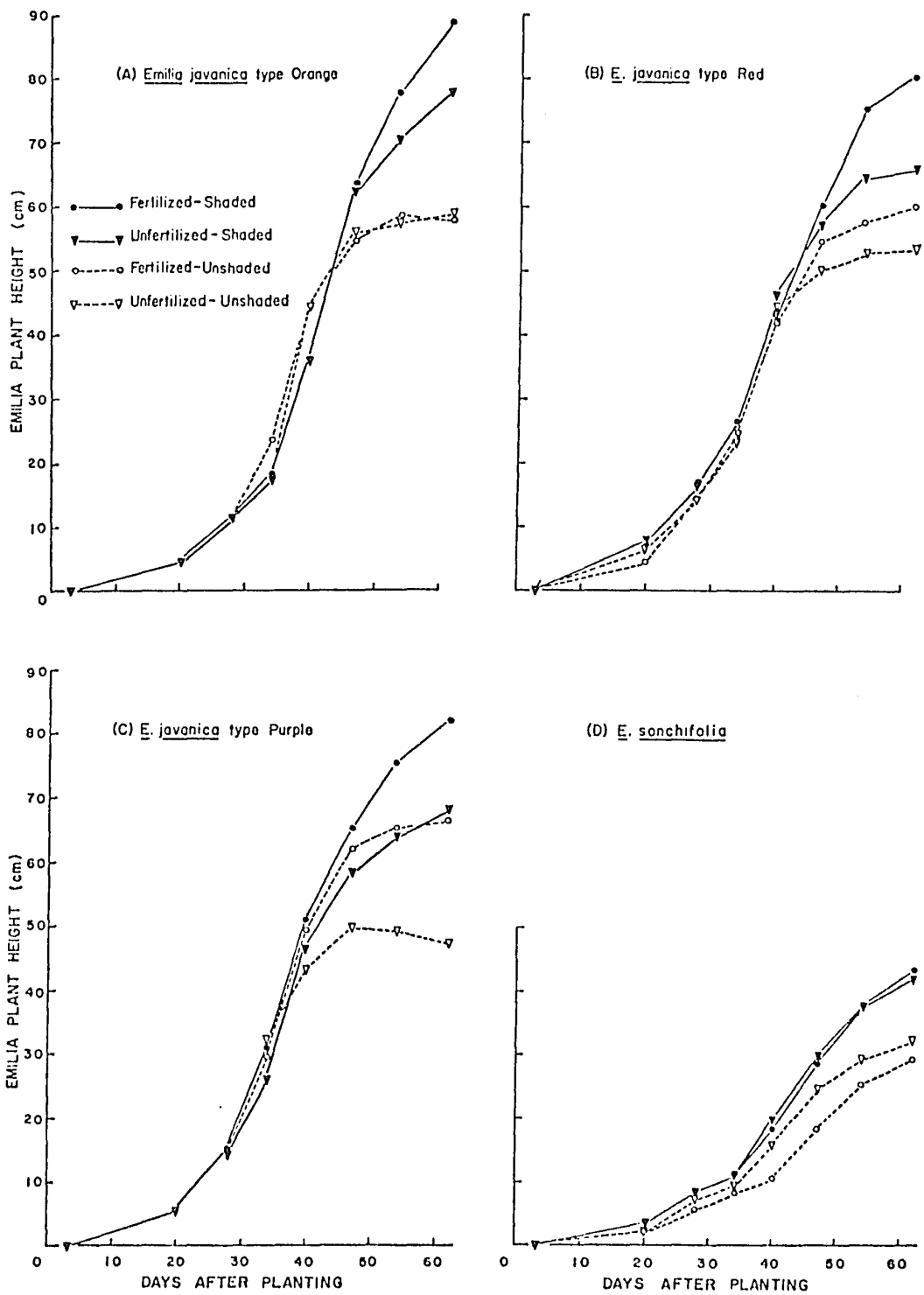
The occurrence of segregation in some of the different types of E. javanica clearly demonstrated that the different types, particularly, the Reds, Orange-reds, and Oranges, readily hybridized under field conditions. The similarities in vegetative and floral morphology in addition to their ability to interbreed indicated that they belong to the same species.

Effect of fertilizer application and shading

a. Growth curves

Based on plant height, both species showed the same sigmoid pattern of growth (Figure 1.2). However, the fertilized plants under 55% shade had a greater growth rate and they continued growing up to 62 DAS when measurements were terminated, while the unfertilized plants under full sunlight were the shortest attaining their maximum height at 48 DAS. The time at which rapid growth began also differed between the two species: 4 weeks after sowing (WAS) with E. javanica; and 5 WAS with E. sonchifolia.

Figure 1.2. Growth curves of the (A) Orange, (B) Red and (C) Purple types of E. javanica and of (D) E. sonchifolia grown under two levels each of shading and fertilizer treatments.


(A) Emilia javanica type Orange
(B) E. javanica type Red
(C) E. javanica type Purple
(D) E. sonchifolia
Fertilized-Shaded
Unfertilized-Shaded
Fertilized-Unshaded
Unfertilized-Unshaded
EMILIA PLANT HEIGHT (cm)
DAYS AFTER PLANTING
0
10
20
30
40
50
60
70
80
90

All the E. javanica types were taller than E. sonchifolia in all different fertilizer and light regimes. At the time of flowering (47 DAS), the height of the E. javanica types ranged from 50 to 62 cm, E. sonchifolia from 19 to 30 cm and at 62 DAS, E. javanica types were 50 to 85 cm tall while E. sonchifolia grew only 29 to 43 cm.

b. Capitulum size

In general, only the involucre length and the width of the base and mid-section of the capitulum of the different Emilias grown under full sunlight varied with fertilizer level (Table 1.4 and 1.5). The capitulum size of the Emilias grown under 55% shade was not influenced by the fertilizer treatments (Table 1.5).

Shading or fertilizer treatments did not affect the total length of the capitulum of the Emilias (Tables 1.4 and 1.5). However, the total length of the capitulum of the E. javanica types (12.5 to 13 mm) were longer than E. sonchifolia (10.5 to 11 mm). Where grown under full sunlight with N-P-K fertilizer, involucre length of E. javanica remained unchanged regardless of fertilizer or shading treatment (Table 1.4). In full sunlight, the involucre length of E. sonchifolia increased from 10 mm to 11 mm with N-P-K fertilizer.

The width of the base of the capitulum of the Purple type of E. javanica was slightly increased under full sunlight than in 55% shade. However, the widths of the mid-section and neck of the capitulum of the Emilias were not affected by the fertilizer treatment (Table 1.4). The mean width of the base of E. javanica was 1 mm wider than E. sonchifolia. The width of the mid-section of the capitulum of both species was 0.5 to 1.0 mm narrower than their base.

Table 1.4. Effect of fertilizer application under full sunlight on the capitulum size of three types of E. javanica and E. sonchifolia.

Species and types	Capitulum size α/				
	Length		Width		
	total mm	involucre mm	base mm	mid-section mm	neck mm
		Fertilized			
E. javanica					
Orange	13.0 a	10.0 b	4.5 a	4.0 a	4.5 a
Red	13.0 a	10.0 b	4.5 a	4.0 a	4.5 a
Purple	13.0 a	10.5 ab	4.5 a	3.5 a	4.0 a
E. sonchifolia					
Mean	12.0 a'	10.5 a'	4.0 a'	3.5 a'	4.0 a'
		Unfertilized			
E. javanica					
Orange	13.0 a	10.0 b	4.5 a	4.0 a	4.5 a
Red	13.0 a	10.0 b	4.5 a	3.4 a	4.0 a
Purple	12.5 a	10.0 b	4.0 b	3.5 a	4.0 a
E. sonchifolia	11.0 b	10.0 b	3.5 c	3.0 b	4.0 a
Mean	12.5 a'	10.0 a'	4.0 a'	3.5 a'	4.0 a'

α/ Treatment differences are based on Duncan's Bayes lsd.

Any two means followed by the same letter under the same column are not significantly different at 5% level.

Table 1.5. Effect of fertilizer application under 55 percent shading on the capitulum size of three types of E. javanica and E. sonchifolia.

Species and types	Capitulum size α/				
	Length		Width		
	total mm	involucre mm	base mm	mid-section mm	neck mm
			Fertilized		
E. javanica					
Orange	13.0 a	10.0 a	4.5 a	3.5 a	4.5 a
Red	12.5 a	10.0 a	4.5 a	3.5 a	4.0 a
Purple	13.0 a	10.0 a	4.5 a	3.5 a	4.0 a
E. sonchifolia	10.5 b	10.0 a	3.5 b	3.0 b	3.5 b
Mean	12.0 a'	10.0 a'	4.0 a'	3.5 a'	4.0 a'
			Unfertilized		
E. javanica					
Orange	12.5 a	9.5 a	4.5 a	3.5 a	4.0 a
Red	12.5 a	10.0 a	4.5 a	3.5 a	4.0 a
Purple	12.5 a	10.0 a	4.0 a	3.5 a	4.0 a
E. sonchifolia	10.5 b	10.0 a	3.5 b	3.0 b	3.5 b
Mean	12.0 a'	10.0 a'	4.0 a'	3.5 a'	4.0 a'

α/ Treatment differences are based on Duncan's Bayes lsd.

Any two means followed by the same letter under the same column are not significantly different at 5% level.

c. Number of seeds per capitulum

Under full sunlight and fertilizer, the various Emilias differed in the total number of seeds per capitulum (Table 1.6). The number of seeds varied among the E. javanica types, with Orange, Red and Purple types having 70, 64 and 57 seeds, respectively. E. sonchifolia produced about the same amount of seeds per head as the E. javanica purple type. The number of light-colored seeds also varied among the Emilias. The number of dark-colored seeds per capitulum (9 to 10 seeds) of the Red and Purple types of E. javanica and E. sonchifolia was the same. However, the Orange type of E. javanica which had the greatest number of dark seeds with 17 per head differed from the other Emilias.

The number of unfilled seeds gave an indication of the seed setting percentages. E. sonchifolia set seed best (90%), followed by the Orange (83%), Red (70%), and Purple (67%) types of E. javanica.

In E. javanica type Red, the number of dark seeds and total seeds per capitulum were not affected by shading or fertilizer (Table 1.7). The greatest number of unfilled seeds occurred in the shade with fertilizer. In general, there were 17% more light-colored seeds and 75% more unfilled seeds under full sunlight than under 55% shade regardless of fertilizer level. This indicated that seed setting decreased under shade, particularly in highly fertile soils.

d. Number of capitula per plant

The number of capitula produced per plant was influenced by shading, fertilizer treatments, and by the Emilia species and types (Table 1.8). The Emilias produced the greatest number of capitula under full sunlight

Table 1.6. Number of seeds per capitulum of three types of E. javanica and E. sonchifolia grown under full sunlight with N-P-K fertilizer

Species and types	Number of seeds per capitulum α/			
	light	dark	unfilled	total
E. javanica				
Orange	41 b	17 a	12 b	70 a
Red	35 c	10 b	19 a	64 b
Purple	29 d	9 b	19 a	57 c
E. sonchifolia	45 a	9 b	6 c	60 c

α/ Treatment differences are based on Duncan's Bayes lsd.

Any two means followed by the same letter under the same column are not significantly different at 5% level.

Table 1.7. Effect of shading and fertilizer application on the number of seeds per capitulum of E. javanica type Red.

Shading and fertilizer treatments	Number of seeds per capitulum α/			
	light	dark	unfilled	total
Full sunlight				
Fertilized	36 a	10 a	19 b	65 a
Unfertilized	37 a	10 a	19 b	64 a
Mean (full sunlight)	36 a'	10 a'	18 b'	64 a'
55% shading				
Fertilized	31 b	8 a	26 a	65 a
Unfertilized	28 b	10 a	22 b	60 b
Mean (55% shading)	30 b'	9 a'	24 a'	63 a'

α/ Treatment differences are based on Duncan's Bayes lsd. Any two means followed by the same letter under the same column are not significantly different at 5% level.

Table 1.8. Effect of fertilizer application and shading on the number of capitula produced by E. javanica types and E. sonchifolia.

Species and types	Total number of flower heads per plant α/	
	Full sunlight	55% shading
Fertilized		
E. javanica		
Orange	127 b	101 a
Red	139 b	89 ab
Purple	170 a	73 b
E. sonchifolia	117 b	66 b
Mean	138 a'	82 a'
Unfertilized		
E. javanica		
Orange	27 c	21 c
Red	32 c	22 c
Purple	27 c	24 c
E. sonchifolia		
Mean	27 b'	23 b'
Mean (shading)	82	52

α/ Treatment differences are based on Duncan's Bayes lsd. Any two means followed by the same letters under the same column are not significantly different at 5% level.

with fertilizer and the least under 55% shade with no fertilizer. Under full sunlight and with fertilizer, the E. javanica type Purple produced more flowers than the other types or species. Without fertilizer, Emilia species and types produced the same number of capitula when planted at the same time either under full sunlight or 55% shade. The Emilias under shade produced more flowers when fertilized.

These results show that the Emilias responded to differences in solar radiation and fertilizer, and that shading effects can be partly compensated by adequate fertilization.

e. Phenology

Under full sunlight, fertilizer delayed maturity for the Red and Purple types of E. javanica by one day and E. sonchifolia by 5 days (Table 1.9). In contrast, the Orange type of E. javanica matured 2 days earlier when fertilized.

Under shade, the phenology of individual species and types was generally unaffected by fertilizer level (Table 1.10).

Regardless of fertilizer treatment shading delayed maturity of all the Emilias from 2 to 5 days with the exception of E. sonchifolia under full sunlight with fertilizer (Table 1.9 and 1.10).

Among the Emilias, the Purple type of E. javanica matured (seed to seed) the earliest (48 $\pm$ 2 DAS) followed by the Red (51 $\pm$ 1), Orange (52 $\pm$ 1), and E. sonchifolia (53 $\pm$ 3). However, all of the Emilia species and types regardless of shade or fertility level matured within 3 to 9 days from each other when planted at the same time under the same conditions. These results indicate that the different Emilia species and types showed little variation in maturity under varying shade and

Table 1.9. Effect of fertilizer application under full sunlight on the growth duration of three types of E. javanica and of E. sonchifolia.

Species and types	Number of days from seeding to α/		
	flower bud emergence	full bloom	seed maturity
	Fertilized		
E. javanica			
Orange	27 c	40 b	49 d
Red	28 b	41 b	50 c
Purple	26 c	36 c	47 e
E. sonchifolia	32 a	44 a	56 a
Mean	28 a'	40 a'	50 a'
	Unfertilized		
E. javanica			
Orange	29 b	41 b	51 b
Red	26 c	40 b	49 d
Purple	36 c	37 c	46 f
E. sonchifolia	28 b	41 b	51 b
Mean	27 a'	40 a'	49 a'

α/ Treatment differences are based on Duncan's Bayes lsd. Any two means followed by the same letter under the same column are not significantly different at 5% level.

Table 1.10. Effect of fertilizer application under 55 percent shading on the growth duration of three types of E. javanica and E. sonchifolia.

Emilia species and types	Number of days from planting to α/		
	flower bud emergence	full bloom	seed maturity
	Fertilized		
E. javanica			
Orange	31 a	44 a	54 a
Red	28 b	40 c	52 c
Purple	26 c	39 d	49 d
E. sonchifolia	28 b	42 b	53 b
Mean	28 a'	41 b'	52 a'
	Unfertilized		
E. javanica			
Orange	29 b	44 a	53 a
Red	28 b	42 c	51 c
Purple	26 c	40 d	50 d
E. sonchifolia	27 b	42 b	52 b
Mean	28 a'	42 a'	52 a'

α/ Treatment differences are based on Duncan's Bayes lsd. Any two means followed by the same letter under the same column are not significantly different at 5% level.

fertilizer levels.

Seed germination characteristics

a. Effect of stage of flower maturity on seed germination

The two Emilia species varied in the length of time required to form viable seeds (Table 1.11). As early as 3 days after full bloom, seeds of E. javanica type Red germinated 40%. With E. sonchifolia only 5% germination was obtained 5 days after full bloom.

Viable seeds were formed in both species before the capitula were ready to dehisce. This observation suggests that Emilia plants should be controlled before they reach the flowering stage to avoid the production of viable seeds for future infestations.

b. Effect of length of storage, seed color, and light on seed germination

The germination percentage of seeds of the different Emilias was influenced by length of storage, species and color types, seed color, and light (Table 1.12). Seeds of the Emilia species and color types required light for germination up to 4 weeks after harvest (WAH). The low percentage germination of both the light- and dark-colored seeds of E. javanica type Orange indicated that the seeds were dormant even in the presence of light. It is also interesting to note that at 4 WAH the dark seeds of all the E. javanica types germinated poorly even in the presence of light. At 14 WAH light was no longer required for germination by most seeds of the Emilia species and types regardless of color. However, maximum germination occurred in the presence of light.

Table 1.11. Percentage germination of seeds of E. javanica red type and E. sonchifolia collected at different stages of maturity.

Days after full bloom of capitulum	% Germination α/	
	E. javanica type red	E. sonchifolia
3	40 ± 2	0
4	40 ± 2	0
5	81 ± 9	5 ± 1
6	26 ± 7	23 ± 2
7	57 ± 2	-
8	78 ± 2	54 ± 7
9	60 ± 7	76 ± 4
10	77 ± 3	66 ± 6

α/ Based on the total number of seeds that germinated within 25 days. Seeds were germinated 39 days after full bloom.

Table 1.12. Germination percentage of the dark and light colored seeds of Emilia species and types at different periods after harvest under continuous light or darkness.

Seed color	Period of seed storage before germination									
	1 Day		7 Days		4 Weeks		14 Weeks		38 Weeks	
	CL α/	CD β/	CL	CD	CL	CD	CL	CD	CL	CD
	% Germination γ/									
					Orange (E. javanica)					
Light	4 ± 2	0	79 ± 5	0	59 ± 10	0	100	76 ± 5	100	78 ± 3
Dark	4 ± .3	0	70 ± 14	0	3 ± 1	0	100	70 ± 4	100	52 ± 10
					Red (E. javanica)					
Light	100	.5 ± .3	100	.3 ± .3	97 ± 2	2.0 ± 1	100	99 ± .3	100	94 ± 4
Dark	100	.8 ± .2	100	.5 ± .3	33 ± 8	0	100	99 ± .4	100	92 ± 2
					Purple (E. javanica)					
Light	100	.3 ± .3	100	0	99 ± 1	.3 ± .3	100	100	100	94 ± 1
Dark	100	0	100	0	47 ± 17	0	100	99 ± .5	100	98 ± 1
					E. sonchifolia					
Light	100	0	100	0	100	0	100	82 ± 5	64 ± 4	43 ± 11
Dark	100	0	100	0	100	0	100	80 ± 5	91 ± 2	27 ± 12

α/ CL - continuous light at 9.29 lux from fluorescent light at 25 C.

β/ CD - continuous darkness at 25 C.

γ/ Based on total number of seeds that germinated within 3 weeks.

The reduction of germination in E. sonchifolia at 38 WAH was due to loss of viability since the seeds that did not germinate under both light regimes rotted. Dark-colored seeds of E. sonchifolia did not lose viability as rapidly as light-colored seeds.

e. Effect of temperature on seed germination

None of the newly harvested light-colored seeds of any of the Emilias germinated at 5 C and a very low percentage germinated at 45 C (Figure 1.3). Between 15 and 35 C, there was a differential response between species and among the E. javanica types. E. sonchifolia can germinate better under a wider temperature range (15 to 35 C) than the E. javanica types (25 to 35 C). Among the E. javanica types, the Orange type showed the narrowest temperature range (only germinated at 35 C).

Effect of photoperiod on vegetative and floral development

In the first experiment, the time of bud appearance of the different Emilia species and types varied with photoperiod (Table 1.13). Flowering was earliest at 12 hours photoperiod (24 to 26 DAS) and latest at 8 hours (32 to 38 DAS). Bud appearance at 16 hours was intermediate (28 to 31 DAS).

The leaf number at bud formation also differed between different photoperiods. There was about three to five leaves formed when the flower buds appeared at 12 hours and normal daylength while there were about five to eight leaves formed at 8 or 16 hours. E. sonchifolia had 1 to 3 fewer leaves than the E. javanica types at the time flower buds emerged.

Plant height of the Emilia species and types at 42 DAS were also

Figure 1.3. Response of newly-harvested light-colored seeds of the Orange, Red and Purple types of E. javanica and E. sonchifolia to 5 levels of constant temperature under alternate 12-hour light and 12-hour darkness.

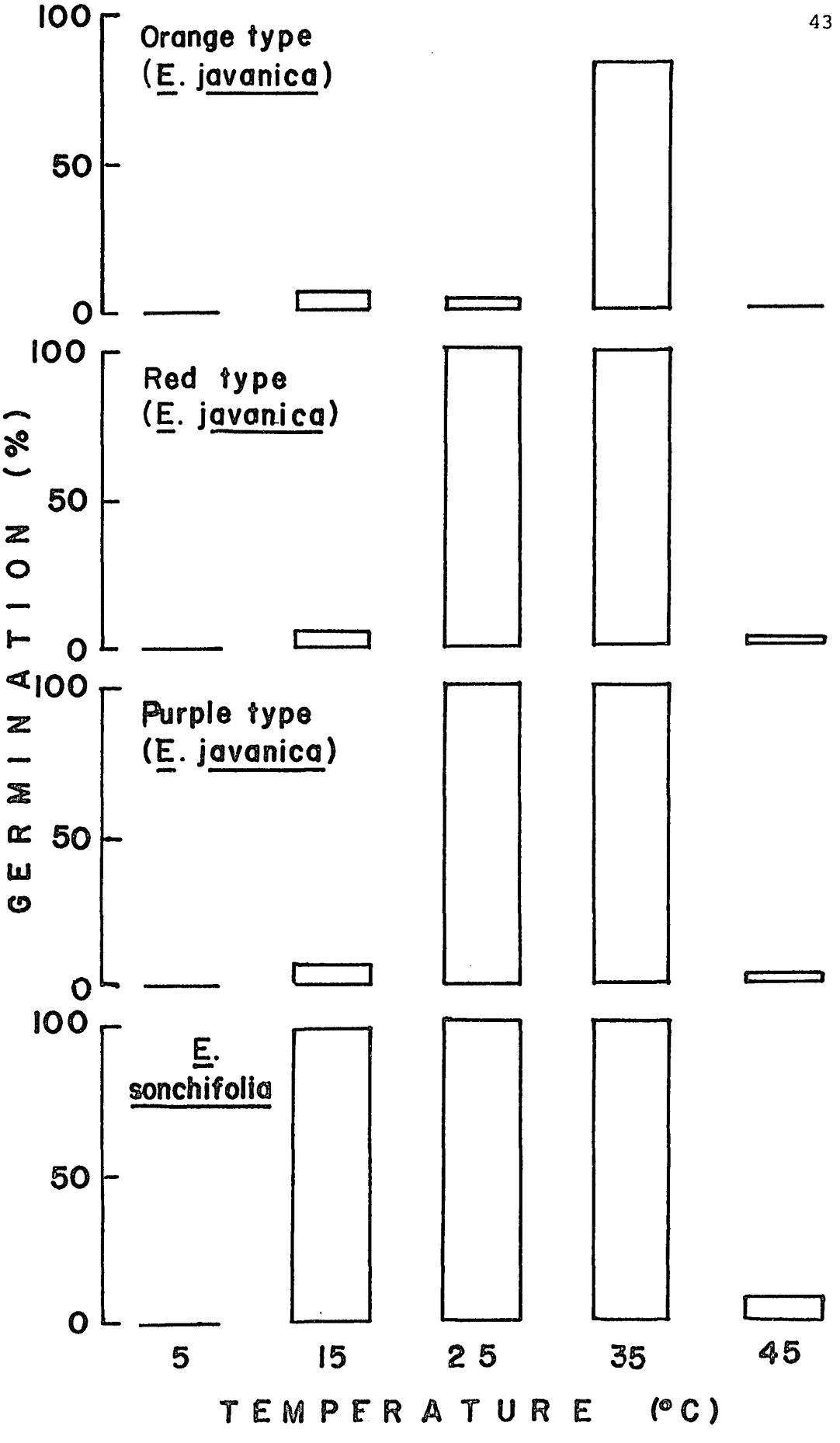

100
50
0
Orange type
(E. javanica)
Red type
(E. javanica)
Purple type
(E. javanica)
E.
sonchifolia
GERMINATION (%)
5
15
25
35
45
TEMPERATURE (°C)

Table 1.13. Effect of different photoperiods on the time of bud appearance and the leaf stage of the different *Emilia* species and types.

Emilia species and types	Duration of photoperiod							
	Natural day length α/		8 hours		12 hours		16 hours	
	Flower bud β/	LN γ/	Flower bud	LN	Flower bud	LN	Flower bud	LN
E. javanica								
Orange	26 ± 0.5	4 ± 0	38 ± 1.5	7 ± 0	25 ± 0.5	5 ± 0.5	31 ± 0.5	6 ± 0.5
Red	26 ± 0.5	4 ± 0	38 ± 0.5	8 ± 0	26 ± 2.0	5 ± 0.5	30 ± 1.0	6 ± 0
Purple	25 ± 0.5	4 ± 0	32 ± 0	6 ± 0	24 ± 0	4 ± 0	28 ± 0.5	6 ± 0
E. sonchifolia	27 ± 0.5	3 ± 0	32 ± 0	5 ± 0.5	24 ± 0	3 ± 0.5	28 ± 0	5 ± 0

α/ 11 hours 58 min. = average daylength between September 15 and October 15.

β/ Number of days from planting to appearance of flower buds. Mean of 8 plants.

γ/ LN - leaf number based on the number of fully expanded leaves at bud formation.

Table 1.14. Effect of different photoperiods on the plant height of the different Emilia species and types at 42 days after seeding.

Emilia species and types	Duration of photoperiod			
	Natural day length α/	8 hour	12 hour	16 hour
	Plant height (cm) β/			
E. javanica				
Orange	38 ± 4	12 ± 1	61 ± 3	44 ± 6
Red	33 ± 4	12 ± 2	45 ± 2	46 ± 3
Purple	34 ± 2	19 ± 1	58 ± 1	58 ± 3
E. sonchifolia	20 ± 1	8 ± 1	29 ± 1	22 ± 1

α/ 11 hours 58 min. = average daylength between September 15 and October 15.

β/ Mean of 8 plants

Table 15. Effect of different photoperiods on the floral and vegetative development of *E. javanica* red type.

Emilia growth stage	Duration of photoperiod			
	Natural day length α/	8 hour	12 hour	16 hour
Days from seeding to:				
floral initiation β/	20	20	20	20
bud appearance γ/	30	30	29	29
full bloom γ/	43	45	39	41
Leaf stage at:				
floral initiation	2-3	2-3	3-4	3-4
bud appearance	6-7	5-6	6-7	6-7
Plant height (cm) δ/ at:				
bud appearance	15 ± 0.5	12 ± 0.5	17 ± 0.5	19 ± 0.5
flowering	38 ± 2.5	26 ± 2.0	40 ± 1.0	47 ± 1.5

α/ 12 hours 19 min. = average day length between March 15 and April 15.

β/ Mean of 2 plants

γ/ Based on the first plants showing buds or that attained full bloom.

δ/ Mean of 6 plants. DAS = days after seeding

affected by photoperiod (Table 1.14). At the 12 hour photoperiod, the Orange and Purple types of E. javanica were taller than either the Red type. Generally, the E. javanica types were taller than E. sonchifolia regardless of treatment. Plants grown at 12 to 16 hours were taller than those grown at either 8 hours or normal daylight. Although normal daylength is about 12 hours, the discrepancy between the 12-hour and normal daylength may be due to temperature and spectral differences. All the plants grown at 8 hours were shorter in height.

To determine if the time of flower initiation or the development of the inflorescence was affected by photoperiod, another experiment was conducted. Floral imitation of E. javanica type Red plants grown under 8, 12, 16 and natural daylength all occurred at 20 DAS (Table 1.15). However, the plants grown under 12 and 16 hour treatments produced buds 1 day ahead of the 8-hour and natural daylength controls. At flowering time, the effect of the different photoperiods on the time of flowering became more pronounced. The plants grown at 12 hours flowered the earliest at 39 DAS while the plants at 8 hours flowered last at 45 DAS.

The leaf number at the time of floral initiation and bud appearance differed slightly among the treatments but plant height (Table 1.15) was marked affected by the photoperiod treatments. Plant height was increased as the duration of photoperiod was lengthened at 30 and 46 DAS. Similar results were observed by Allard and Garner (1940) who worked on E. flammea.

The variation in the time of bud appearance between the two experiments may have been due to the higher and somewhat greater temperature fluctuation in the first experiment. Different light sources were also

used in supplementing the photoperiod treatments in the two experiments.

These results indicated that the different Emilia species and types were day neutral with respect to flowering response to photoperiod. Similar results were also observed by Allard and Garner (1940) on E. flammea. The difference in the time of flowering was due to differential development of the inflorescence rather than to differential initiation of the floral primordium. This may explain the findings of Ramaley (1934) who noted that flowering of E. flammea based on the time of blooming was hastened by long days "when a considerable number of flowers have appeared". This flowering characteristic of the Emilias is important in their adaptation for survival in areas with widely varying photoperiods. It also enables the plants to produce seeds continuously provided other climatic and edaphic factors are favorable for growth and reproduction.

SUMMARY AND CONCLUSIONS

Surveys were made to ascertain the number of Emilia species and/or types in Hawaii. The effects of fertilizer, shading, light, temperature, and photoperiod on the life history and morphology of representative species and types were also investigated.

Of the four species previously reported to be present in Hawaii, only E. javanica and E. sonchifolia were found on the islands of Oahu and Kauai, while on Lanai only the Red and Orange types of E. javanica were observed. The flower colors of E. javanica ranged from a spectrum of orange, red and purple. The E. javanica type Purple was found only in limited areas on Oahu and Kauai. The E. javanica types, particularly the Red type, which were referred to as E. sonchifolia or E. sagittata by other workers, are the most predominant types on Oahu, Kauai and Lanai.

Segregation on the basis of flower color in the Red, Red-Orange, and Orange types of E. javanica clearly demonstrated that these three types hybridize under field conditions. The similarities in vegetative and floral morphology of the different color types of E. javanica, in addition to their ability to interbreed or hybridize indicate that they belong to the same species.

Plant height, capitulum size, number of achenes (seeds) per capitulum, and number of capitula per plant were influenced by fertilizer and shading treatments. The E. javanica types were taller (50 to 62 cm) than E. sonchifolia (19 to 31 cm) at flowering. Fertilized Emilias grown under 55% shade were tallest while unfertilized plants under full

sunlight were shortest. The total length of the capitulum of the E. javanica types ranged from 12.5 to 13 mm compared with 10.5 to 11 mm for E. sonchifolia. When fertilized with N-P-K and grown in full sunlight, the Orange, Red, and Purple types of E. javanica had 70, 64 and 57 seeds per capitulum, respectively, while E. sonchifolia had 60. Among the Emilias, the E. javanica type Purple produced the greatest number of capitula per plant. The period from sowing to seed maturization was quite short, usually averaging about 51 days. The Purple type of E. javanica was the earliest to mature (seed to seed) (48 $\pm$ 2 days), followed by the Red (51 $\pm$ 1 day, Orange (52 $\pm$ 1 day) and E. sonchifolia (53 $\pm$ 3 days).

Seed germination studies showed that seeds of E. javanica matured earlier than E. sonchifolia. However, viable seeds were formed in both species before the capitula were ready to dehisce. All Emilias examined produced both light and dark-colored seeds. The light-colored seeds of E. sonchifolia showed similar germination percentage as the Red and Purple types of E. javanica when stored and germinated under the same conditions. However, viability of E. sonchifolia seeds deteriorated more rapidly than those of the E. javanica types. Among the E. javanica types, seeds produced by the Orange type were more dormant than either the Red or Purple types and dormancy was caused by factors other than a light requirement. In general, seeds of Emilias required light for germination up to a period of 4 weeks after harvest. Newly harvested seeds of E. sonchifolia had a higher percentage of germination over a wider range of temperatures (15 to 35 C) than the E.

javanica types (25 to 35 C). Among the E. javanica types, the Orange type germinated well only at 35 C while the Red and Purple types were intermediate (25 to 35 C) between E. sonchifolia and E. javanica types.

Flowering response of the Emilia species and types were day neutral with respect to photoperiod. Observed differences in time of flowering were due to differential rates of inflorescence development rather than to differential initiation of the floral primordium. Plants grew taller as the photoperiod was lengthened.

These results indicate that the different Emilia species and/or types could be differentiated by means of their life history and response to environmental factors such as light, temperature and photoperiod. The seed germination and non-photoperiodic characteristics of E. sonchifolia and E. javanica type Purple should not prevent their occurrence and wide distribution in the Hawaiian Islands. The apparent absence of these types on Lanai and their limited occurrence on Oahu and Kauai are not due to limitations of the physical environment. The high mortality of E. sonchifolia inoculated with tomato spotted wilt virus suggests disease may keep the plant in check. Reasons for the absence or low population of the E. javanica type Purple are not known.

The characteristics of E. javanica types and E. sonchifolia such as high seed production, presence of seed dormancy, high germination percentage, rapid maturity of some seeds, and non-sensitivity to photoperiod indicate that the weeds would be difficult to eradicate once established in an area. However, effective herbicides are available that can keep them under control.

CHAPTER II

EMILIA SPECIES AND TYPES AS TSWV RESERVOIRS

INTRODUCTION

In Hawaii, the importance of Emilia javanica (Burm.) Rob. as a virus disease reservoir came into prominence in 1932 when it was established as a favored host for both the yellow spot virus of pineapple and the virus vector, Thrips tabaci (Lind.) (Linford, 1932; Sakimura, 1932, 1938; Carter, 1939). The pineapple yellow spot virus has since been established to be the same as the tomato spotted wilt virus (TSWV) (Parris, 1940; Sakimura, 1940). TSWV is of major concern because of its wide geographical distribution, its large number of host plants. It also has a polyphagous vector that parallels the virus in its geographic distribution and plant host occurrence.

E. javanica has been erroneously referred to as Emilia sonchifolia (L.) DC by several workers like St. John and Hosaka (1932), Carter (1939), Sakimura (1961), Crozier and Romanowski (1969), Romanowski and Nakagawa (1969), Cardenas, Reyes and Doll (1972) and Thresh (1974). E. sonchifolia is a distinct species which has not been shown in the literature to harbor nor to transmit the TSWV. E. javanica and E. sonchifolia can be distinguished from each other by differences in capitulum and seed size, leaf shape and size, and plant height at full bloom (Chapter I). The species, E. javanica has been found to exhibit a spectrum of flower colors from orange, red and purple in the Hawaiian Islands (Chapter I). Since only the Red type of E. javanica was used in the previous studies implicating

the weed as an important virus reservoir (Linford, 1931), it is not known whether the other color types of E. javanica and E. sonchifolia can harbor the virus and serve as reservoirs for subsequent transmission.

Previous studies of three color types of E. javanica and E. sonchifolia revealed that physiological differences among the types and species might be important in the survival of the weeds (Chapter I). Differences which may exist among the different types and species of Emilia with respect to virus disease infection and transmission could be important. It is necessary to know the relative importance of the various species and types of Emilia as disease reservoirs if control of plant diseases like TSWV is to be accomplished by reducing these reservoirs. Weed control would probably be as effective as control of the vectors, if a plant like Emilia is involved in a disease cycle of a virus disease transmitted by an insect (Daffus, 1971).

Glasshouse studies using a sap inoculation technique were undertaken to: (1) determine if differences exist among the Orange, Red and Purple types of E. javanica and E. sonchifolia in harboring the TSWV, (2) determine if age of Emilia seedlings influence the incidence of TSWV infection, (3) further demonstrate if the TSWV-infected Emilia species and/or types can also transmit the virus to crop plants like tomato (Lycopersicon esculentum Mill.) and lettuce (Lactuca sativa L.) and (4) determine if the TSWV in tomato and lettuce can be used to inoculate healthy Emilia plants.

Review of Literature

Excellent reviews on the tomato spotted wilt virus (TSWV) (Best, 1968) and on the thrips as insect vectors (Sakimura, 1962) have already been published. Other reviews on specific topics such as on the genetics of TSWV resistance (Holmes, 1954, 1958) and on the epidemiology of TSWV (Thresh, 1974) are also available. Descriptions of the symptoms of TSWV on some important crops have been compiled (Chupp and Sherf, 1960; Smith, 1972). Therefore, only the distribution and mode of transmission of the virus, and the role of *Emilia* as a virus carrier will be covered.

a. The TSWV

The tomato spotted wilt of tomato was first noted in 1915 in Victoria, Australia by Brittlebank (1919). Subsequently the disease has been reported in Europe, South America, North America, Africa and Asia (Best, 1968; Sakimura, 1962).

Chemically, the TSWV is characterized as an RNA virus (Best and Symons, 1963) containing 19% lipid and 7% carbohydrate with high lysine and histidine contents (Best and Katekar, 1964). Its physical properties include: a low thermal inactivation temperature of 46 $\pm$ 1 C with a half-life of 20 minutes at 35 C (Best, 1964 a); *in vitro* life of less than 24 hours in extracted plant sap or buffer solution at pH 7 at room temperature. The *in vitro* life can be extended beyond 24 hours by adding a reductant such as cysteine, sodium sulfite or thioglycollate to a concentration of 0.01 M at pH 7 (Bald and Samuel, 1931, 1934). The virus was rapidly inactivated below pH 6 (Best, 1966) and by oxidants which induced a redox potential (Eh) of + 0.2 volt or more in a virus solution

buffered at pH 7, the optimum pH value for its infectivity (Best and Samuel, 1936).

The symptoms of TSWV varied with different hosts. Furthermore, on the same host, symptoms varied with the age and level of nutrition of the plant, light, and temperature (Best, 1968). Most variations were due to differences in the proportion of the strain present (Norris, 1941). The existence of strains has been reported by Norris (1941, 1946) Best and Gallus (1953), Finlay (1952) and recently by Abu Bakar (1974).

According to Best (1968), "symptomatology (of the TSWV) covers the range through hypersensitivity, spreading necrotic disc lesions (primary and systemic), necrotic ring spotting, non-necrotic ring spotting, vein or net chlorosis, non-necrotic vein clearing, yellowing and chlorotic mottling".

In 1968, Best reported that the host range of TSWV includes 166 species of plants from 34 families but recently Abu Bakar (1974) estimated 270 species in 6 monocotyledonous and 41 dicotuledonous families. Some of the plants susceptible to TSWV are: crops such as tobacco (Nicotiana tabacum L.), potato (Solanum tuberosum L.), eggplant (S. melongena L.), pepper (Capsicum annum L.), peanut (Arachis hypogaea L.), snap beans (Phaseolus vulgaris L.), lettuce (Lactuca sative L.), pineapple (Ananas comosus (L.) Merr.) and papaya (Carica papaya L.); ornamentals such as calla lily (Zandeschia aethiopica (L.) Spreng.), Gladiolus spp, dahlia (Dahlia variabilis Desf.), and Zinnia spp; among the common weeds are Amaranthus spp, Emilia javanica, Crepis spp, Sonchus oleraceus L. and Bidens pilosa L.

b. Transmission by Thrips

Under natural conditions, the only known means by which TSWV is transmitted is by members of the Thripidae (Sakimura, 1962). Thrips tabaci (Lind.) was the first vector shown to transmit TSWV to healthy plants by Pittman in 1927. Sakimura (1962) reported four species which have proved to be vectors of TSWV, namely, T. tabaci (Lind.), Frankleniella schultzei (Trybom), F. fusca (Hinds) and F. occidentalis (Pergande).

Adult thrips do not acquire the virus (Bald and Samuel, 1931; Linford, 1932; Smith, 1932; Sakimura, 1960). Acquisition of the virus occurs only during the larval stage (Sakimura, 1962). Limited data on the acquisition threshold showed a minimum feeding time of 30 minutes with T. tabaci in Russia (Razvyazkina, as cited by Sakimura, 1962). The inoculation threshold (Razvyazkina, as cited by Sakimura, 1962) ranged from 5 to 15 minutes and an increase in percentage of infection was observed as feeding time increased (Sakimura, 1960). The latent (incubation) period ranged from 5 to 10 days for the four species of vectors (Smith, 1932; Linford, 1932; Bald and Samuel, 1931; Bailey, 1935). The retention period varied from a short period to the entire life of the insect (Sakimura, 1962). There was little difference in the transmission efficiency among the different vector species (Sakimura, 1962).

According to Sakimura (1962), T. tabaci is distributed throughout the world. This highly polyphagous species parallels the disease in geographical distribution and is considered the major vector for the field transmission of the virus. All Frankliniella species are

regional. These species are also polyphagous but are believed to be minor vectors of the virus.

c. Mechanical Transmission

Samuel and Bald (1933) showed that TSWV can be mechanically transmitted to various hosts. According to Sakimura (1962) all the strains of TSWV were readily juice transmissible. Some difficulties in transmission were primarily due to a short retention period of a high titer of the virus *in vivo* and the rapid oxidation of the virus *in vitro*. Best (1968) stated that the optimum conditions for mechanical inoculation are the use of a buffered medium containing a reductant at pH 7, the use of an abrasive such as celite, and conditioning plants in a period of darkness before inoculation. Best (1936) also found lesions appeared rapidly at 20 C than at 15 C.

d. Control of TSWV

Attempts to control TSWV have been made mostly on tomatoes. Measures included growing of resistant crop varieties (Kikuta et al., 1945, Frazier et al., 1950, Holmes, 1948), spraying insecticides to kill the vector (Moore, 1941, Gardner and Michelbacher, 1946), control of carrier-host plants (Bald, 1937) and growing the crop under conditions unfavorable to the insect vector (Best, 1968). Among these, no one method of control has been demonstrated to be universally applicable although some success has been reported in each case. Because of the variable nature of the virus and its complex virus-vector relationship, a successful method of control of the TSWV in one area have not been attained in another (Best, 1968).

Emilia javanica (Burm.) DC as a TSWV Host

In Hawaii, E. javanica which has been previously referred to as E. sagittata or E. sonchifolia, has been established to be a favored host of the TSWV and the virus vector, T. tabaci (Linford, 1931, 1932; Sakimura, 1932, 1938; Carter, 1939). E. javanica is not only highly susceptible to virus infection but the weed can persist in diseased condition thus maintaining a colony of infective thrips for several months (Linford, 1932). E. javanica has also been shown to be satisfactory as a rearing, source, and test plant for various species of Thrips (Sakimura, 1961).

In England, Hollings and Stone (1963) stated that few plants in the Compositae have been shown to be suitable as virus test plants as contrasted to the many species in the Solanaceae and Chenopodiaceae. They found that E. javanica (= E. sagittata) was a satisfactory host plant from which viruses were readily transferred to other plants, or from which purified virus preparations were obtained. They explained that many Compositae contain tannins, phenol oxidase systems, later, or other substances which interfere with the transfer of viruses from them to other plants. Satisfactory purification of virus from them was also difficult. They also stated that Emilia contains few or none of these substances, thus viruses can readily inoculate a wide range of other plants. Using a sap inoculation method, Hollings and Stone (1963) were able to infect E. javanica with 25 viruses out of 44 viruses inoculated.

A review of the literature has shown that E. javanica can be an important reservoir of both viruses and the insect vectors. The importance of Emilia in the disease cycle of a plant virus disease

transmitted by an insect indicate that weed control would probably be as effective as chemical control of the vectors (Daffus, 1971). Effective control of virus diseases by weed control have been demonstrated in some instances (Stubbs, Guy & Stubbs, 1963; Wellman, 1937, Piemiesel, 1954; Piemiesel and Chamberlain, 1963). Broadbent (1964) stated that "before measures to control a disease can be formulated and applied it is usually necessary to know the identity of the virus causing it and of the vectors spreading the virus as well as the sources of both virus and vectors. If this knowledge is not available attempts to control can be very 'hit or miss'."

MATERIALS AND METHODS

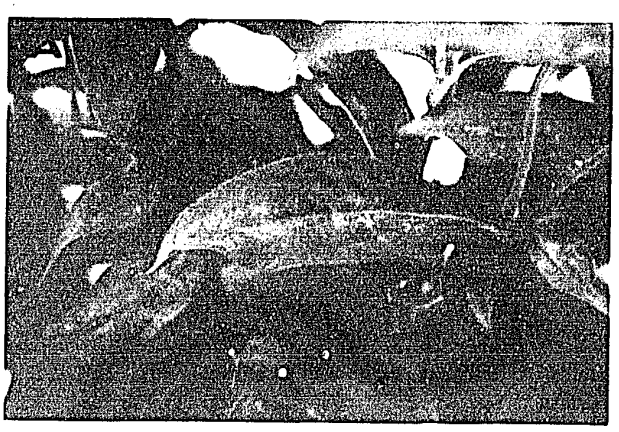
Sequential virus transmission experiments were conducted in the glasshouse from August 1974 to June 1975.

Source of inoculum and method of transmission

Initial inoculum of the tomato spotted wilt virus was obtained from an infected ornamental, Gomphrena globosa L. (Figure 2.1A) maintained as a TSWV source by the department of Plant Pathology, University of Hawaii. The plant sap inoculation method of virus transmission was used.

The inoculum was prepared by grinding the infected leaf tissue in a mortar and pestle with pre-chilled phosphate buffer at pH 7.0 with 0.1% Na_2SO_3 (W/V) as a reducing agent. The concentration of the tissue to buffer diluent was about 1:10 (W/V). The leaves for inoculation were evenly dusted with 400 mesh carborundum powder. The inoculum was gently rubbed on the leaf surface using a cotton swab applicator and later

Figure 2.1. (A) Initial TSWV source, Gomphrena globosa. (B) Healthy Emilia (left) and TSWV-infected Emilia (right) showing systemic symptoms.




B

rinsed with distilled water after inoculation.

Each time an inoculation was done, a freshly prepared inoculum was used. In all cases, the first two recently expanded leaves of the test plants were inoculated. Test plants were inoculated late in the afternoon or at night when temperatures were cooler. Night temperature inside the glasshouse was between 21 and 24 C while day temperature fluctuated between 25 and 29 C.

Establishment and care of test plants

The Orange (29A), Red (39A) and Purple (77B) types of E. javanica and E. sonchifolia were selected as the representative test plants among the Emilias found in Hawaii. The alphanumeric designations refer to specific colors in the 1966 colour chart of the Royal Horticultural Society of London. Tomato 'Tropic' and lettuce 'Anuenue' were used as the crop test plants.

Seeds of the test plants were first germinated on Petri-dishes. Seedlings were transplanted to 1-liter plastic pots containing autoclaved soil. Seedlings were inoculated at 3 to 6 weeks after transplanting unless otherwise specified.

The observations recorded were the number of days from inoculation to the time primary and/or secondary symptoms appeared. The dates of mortality of the infected Emilia species and types were recorded. Symptoms were described and the severity of infection was noted.

Depending on the nature of the experiments, one or two types of control plants were used. The type I control plants were dusted with carborundum but rubbed with distilled water. The type I control

indicated whether the symptoms observed were caused by mechanical injury or by the virus. The type II control plants were Emilia species inoculated after all treatment inoculations to crop plants were concluded. This control was necessary to indicate infectivity of inoculum.

Experiment 1. Transmission of TSWV from Comphrena globosa to Emilia species.

Seedlings (31-days old) of the Emilia species and types were inoculated with TSWV from an infected plant of Gomphrena globosa (Figure 2.1A). Two Emilia seedlings for each Emilia species or type inoculated with TSWV were used as type I control plants.

Experiment 2. Transmission of TSWV from Emilia to Emilia plants at varying ages.

Three types of E. javanica i.e., Orange, Red and Purple and E. sonchifolia varying in ages from 24 to 52 days old were inoculated with TSWV from infected plants from Experiment I.

Experiment 3a and 3b. Transmission of TSWV from Emilia to lettuce.

Two sets of experiments were conducted with lettuce 'Anuenue' as test plants and TSWV-infected Emilia species and types as source of inoculum. In Experiment 3a, 21-day old lettuce plants were inoculated from each source of TSWV-infected Emilia inoculum in Experiment 2. In Experiment 3b, 23 to 33 day old plants were inoculated with TSWV-infected Emilia plants. Type I and type II control plants were included. Two plants of lettuce from each source of Emilia inoculum were used as type I control plants.

Experiment 4a and 4b. Transmission of TSWV from Emilia to tomato.

Two sets of experiments were conducted using tomato 'Tropic' as the test crop and TSWV-infected Emilia as the virus source of inoculum. Two types of control plants similar to Experiment 3a and 3b were used.

Experiment 5a and 5b. Transmission of TSWV from tomato and lettuce to Emilia.

In Experiment 5a, E. javanica red type seedlings were used as the test plants. Infected tomato 'Tropic' in Experiment 4a was used as the source of the virus inoculum. Four 25-day old E. javanica type Red plants were inoculated from each tomato source of inoculum. Two E. javanica type Red plants were also provided as type I control plants for each tomato inoculum source.

In Experiment 5b, tomato 'Tropic' infected by E. javanica Orange and another tomato plant infected by E. sonchifolia, and lettuce infected by E. javanica type Orange were used as the inoculum source.

RESULTS AND DISCUSSION

Experiment 1. Transmission of TSWV from Gomphrena globosa to Emilia.

All plants of the Emilia species and types were successfully infected with TSWV by sap inoculations from infected Gomphrena globosa (Table 2.1). Primary or local lesion symptoms on the leaves of all the inoculated plants appeared at 4 days after inoculation. Secondary or systemic symptoms showed up on other parts of the plants 1 to 4 days later than the primary symptoms (Figure 2.1B).

Table 2.1. Infection of different *Emilia* species and types after sap inoculation with tomato spotted wilt virus (TSWV) from infected *Gomphrena globosa*.

Inoculated *Emilia*	Total number of plants		Number of days from inoculation to α/	
	Inoculated	Infected	1^{o} symptoms	2^{o} symptoms
E. javanica				
Red	2	2	4	5-6
Purple	2	2	4	5-8
E. sonchifolia	3	3	4	5-6
Control β/	8	0	-	-

α/ 1^{o} - appearance of primary symptoms; 2^{o} - appearance of systemic or secondary symptoms.

β/ Control plants were dusted with carborundum and rubbed with distilled water. Two *Emilia* plants for each *Emilia* species or type inoculated with TSWV.

a. Symptoms on E. javanica

Primary or local lesion symptoms appeared as faint chlorotic rings which developed into necrotic etchings (Figure 2.2A). About one to six ringspots developed on an inoculated leaf. Secondary or systemic symptoms occurred initially as vein clearing and necrotic etchings on the upper leaves. Later, numerous etched chlorotic ringspots or mottling also appeared (Figure 2.2B). The infected leaf remained alive for an indefinite period even when the entire leaf showed the characteristic symptoms. Flower heads of infected plants developed necrotic spots on the involucre or on the peduncle just below the flower head, causing the entire head to dry. In other cases, the flower heads that did not dehisce contained unfilled achenes. The infected plants produced some seemingly healthy flowers that contained viable seeds.

b. Symptoms on E. sonchifolia

Primary symptoms were similar to those produced on E. javanica types (Figure 2.3A) but the area around the ringspot dried and enlarged until the entire leaf dried prematurely within 2 to 3 weeks.

Systemic symptoms also appeared on the upper leaves as scattered spots in various patterns and forms (Figure 2.3B). In severe cases, the infected branch dried and in other cases ringspots first appeared on a leaf before the whole branch dried. In most cases death of the entire plant resulted within 6 weeks after inoculation (Figure 2.3C).

These results demonstrated that the Red and Purple types of E. javanica and E. sonchifolia were readily infected with TSWV from Gomphrena globosa. However, E. sonchifolia showed a lethal reaction to

TSWV infection while the different types of E. javanica seem to have tolerated infection.

Experiment 2. Transmission of TSWV from Emilia to Emilia at varying ages

The results of inoculating the three types of E. javanica and E. sonchifolia at varying ages with TSWV-infected E. javanica type Red and with the Purple type are shown in Tables 2.2 and 2.3, respectively. All the Emilias at all growth stages developed systemic symptoms (Tables 2.2 and 2.3). The only striking difference with the inoculated plants at various ages was the time of appearance and development of the symptoms. Systemic symptoms appeared earlier when plants were inoculated at 24 days than at 36 to 52 days. The symptoms of these infected plants varied as those in Experiment 1 (Figures 2.2B, 2.2C and 2.3D). E. sonchifolia also displayed severe reactions to TSWV infections which resulted in the death of most of the infected plants, or the branches with symptoms, within 5 to 6 weeks after inoculation (Table 2.4). After 9 months, 82 percent of the infected E. sonchifolia plants died while the E. javanica types showed only a 7 to 21 percent mortality.

Experiment 3a and 3b. Transmission of TSWV from Emilia to lettuce.

Except for E. javanica type Red, all the other sources of TSWV inoculum produced primary or systemic symptoms on lettuce (Table 2.5). Primary symptoms on inoculated leaves occurred at 8 days after inoculation on all the lettuce plants. Systemic symptoms appeared 8 days later.

The primary lesion first appeared as a circular blotchy necrotic spot which enlarged to about 6 to 8 mm in diameter. Usually one to

Figure 2.2. Symptoms of TSWV on E. javanica: (A) primary lesion; secondary or systemic symptoms appearing as (B) chlorotic ringspots or mottling, (C) zig-zag necrotic etchings, (D) and a combination of chlorotic ringspots, vein clearing, and zig-zag patterns.

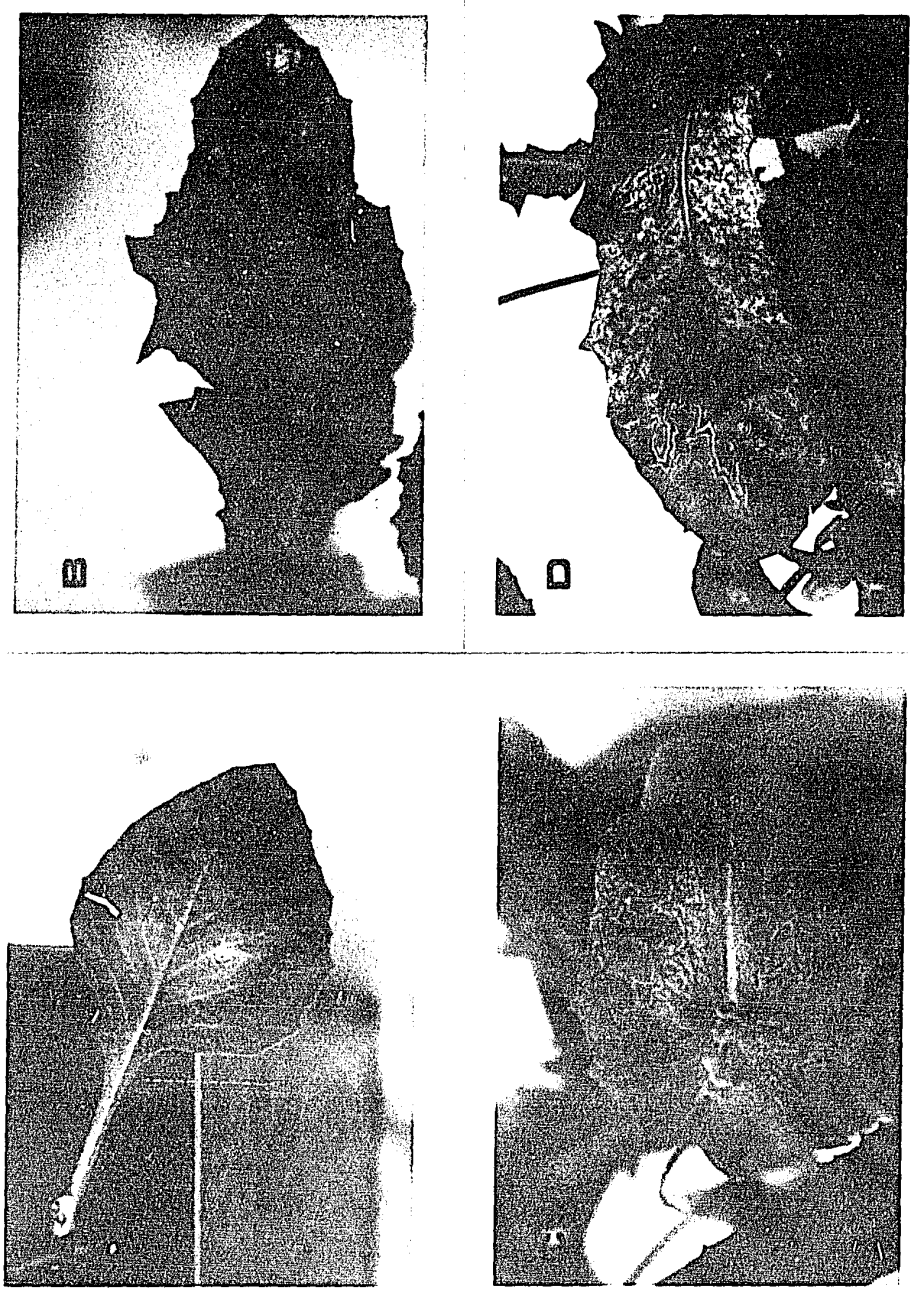
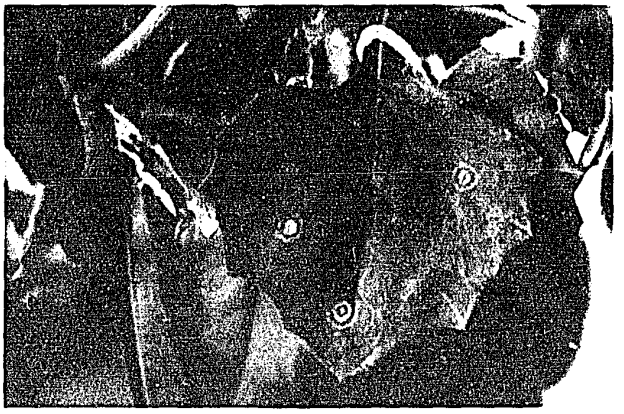


Figure 2.3. Symptoms of TSWV on E. sonchifolia: (A) primary symptoms; (B) secondary or systemic symptoms appearing as necrotic ringspots or zig-zag patterns; (C) drying TSWV-infected plants.



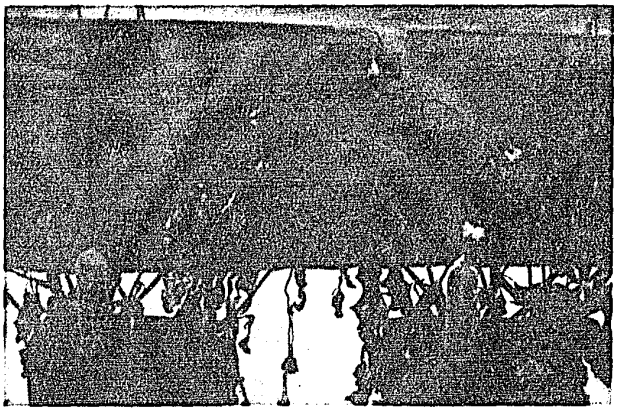


Table 2.2. Infection of different *Emilia* species and types at 36 and 44 days old after sap inoculation with TSWV from infected *E. javanica* type Red.

Inoculated *Emilia*	Age of *Emilia* plants (days)		Total number of plants
	36 α/	44 β/	
	No. of infected plants/no. of inoculated plants		
E. javanica			
Orange	1/1	2/6	3/7
Red	-	5/6	5/6
Purple	1/1	7/8	8/9
E. sonchifolia	1/1	12/16	13/16

α/ Secondary symptoms appeared from 5 to 11 days after inoculation.

β/ Secondary symptoms appeared from 11 to 16 days after inoculation.

Table 2.3. Infection of different Emilia species and types at varying ages after sap inoculation with TSWV from infected E. javanica type Purple.

Inoculated Emilia	Ages of Emilia plants (days)				Total number of plants
	24 α/	36 β/	47 β/	52 β/	
	(no. of infected plants/no. of inoculated plants)				
E. javanica					
Orange	1/1	6/10	2/3	4/4	13/18
Red	1/1	3/6	2/3	1/1	7/11
Purple	2/2	2/4	2/3	-	6/9
E. sonchifolia	2/2	1/2	2/5	1/1	6/10

α/ Systemic symptoms appeared within 11 days after inoculation.

β/ Systemic symptoms appeared from 9 days to 6 weeks after inoculation.

Table 2.4. Number of surviving plants of *Emilia* species and types infected with TSWV 9 months after inoculation.

Emilia species and types	Number of infected plants	Number of surviving plants at			% mortality
		6 weeks	6 months	9 months	
E. javanica					
Orange	13	12	11	11	15
Red	14	14	14	13	7
Purple	24	23	21	19	21
E. sonchifolia	22	13	9	4	82

Table 2.5. Infection of lettuce 'Anuenue' after sap inoculation with TSWV from infected Emilia plants.

Source of inoculum	Number of lettuce plants		Number of days from inoculation to α/	
	Inoculated	Infected	1^{o} symptoms	2^{o} symptoms
E. javanica				
Orange	2	1	8	16
Red	2	0	-	-
Purple	2	1	8	16
E. sonchifolia	2	1	8	16
Control β/	8	0	-	-

α/ 1^{o} - appearance of primary symptoms
2^{o} - appearance of systemic or secondary symptoms

β/ Control plants of lettuce were dusted with carborundum and rubbed with distilled water. Two lettuce plants for each source of TSWV inoculum.

three circular necrotic spots were produced in each inoculated leaf (Figure 2-4A).

Systemic symptoms appeared on the upper younger leaves as numerous 1- to 3-mm circular, brownish spots; more often, the spots were water-soaked which gradually enlarged and turned into parchment-like areas (Figure 2.4B). Other spots enlarged and encompassed the entire leaf which eventually caused the death of the plant.

Experiment 3b was conducted using more lettuce test plants. All the infected Emilia species and types produced systemic infection in the lettuce plants (Table 2.6). However, it was observed that even when primary symptoms appeared, they did not result in systemic development of the disease. Since only the plants that showed systemic symptoms were considered as infected, a higher percentage of infection would have been obtained if all the plants that produced primary symptoms also developed systemic symptoms.

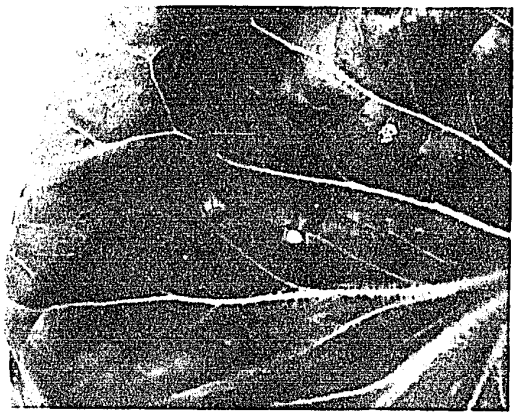
Experiment 4a and 4b. Transmission of TSWV from Emilia to tomato.

All sources of inoculum produced systemic infection in tomato plants (Table 2.7). The type II control plants indicated that the inocula were infective.

No distinct primary symptoms were observed. Systemic symptoms did not appear until almost 6 weeks after inoculation. The symptoms first appeared as irregular chlorotic spots which later became necrotic. The necrotic areas were bronze colored (Figure 2.5A) which turned dark (Figure 2.5B). Infected leaves later dried. Younger leaves were smaller in size and crinkled. In some instances the growing points dried. In a few cases, a faint ringspot outline appeared.

Figure 2.4. Symptoms of TSWV on lettuce 'Anuenue': (A) primary symptoms: (B) systemic symptoms showing brownigh, water-soaked spots and parchment-like areas.

A



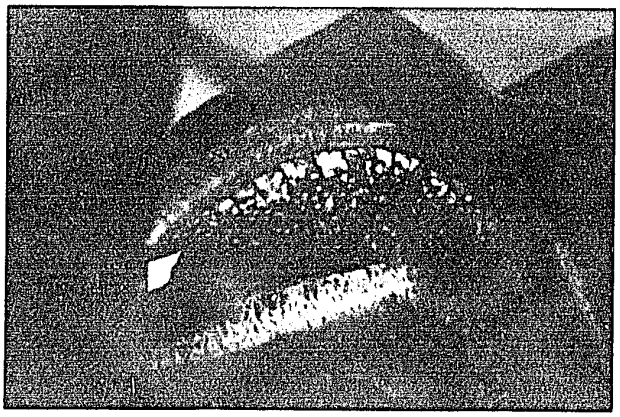


Table 2.6. Infection of lettuce 'Anuenue' after sap inoculation with TSWV from different *Emilia* species and types.

Source of inoculum	Inoculated Plants	
	Lettuce α/	*E. javanica* type red β/
	(no. of infected plants/no. of inoculated plants)	
E. javanica		
Orange	7/11	7/7
Red	3/10	6/6
Purple	4/11	6/6
E. sonchifolia	2/6	3/4
Control γ/	0/8	-

α/ Systemic symptoms appeared from 7 to 26 days after inoculation (DAI).

β/ Control plants to indicate whether inoculum is infective. Systemic symptoms appeared within 8 DAI.

γ/ Control plants of lettuce dusted with carborundum and rubbed with distilled water. Two plants for each *Emilia* source of inoculum.

Table 2.7. Infection of tomato after sap inoculations with TSWV from infected Emilia species and types.

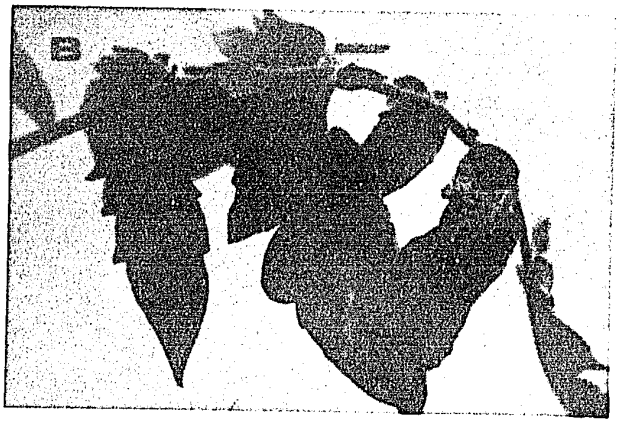
Source of inoculum	Inoculated Plants			
	Tomato 'Tropic' α/	Emilia species and types β/		
		E. javanica		E. sonchifolia
		Orange	Red	
	(no. of infected plants/no. of inoculated plants)			
E. javanica				
Orange	1/4	-	2/2	-
Red	3/4	-	1/1	1/1
Purple	1/4	-	1/1	1/1
E. sonchifolia	3/4	1/4	-	1/1
Control γ/	0/8			

α/ Systemic symptoms appeared from 4 to 6 weeks after inoculation.

β/ Control plants to indicate whether inoculum is infective. Systemic symptoms appeared within 2 weeks after inoculation.

γ/ Control plants of tomato were dusted with carborundum and rubbed with distilled water. Two tomato plants for each source of TSWV inoculum.

Figure 2.5. Systemic symptoms of TSWV on tomato 'Tropic': (A) bronze colored, irregular necrotic spots (B) or dark gray irregular spots on infected leaves.


B

Although relatively more tomato plants were inoculated in Experiment 4B, there was even a lower incidence of infection than in Experiment 4a (Table 2.8).

Experiment 5a and 5b. Transmission of TSWV from tomato back to Emilia.

Virus from TSWV-infected tomatoes 'Tropic' was transmitted back to E. javanica type Red (Table 2.9). Virus from all the infected tomatoes produced the characteristic ringspot TSWV symptoms on the Red type of E. javanica except for the tomato infected with TSWV from E. javanica type Orange. The high percentage of infection in Emilia demonstrate that the plants are readily infected with TSWV.

Experiment 5b was conducted to determine if the virus from TSWV-infected tomato and lettuce could be re-inoculated back to the different Emilia species and types. The results demonstrated clearly that the TSWV in other crop plants, originally from the Emilias were readily re-inoculated back to all of the Emilias tested (Table 2.10).

These results clearly demonstrate that all the Emilia species and the types tested i.e., Orange, Red and Purple types of E. javanica and E. sonchifolia were readily infected with TSWV from other host plants. This was shown by the high percentage of disease incidence, rapid development of systemic symptoms, and ease of infection from other crop plants like lettuce and tomato. The conclusion of Hollings and Stone (1963) that E. javanica (= E. sagittata) is a satisfactory host plant from which viruses were readily transferred to other plants was borne out by these experiments. Except for E. sonchifolia which showed a lethal reaction to TSWV infection, all the other color types of E. javanica, the Orange, Red and Purple were readily infected and tolerated

Table 2.8. Infection of tomato after sap inoculations with TSWV from different infected *Emilia* species and types.

Source of inoculum	Inoculated Plants	
	Tomato "Tropic' α/	*E. javanica* type Red β/
	(no. of infected plants/no. of inoculated plants)	
E. javanica		
Orange	4/6	7/7
Red	0/6	6/6
Purple	0/6	6/6
E. sonchifolia	1/6	3/4
Control γ/	0/8	-

α/ Systemic symptoms appeared from 19 to 38 days after inoculation (DAI)

β/ Control plants to indicate whether inoculum is infective. Systemic symptoms appeared within 8 DAI.

γ/ Control plants of tomato dusted with carborum and rubbed with distilled water. Two plants for each *Emilia* source of inoculum.

Table 2.9. Infection of E. javanica type Red after inoculation of TSWV from tomato 'Tropic'.

Source of inoculum α/	Inoculated E. javanica			
	Total number of Emilia plants		Number of days from inoculation to β/	
	Inoculated	Infected	1° symptoms	2° symptoms
Tomato/ E. javanica Orange	4	0	-	-
Tomato/ E. javanica Red	4	4	6	13
Tomato/ E. javanica Purple	4	4	6	8
Tomato/ E. sonchifolia	4	4	6	8
Control γ/	8	0	-	-

α/ Denominator indicates the source of TSWV of the tomato.

β/ 1° - appearance of primary symptoms
2° - appearance of secondary or systemic symptoms

γ/ Control plant of Red type of E. javanica dusted with carborundum and rubbed with distilled water. Two Emilia plants for each source of TSWV inoculum.

Table 2.10. Infection of different types of E. javanica and E. sonchifolia after sap inoculation with TSWV from infected tomato and lettuce.

Source of inoculum α/	Inoculated Emilia β/			
	E. javanica			E. sonchifolia
	Orange	Red	Purple	
	(no. of infected plants/no. of inoculated plants)			
Tomato 'Tropic'/ E. javanica Orange type	2/2	2/2	2/2	4/6
Tomato 'Tropic'/ E. sonchifolia	-	-	-	2/4
Lettuce 'Anuenue'/ E. javanica Orange type	2/2	2/2	2/2	2/2

α/ Denominator indicates the source of TSWV of the tomato.

β/ Systemic symptoms appeared within 17 days after inoculation.

the TSWV infection. This confirms the observation of Linford (1932) that E. javanica (= E. sagittata) lives long in the diseased condition. This also suggests that E. javanica poses a greater potential danger than E. sonchifolia as the reservoir of TSWV.

Results obtained in this study seem to be contrary to Abu Bakar's (1974) opinion that E. javanica would not tolerate some of the more virulent local strains of TSWV. However, Abu Bakar based his hypothesis on pure strains while the TSWV used in this study may have been a mixture of different strains. It is possible, therefore, that "cross protection" may have occurred since both mild and severe strains of TSWV, based on symptomatology, were observed. Best (1954) found that tomato plants inoculated with both mild and severe strains of TSWV produced intermediate symptoms on the plants 40 days later.

SUMMARY AND CONCLUSIONS

Sequential virus transmission experiments by a sap inoculation method were conducted under glasshouse conditions to determine if differences exist among Emilia species and types in harboring and transmitting tomato spotted wilt virus (TSWV) to some vegetable crops.

All the Emilia javanica types (Orange, Red and Purple) and E. sonchifolia were infected with the TSWV when inoculated with sap from infected Emilia plants. There was a differential response to TSWV infection between the two Emilia species. E. sonchifolia showed a lethal reaction upon infection with TSWV whereas the different types of E. javanica tolerated infection. This suggests that E. javanica poses a greater potential danger as the reservoir of TSWV than E. sonchifolia.

The TSWV of the infected Emilia species and types were transmitted to tomato 'Tropic' and lettuce 'Anuenue'. Furthermore, TSWV from these tomato and lettuce plants reinfected the Emilias. These results, in addition to the high percentage of virus incidence and rapid development of systemic symptoms, clearly demonstrate that the Emilia species and types serve as favorable virus host plants which can readily transfer TSWV to other host plants.

CHAPTER III

EMILIA AS A CROP COMPETITOR

INTRODUCTION

Emilia javanica (Burm.) Rob. is the most widespread among the four species reported by Fosberg (1948) present in the Hawaiian Islands. This species has been previously referred to in some literature as E. sonchifolia (L.) DC (St. John and Hosaka, 1932; Carter, 1939; Crozier and Romanowski, 1969; Romanowski and Nakagawa, 1969; Cardenas, Reyes and Doll, 1972) or E. sagittata (Vahl) DC (Linford, 1931, 1932; Hollings and Stone, 1963; Sakimura, 1932). Several flower color types of the species can be found in the Islands and they can be grouped into Red, Orange and Purple types. Variations of these colors such as red-orange are found in E. javanica.

The importance of E. javanica as carrier of the TSWV was fully discussed in Chapter II.

In Hawaii, E. javanica has been reported infesting vegetable farms (Romanowski and Nakagawa, 1969), pineapple fields (St. John and Hosaka, 1932), sugar cane (Saccharum officinarum L.) (Anonymous, 1962), and banana (Musa sp) and papaya (Carica papaya L.) orchards (Crozier and Romanowski, 1969). It is also a common weed along roadsides, moist places, around buildings and in home gardens. It is reported to be found in the tropics of Latin America and the Caribbean (Cardenas, 1972), India (Hooker, 1882), tropical Africa (Oliver, 1877), Philippines (Robinson, 1908), Japan (Makino, 1948), and Bermuda (Britton, 1918). This weed has not been generally considered as a serious crop

competitor. However, it has been observed that E. javanica can become established in thick stands when left uncontrolled.

The weed has also been reported to be tolerant to pre- and post-emergence herbicides (Chapter I). It is therefore possible that it may become the predominant weed species in a given area unless effective control measures are used to keep the weed in check.

Thus far, there has been no published work on the effects of Emilia competition on any crop. Therefore, the objective of this study was to evaluate the effects of specific densities of Emilia on the growth and yield of four vegetable crops.

REVIEW OF LITERATURE

Brief discussions on the competition between crops and weeds have been included in reviews on the competitive relationships among grassland plants (Donald, 1963; Risser, 1961) and among crop plants (Donald, 1963). The textbook of Crafts and Robbins (1962) and the report of the National Research Council (1968) provide an excellent introduction to the study of competition between crops and weeds.

Nature of Crop-Weed Competition

Most studies have shown that crops and weeds generally compete for light, nutrients and moisture. Other than these factors, crops and weeds may also influence each other by metabolic products which are secreted or remain in the soil as residues of decaying plant material (Retig, Holm, and Stuckmeyer, 1972).

Competitive interaction

Donald (1958) stated that "competition for light, or for any single factor, is not a simple effect but has at least two components which themselves interact. For example, a plant heavily shaded by its neighbor has reduced photosynthetic activity. This leads to reduced top and root growth; the latter reduces uptake of water or minerals.

Nieto and Staniforth (1961) studied the interaction between fertility status (level of N application), density of corn population, yield of corn and growth of 2 weedy foxtail species. They found that a marked competition for N was reduced as N level was raised; consequently as the yields of both corn and foxtail rose, the depression in corn yields due

to foxtail competition became less. Corn, because of its greater height, was able to compete for light more readily than the foxtails. As a result, as corn populations increased the foxtails' growth and yields were greatly reduced. Thus the combination of high nitrogen and high density was effective in minimizing the depression of corn yield due to these weeds.

Factors affecting competition between crops and weeds

Various investigators have demonstrated that the competitive relationships between crops and weeds are influenced by:

1. Species and variety of weed (Blackman and Templeman, 1938; Buchanan & Burns, 1971; Weatherspoon and Schweizer, 1970), its density (Buchanan and Burns, 1971; Gruenhagen and Nalewaja, 1969), duration of growth (Buchanan and Burns, 1970; Gruenhagen and Nalewaja, 1960), distribution (Thurlow and Buchanan, 1972), and time of emergence Burnside and Wicks (1967); De Datta, Moomaw and Bantilan, 1969.

2. Crop species (Burnside and Wicks, 1967; Dawson, 1964), varieties (Burnside, 1972; De Datta et al., 1969), and hybrids (Burnside and Wicks, 1972; Staniforth, 1961) and seed rate or spacing (Gruenhagen and Nalewaja, 1969; Weber and Staniforth, 1957).

3. Cultural factors (Bantilan et al., 1974; De Datta et al., 1967) and weed control methods (Bantilan et al., 1974; Triplett and Lytle, 1972).

4. Climatic and edaphic conditions (Buchanan and Burns, 1971; De Datta et al., 1969).

5. Allelopathy (Kommendahl, Kotheimer, Bernadin, 1959; Rovira, 1969).

Crop-weed density competition studies

Crop-density competition studies have used single weed species or a mixture of weed species to measure the effect of weed competition on crop yields. Other competition studies have determined how long weeds must be controlled after planting the crop to attain maximum yields.

The effect on specific weed densities of a few weed species on crop yields have been measured. Full season weed competition of specific weed densities show that: in soybean, morning glory (Ipomoea purpurea (L.) Roth or I. hederacea Jacq.) at 1.6 to 26.3 plants per m of row reduced yields 12 to 44% (Wilson and Cole, 1966); giant foxtail (Setaria faberii (Herrm.) at 148 plants per m of row depressed yield 27% (Knake and Slife, 1965), while smooth pigweed (Amaranthus hybridus L.) at 3.3 plants per m of row reduced yields 25 to 30% (Nave and Wax, 1971); in corn, smooth pigweed at 39.4 plants per m of row reduced yields 36% (Moolani, Knake and Slife, 1964), giant foxtail at 197 plants per m of row decreased yields 13% (Knake and Slife, 1965). In sugar beets, green foxtail (Setaria viridis (L.) Beauv.) and rough pigweed (Amaranthus retroflexus L.) each at 3.28 plants per m of row reduced root yields 24 to 70%, respectively (Brimhall, Chamberlain and Alley, 1965). In peas, white mustard (Brassica hirta Moensch) and foxtail millet (Setaria italica (L.) Beauv.) at 32.3 and 290 plants per sq m, respectively, depressed seed yield 0 to 64% (Nelson and Nyland, 1963). In cotton, at Alabama, sicklepod (Cassia obtusifolia L.) at 1.09 plants per m of row reduced yields from 10 to 23% on Norfolk soil and about 40% on Lucedale soil while tall morning glory (Ipomoea purpurea (L.) Roth) at 1.09 plants per m of row decreased yields 10 to 40% on Norfolk soil and 50 to

75% on the Lucedale soil. In sorghum, yellow foxtail at 13.1 plants per m of row did not affect grain yields.

The weed-free period required to prevent yield losses is 3 weeks after planting for corn (Knake and Slife, 1965), 4 weeks after planting for sorghum (Burnside and Wicks, 1967, 1969), 2 to 4 weeks after emergence for soybeans against sicklepod (Thurlow and Buchanan, 1972) or 6 to 8 weeks after planting against morning glory (Wilson and Cole, 1966), 5 to 7 weeks after planting for field beans (Dawson, 1964), 4-8 weeks after planting for peanuts (Hill and Santelman, 1969), 8 weeks after emergence for cotton (Buchanan & Burns, 1970), 10 to 12 weeks after emergence for sugar beets (Dawson, 1965), and 12 weeks after emergence for onions (Wicks et al., 1973).

These studies on crop-weed density relationships demonstrated that:

1. Different weed species varied in their effects on a given crop.

2. The number of weeds required to induce the same percentage of yield reduction varied among weed species and crops.

3. and suppression of crop or weed species by the other depended on their ability to grow taller and shade out the other plant. In a crop with a mixed-weed infestation, the total amount of dry matter produced by the weeds was usually proportional to the yield reduction in crops (Johnson, 1971; Thurlow and Buchanan, 1972).

MATERIALS AND METHODS

The field experiments were conducted at the Waimanalo Research Station, University of Hawaii, from April 24, 1974 to January 9, 1975.

The soil type is Waialua silty clay. Four vegetable crops varying in growth habits and plant type were used: lettuce (Lactuca sativa L. 'Anuenue'), mustard cabbage (Brassica juncea Czern. & Coss. 'Waianae'), sweet corn (Zea mays L. 'H-68') and transplanted tomato (Lycopersicon esculentum L. '7908' and 'N-52'). The Red type of E. javanica, the most predominant of the color types, was selected as the competitor. Except for lettuce, each crop was tested for two cropping seasons.

Land preparation and weed control

In each cropping season the field was plowed and rotovated to a fine tilth then fumigated with 4.88 kg of methyl bromide per 100 sq m to control weeds, particularly, purple nutsedge. Only pure stands of Emilia were established with each crop. Planting of the weeds and crops was done one week after fumigation in order to avoid injury from methyl bromide.

Method and distance of planting

In the first cropping season (April to September 1974) only mustard cabbage, corn and tomato were tested. Lettuce was not included because the weather was too warm for good growth. Mustard cabbage and corn were direct seeded at 30.5 cm between hills and 91.5 cm between rows. The 5-week old tomato seedlings were transplanted in the field at a planting distance of 91.5 x 91.5 cm.

In the second cropping season (October 1974 to December 1974) lettuce, mustard cabbage and corn were planted at the same planting distance as the first crop. Because of high variability and harvesting difficulties encountered with tomato in the 1st crop, the 2nd tomato

crop was trellised. The second crop of tomato was transplanted at 61 cm between hills and 91.5 cm between rows.

Seeds of red Emilia, harvested a month earlier, were planted at the same time as the crop plants. The Emilia seeds were broadcast as evenly as possible around the crop and lightly raked into the soil. Weed seedlings were thinned to the desired number about 3 to 4 weeks after planting. Weed densities used in the first crop ranged from 1 weed per 0.09 sq m or per crop plant to 16 weeds per 0.09 sq m or per crop plant. In the second crop the lowest weed density used was 5 weeds per 0.09 sq m to as high as 150 weeds per 0.09 sq m.

Fertilization, insect control, and irrigation

Basal applications of 73 kg per ha each of N, P_2O_5 and K_2O were used on lettuce, both crops of mustard cabbage and on the second crop of tomato; while 146 kg per ha each of N, P_2O_5 and K_2O were used on both crops of corn and on the first crop of tomato. All crops were top-dressed with 55 kg per ha N at 5 or 6 weeks after planting depending on the crop. Fertilizers were soil-incorporated on 30.5 cm wide bands centered on the row for lettuce, mustard cabbage and sweet corn. In the transplanted tomato, fertilizer was incorporated around each tomato plant on a 30.5 cm radius in the first crop. On the second crop, it was incorporated on a 61.0 cm wide band centered on the row.

Adequate insect control was provided by spray combinations of malathion [O.O-dimethyl S-(1,2-dicarb ethoxy ethyl) dithiophosphate], diazinon and/or lannate (S-methyl N-[(methyl carbamoyl) oxy] thiocetimidate) once or twice a week.

To insure uniform germination of both weed and crop, the plots were irrigated with a hand-held sprinkler hose for 3 to 4 consecutive days depending on weather conditions. Subsequent irrigations were provided twice weekly as needed by overhead sprinkler.

Experimental design

Each crop was treated as a separate experiment and all experiments were arranged in a randomized complete block design. Each experiment consisted of 4 to 6 weed densities with 4 replications. With the exception of the 1st crop of transplanted tomato which had 5 plants per treatment, each treatment consisted of one row of 10 plants with a border plant at each end of the row and one or two border rows adjacent to the treatment rows.

The following data were collected:

a. lettuce and mustard cabbage

1) plant height of both crop and weed at periodic intervals
2) dry weight of crop at harvest
3) dry weight and stand count of weed at harvest
4) elemental analysis (except for N) of plant tissue of both crop and weed (Emilia/lettuce experiment only) at harvest by X-ray fluorescence quantometer. N was analyzed by the technicon auto analyzer (Kjeldahl).
5) percent shading of the crops at harvest by visual observation. This was done by estimating the percentage of the crop leaf surface that was shaded by the weeds.

b. sweet corn

1) plant height of both crop and weed at periodic intervals

2) stover

3) husked ear weight at harvest

c. transplanted tomato

1) plant height of crop (1st crop only) and weed at final fruit harvest

2) fresh weight of crop (1st crop only)

3) dry weight and stand count of the weeds at harvest

4) fruit weight at weekly intervals and total yields.

Analyses of variance were computed on experimental data. Differences among treatment means were tested with Duncan's Bayes least significant difference for multiple-comparison (Duncan, 1965). Correlation coefficients were computed between crop yield and weed data and equations for predicting these relationships were made.

RESULTS AND DISCUSSION

Lettuce vs Emilia

Lettuce dry matter yield was reduced by 57 percent by Emilia density of five weeds per crop plant (WPCP) (Figure 3.1). At 27 WPCP, dry matter yield of lettuce was reduced by 88 percent. Beyond 27 WPCP, no further significant reductions in lettuce yield resulted. However, at the highest weed density (48 WPCP) it was observed that several lettuce plants died. Plants that survived were 25 percent shorter than the weed-free lettuce plants. Lettuce plants were shaded approximately 35 percent by 5 WPCP and between 11 and 48 WPCP, the lettuce plants were almost completely shaded (Table 3.1) at the time of harvest. Lettuce plants that were almost completely shaded were not of marketable quality.

Figure 3.1. Dry weights of lettuce 'Anuenue' at specific densities of Emilia and the corresponding Emilia dry weights. Points with the same letter on the same curve are not significantly different based on Duncan's Bayes LSD at 5% level.

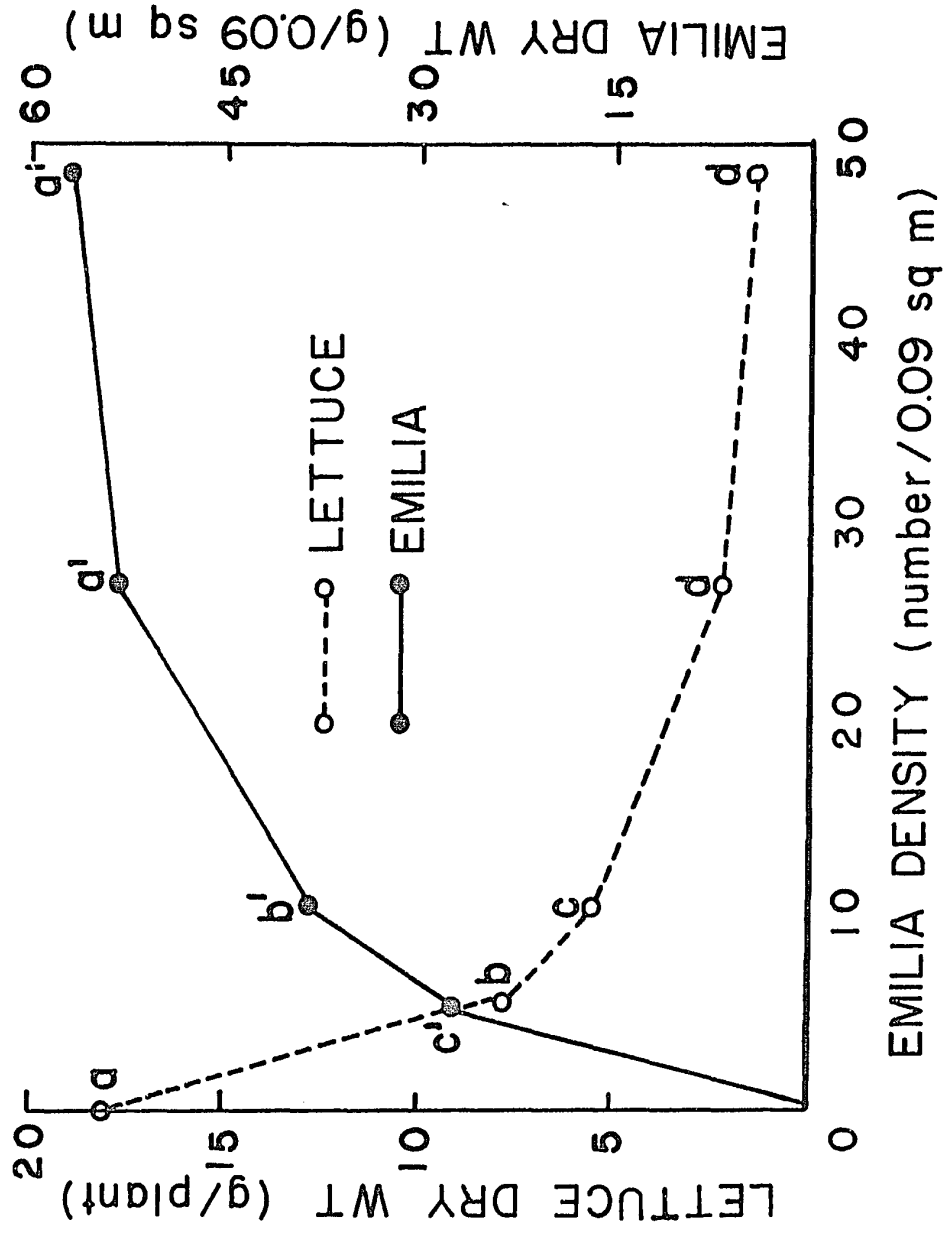

LETTUCE DRY WT (g/plant)
EMILIA DRY WT (g/0.09 sq m)
EMILIA DENSITY (number/0.09 sq m)
LETTUCE
EMILIA
0
5
10
15
20
15
30
45
60
10
20
30
40
50
a
b
c
d
c'
b'
d'
a'
d'
d

Table 3.1. Effect of specific densities of pure stands of E. javanica on the dry matter yields and shading of lettuce 'Anuenue' at harvest.

Crop:weed ratio	% reduction of dry matter	% shading α/
1:0	0	0
1:5	57	35
1:11	70	90
1:27	88	98
1:48	92	92

α/ Estimated by visual observation of the percentage of the crop leaf surface that was shaded by the weeds.

Weed dry weight increased as weed density increased up to 27 weeds per 0.09 sq m or WPCP (Figure 3.1). A further increase in weed density did not result in a significant increase in weed weight. Since Emilia on the plots with 48 WPCP lodged at harvest time, perhaps mutual shading among the Emilia weeds occurred. It is therefore possible that the weeds at densities of 27 and 48 WPCP competed with each other for light.

Figure 3.2 illustrates the growth curves of Emilia and lettuce at crop:weed density ratio of 1:5. The growth rate of both weed and crop were about the same until 4 weeks after planting, at which time Emilia outgrew the lettuce crop. At harvest time light penetration to the crop was estimated visually to have been reduced by about 35 percent. The greater growth rate indicated that Emilia could better utilize light and nutrients than the lettuce crop.

To ascertain whether Emilia competitively affected the nutrient uptake of lettuce, both drop and weed were analyzed for mineral composition. The nitrogen content of lettuce was reduced as the weed density increased (Table 3.2). The content of phosphorus, potassium, calcium, sodium and chlorine in lettuce was higher in the weed-infested lettuce crop particularly at the 27 WPCP than the weed-free plot. Magnesium content, however, was lower in the Emilia infested lettuce than the Emilia-free crop. The silicon content of the crop was not affected by the presence of the weeds. These results indicate that N deficiency was limiting lettuce growth as the weed density increased.

The percentage of N in Emilia differed significantly between the two lowest and two highest WPCP (Table 3.3). The concentration of calcium, magnesium, sulfur and silicon were all higher in weeds grown in

Figure 3.2. Growth curves of lettuce 'Anuenue' and E. javanica type Red at crop:weed density ratio of 1:5.

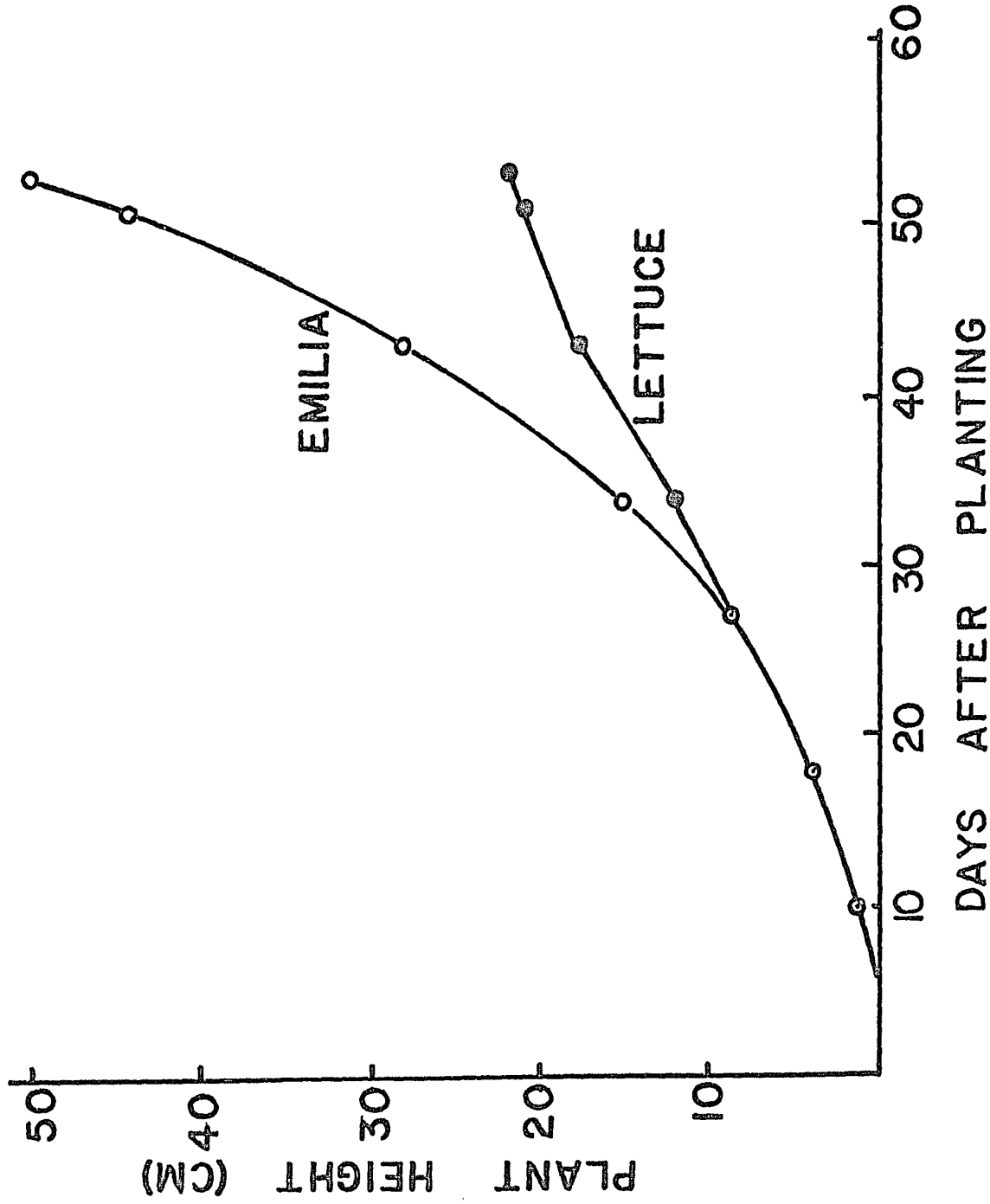

PLANT HEIGHT (CM)
50
40
30
20
10
10
20
30
40
50
60
DAYS AFTER PLANTING
EMILIA
LETTUCE

Table 3.2. Effect of specific densities of E. javanica type Red on the mineral composition of lettuce 'Anuenue' α/.

Crop:Weed ratio	N	P	K	Ca	Mg	S	Na	Cl	Si
				%					
1:0	4.76 a	0.61 b	6.47 d	1.72 b	0.58 a	0.38 b	0.22 b	1.08 b	0.42 a
1:5	4.37 b	0.63 b	7.00 cd	1.76 ab	0.53 b	0.43 b	0.24 b	1.35 a	0.64 a
1:11	4.62 ab	0.73 a	7.68 ab	1.97 ab	0.52 b	0.45 b	0.26 b	1.33 a	0.48 a
1:27	3.98 c	0.71 a	8.12 a	2.10 a	0.50 b	0.54 a	0.28 a	1.37 a	0.62 a
1:48	4.00 c	0.72 a	7.37 b	1.95 ab	0.51 b	0.57 a	0.28 a	1.25 a	0.55 a

α/ Treatment differences are based on Duncan's Bayes lsd. Any two means followed by the same letter are not significantly different at 5% level.

Table 3.3. Mineral composition of pure stands of E. javanica type Red grown at specific densities with lettuce 'Anuenue' α/.

Crop:Weed Ratio	N	P	E	Ca	Mg	S	Na	Cl	Si
				%					
1:5	3.93 a	0.45 a	6.02 a	1.19 b	0.40 c	0.43 b	0.21 a	1.30 a	0.58 c
1:11	3.64 a	0.42 a	5.61 a	1.18 b	0.45 b	0.43 b	0.22 a	1.23 a	0.66 bc
1:27	3.41 b	0.42 a	5.64 a	1.34 a	0.50 a	0.56 a	0.24 a	1.43 a	0.82 a
1:48	3.44 b	0.45 a	5.88 a	1.38 a	0.48 a	0.60 a	0.25 a	1.46 a	0.72 b

α/ Treatment differences are based on Duncan's Bayes lsd. Any two means followed by the same letter are not significantly different at 5% level.

densities exceeding 11 WPCP. In contrast with the composition of the lettuce crop, the phosphorus, potassium, sodium and chlorine concentrations of the weeds did not show any difference with increasing density. It can then be inferred that the lower nitrogen percentages of Emilia at 27 and 48 WPCP densities was a result of nitrogen competition among the weeds. In addition to competition for light, this competition for nitrogen may partly explain why weed dry weights did not increase when weed density increased from 27 to 48 weeds per 0.09 sq m or WPCP. However, the concentration of nitrogen for maximum growth of Emilia and lettuce was not established. Therefore Emilia and lettuce may not have suffered for nitrogen.

The results indicated that Emilia adversely affected the dry matter yields and the growth of lettuce by competition for light and possibly for nitrogen. Lettuce growth and yield decreased as Emilia density increased.

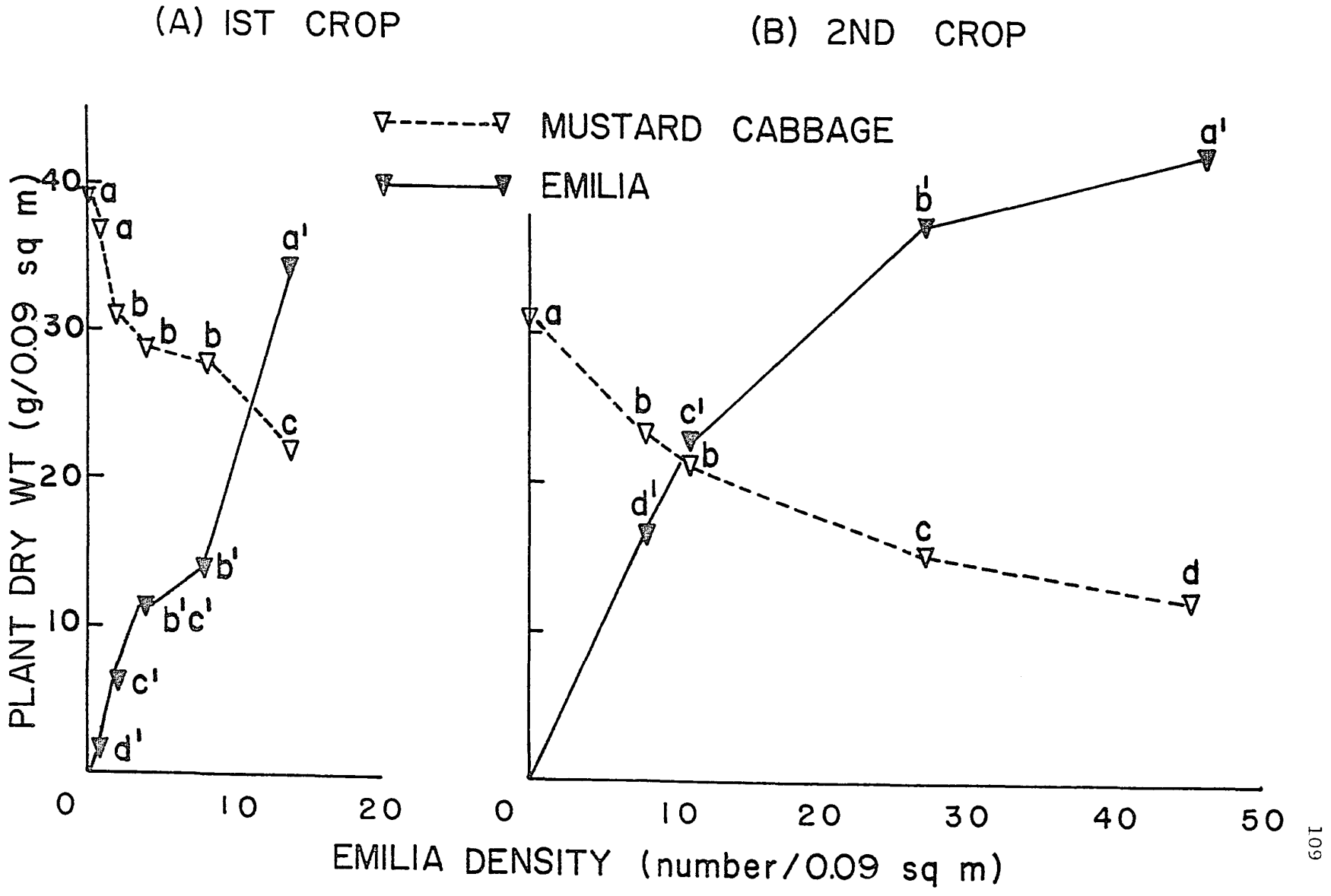
Mustard Cabbage vs Emilia

1st crop

The dry weight of mustard cabbage was decreased as Emilia density increased (Figure 3.3A). At 2 WPCP, cabbage dry weight was reduced by 21 percent over that of the weed-free plot. With 8 WPCP, cabbage dry weight was reduced by 28 percent. Whereas at 14 WPCP, cabbage yield was reduced by 44 percent. Although dry matter production was reduced with increasing weed density, plant height of the crop was not significantly affected.

Successive weed density increments showed a gradual increase in dry

Figure 3.3. Dry weights of mustard cabbage 'Waianae' at specific Emilia densities and corresponding Emilia dry weights, (A) 1st crop (B) and 2nd crop. Points with the same letter on the same curve are not significantly different based on Duncan's Bayes LSD at 5% level.


(A) IST CROP
(B) 2ND CROP
MUSTARD CABBAGE
EMILIA
PLANT DRY WT (g/0.09 sq m)
EMILIA DENSITY (number/0.09 sq m)
0
10
20
30
40
50
a
a
b
b
b
c
a'
b'
b'c'
c'
d'
a
b
c'
b
d'
c
d
b'
a'

weight per unit of area (Figure 3.3A). Figure 3.3A shows that cabbage yields might still be reduced by increasing weed density since Emilia dry weight continued to increase at the highest weed density used (14 WPCP) while cabbage dry weight continued to decline sharply.

2nd crop

The dry weight of mustard cabbage was significantly reduced with each increase in Emilia density (Figure 3.3B). Eight WPCP caused a 23 percent reduction in mustard cabbage dry weight, while the highest weed density (45 WPCP) reduced crop yields by 61 percent over that of the weed-free mustard cabbage. Although there was a rather steep yield decline from 8 to 27 WPCP, a further increase in weed density up to 45 WPCP did not result in a proportionate crop yield loss. Cabbage plants grew significantly taller in plots with high densities of Emilia at 37 days after planting (DAP) (Table 3.4). At harvest time this difference in cabbage plant height disappeared. Shading of the cabbage plants by the Emilia at harvest increased from about 20 percent up to about 74 percent as weed density increased (Table 3.4). Although more shading of the cabbage would be expected at the highest weed densities, some of these weeds lodged and this resulted in low estimated shade readings.

Weed dry weight was significantly increased with each increment of weed density (Figure 3.3B). There was a linear increase up to 11 WPCP but between 27 WPCP and 47 WPCP the curve tended to level off. Like the mustard cabbage, Emilia became significantly taller with each weed increment up to 27 WPCP (Table 3.4). There was no significant difference in plant height between 27 and 45 WPCP. At harvest time signifi-

Table 3.4. Plant heights of both mustard cabbage 'Waianae' and *Emilia* and shading of crop when grown at different crop:weed ratio (2nd crop) α/.

Crop:Weed ratio	Plant height (cm)				Shading of crop at harvest % γ/
	at 37 DAP β/		at harvest		
	M. cabbage	*Emilia*	M. cabbage	*Emilia*	
1:0	18 c		29 a		-
1:8	21 b	19 c	33 a	47 a	20
1:11	21 b	23 b	33 a	50 a	48
1:27	26 a	30 a	32 a	53 a	74
1:45	27 a	32 a	31 a	52 a	72 δ/

α/ Treatment differences are based on Duncan's Bayes lsd. Any two means followed by the same letter are not significantly different at the 5% level.

β/ DAP - days after planting

γ/ Visual observation based on leaf area of crop shaded by *Emilia*.

δ/ *Emilia* weeds lodged in some plots.

cant differences in plant heights disappeared.

These data indicate that Emilia also reduced the yields of mustard cabbage. The greatest yield reduction of 61 percent was observed at 45 WPCP. Increasing weed density did not cause any stunting of the crop but instead increased crop height before harvest time. This might indicate that light was a limiting factor for both crop and weeds when the crop was grown under the high weed densities.

Sweet Corn vs Emilia

1st crop

Table 3.5 indicates that pure stands of E. javanica from one to 16 WPCP did not significantly affect the stover, husked ear yields, or plant height of sweet corn 'H-68'. The dry weights of the weeds increased significantly as weed density increased. Although the weeds tended to become taller as weed density increased, these differences were not statistically significant.

The results indicated that the highest weed density of 16 WPCP did not affect the growth and yield of sweet corn.

2nd crop

In the October to December 1974 planting, Emilia densities in increments of 50 up to 150 WPCP were grown with sweet corn 'H-68'. Although the stover weight of sweet corn was slightly lower in the plots with Emilia, the differences were not statistically significant (Table 3.6). The corn height at specific weed densities was also not significantly different from each other. However, at 5 weeks after planting, the weed-infested corn appeared chlorotic. When nitrogen was top-

Table 3.5. Effect of specific densities of pure stands of E. javanica on the harvest data of both weeds and sweet corn 'H-68' (1st crop) α/.

Crop:Weed ratio	Sweet Corn			E. javanica	
	Stover (g/0.09 sq m)	Husked corn (g/0.09 sq m)	Plant height (cm)	Dry weight (g/0.09 sq m)	Plant height (cm)
1:0	150 a	297 a	278 a	-	-
1:1	158 a	282 a	279 a	5.3 a	75 a
1:2	149 a	315 a	273 a	9.2 b	77 a
1:5	155 a	286 a	278 a	17.9 c	81 a
1:9	152 a	301 a	276 a	23.9 d	81 a
1:16	148 a	304 a	214 a	35.5 e	86 a

α/ Treatment differences are based on Duncan's Bayes lsd. Any two means followed by the same letter are not significantly different at 5% level.

Table 3.6. Effect of specific densities of pure stands of E. javanica on the harvest data of both weeds and sweet corn 'H-68' (2nd crop) α/.

Crop:Weed ratio	Sweet Corn			E. javanica		
	Stover (g/0.09 sq m)	Plant Height (cm)		Stand (no/0.09 sq m)	Dry weight (g/0.09 sq m)	Plant height (cm)
		41 DAP	Harvest			41 DAP β/
1:0	101.8 a	174 a	239 a	-	-	-
1:50	96.5 a	169 a	227 a	46 a	37.3 a	42 a
1:100	92.0 a	166 a	229 a	51 a	41.0 a	40 a
1:150	93.0 a	168 a	234 a	41 a	36.9 a	37 b

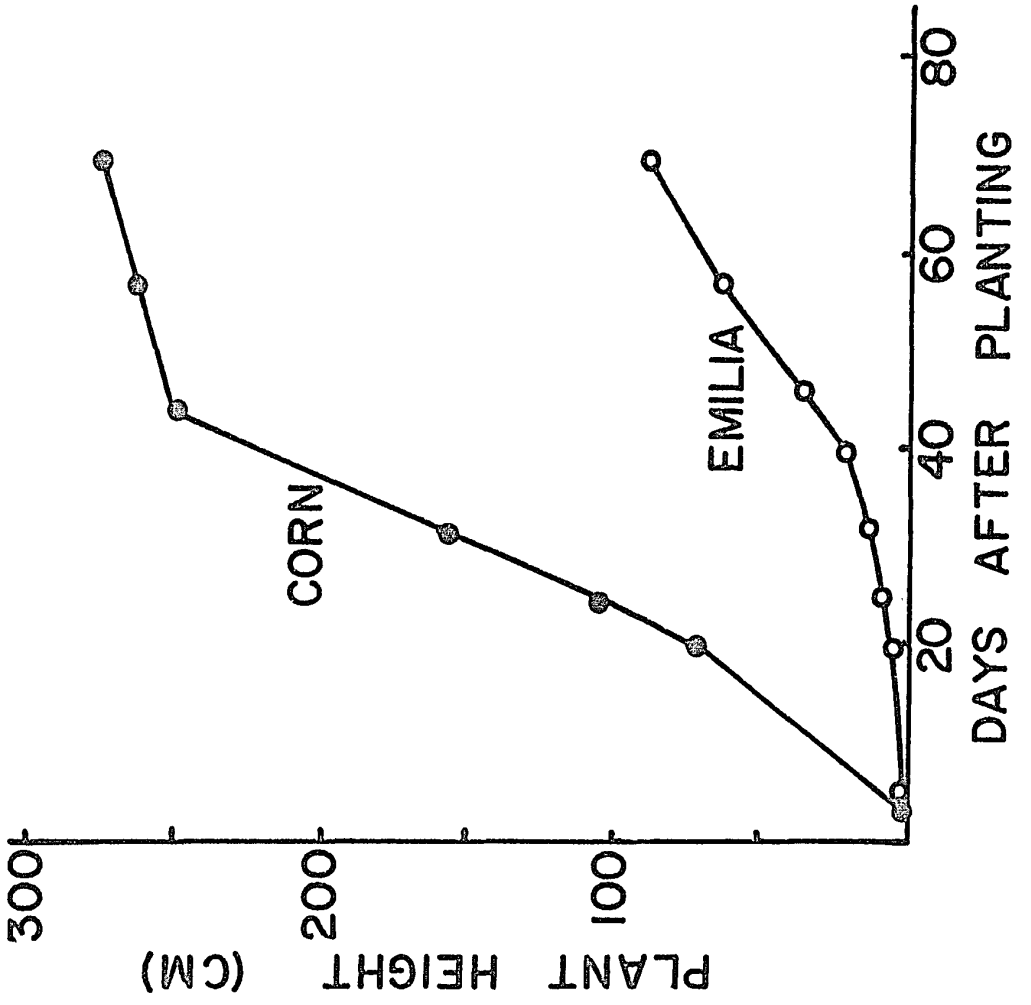
α/ Treatment differences are based on Duncan's Bayes lsd. Any two means followed by the same letter are not significantly different at 5% level.

β/ DAP - days after planting.

dressed, the corn plants regained their normal green color. At 41 DAP the Emilia at densities of 100 and 150 WPCP tended to be slightly shorter than at 50 WPCP. At harvest time, the weed densities of 100 to 150 WPCP were reduced to 51 and 41 WPCP, respectively. This was due to a large number of Emilia plants that died as a result of intra-specific as well as interspecific competition for light and perhaps nutrients. This reduction in weed density was also reflected in the dry weight of the weeds which at harvest were not significantly different.

The results of both sweet corn plantings demonstrated clearly that the growth and yield of sweet corn 'H-68' were not affected by Emilia infestation during the entire crop season even at very high Emilia densities of 150 WPCP; provided, however, that the corn plant was adequately fertilized. This tolerance of corn to high densities of Emilia infestation demonstrate the ability of corn to compete more vigorously than Emilia for light and nutrients. The competitive ability of corn can be attributed to its early establishment and greater growth rate in contrast with the late germination and slow growth of Emilia (Figure 3.4). Corn emerged 2 days before the emergence of Emilia weeds. At 6 weeks, the corn was about eight and one-half times taller than the Emilia in the first crop while in the second crop, corn was four times the height of the weeds. The height advantage of the corn made it impossible for Emilia to compete for light. This limited supply of light for Emilia may have weakened the weeds' ability also to compete for nutrients.

Figure 3.4. Growth curves of sweet corn 'H-68' and E. javanica type Red at crop:weed density ratio of 1:16 (2nd crop).


PLANT HEIGHT (CM)
300
200
100
20
40
60
80
DAYS AFTER PLANTING
CORN
EMILIA

Transplanted Tomato vs Emilia

1st crop

None of the Emilia weed densities tested had any effect on the tomato '7908' plant fresh weight, fruit weight, and number of fruit per plant (Table 3.7). Variability in the experiment was quite great.

2nd crop

In the second crop, the tomato 'N-52' which was more adapted to the 2nd season planting was used. To remedy some of the problems encountered in the first crop, the tomato seedlings were provided with a trellis 1 week after transplanting. Also, 10 tomato plants per treatment were used instead of only five plants. Since the highest density (46 WPCP) in the first crop did not show any adverse effect on the growth and yield of transplanted tomato, the weed density increments used in the 2nd crop was almost double that of the highest weed density of the 1st crop.

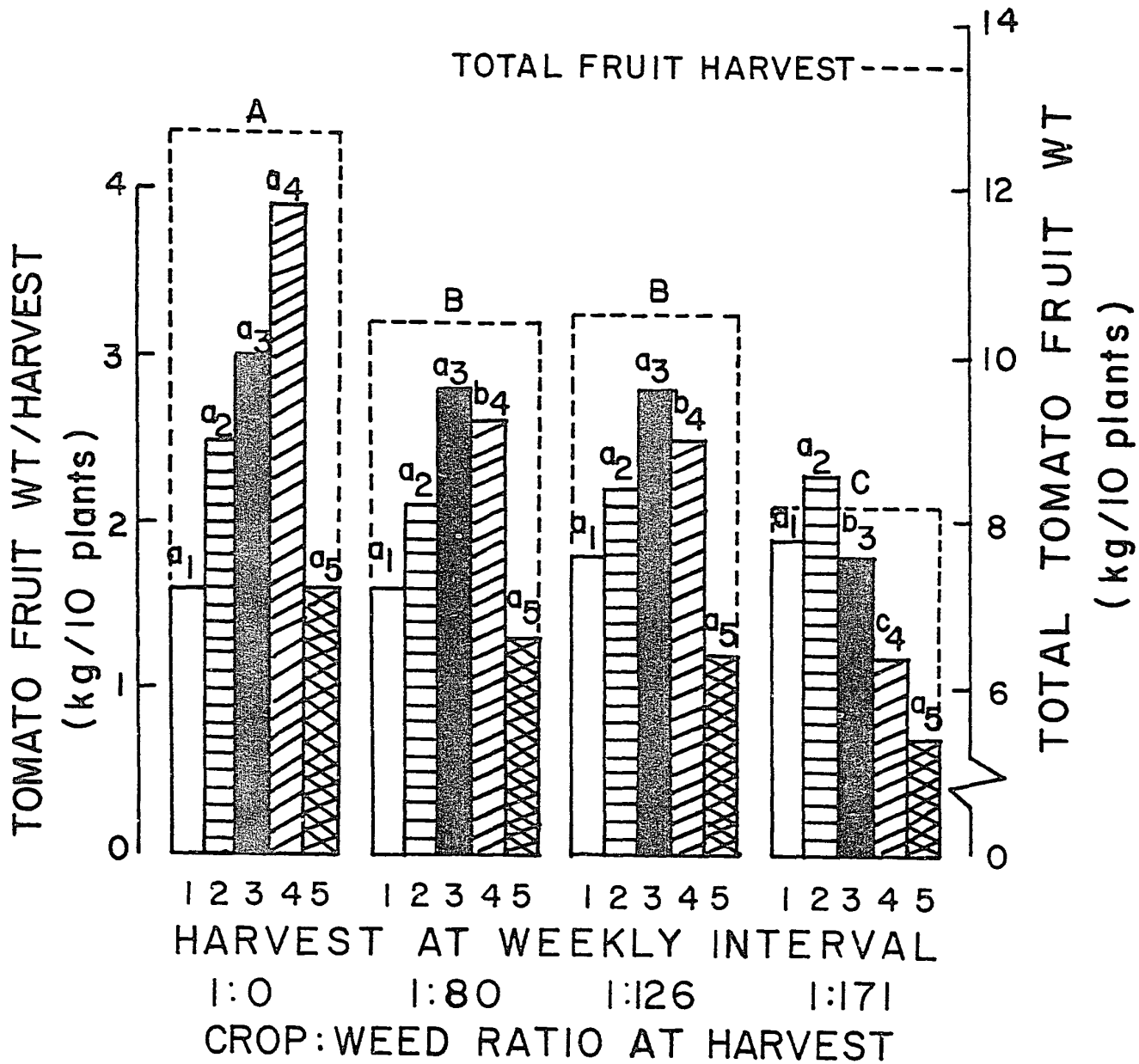
A significant difference in fruit weights measured at weekly intervals appeared on the third week of harvest (Figure 3.5). Only the fruit weight at 171 WPCP was significantly lower than the weed-free plot. On the fourth week of harvest, the fruit weight of plots with 80, 126 and 191 WPCP were all significantly lower than the weed-free plot. By the fifth week of harvest the fruit yields were not statistically significant, nevertheless, the weed-free plot had numerically higher yields than the weedy plots. In terms of total yield, the weed-free plot gave significantly higher yields than the weed infested plots. Emilia densities at both 80 and 126 WPCP significantly reduced yields by about 18 percent. Weed density at 171 WPCP caused a significantly greater yield

Table 3.7. Effect of specific densities of pure stands of E. javanica type Red on the harvest data of both weeds and transplanted tomato '7908' (1st crop) α/.

Crop:Weed ratio	Transplanted tomato			E. javanica	
	Plt. fresh wt. (g/0.36 sq m)	Fruit weight (g/0.36 sq m)	No. of fruits (no/0.36 sq m)	Dry weight (no/0.36 sq m)	Plant height (cm)
1:0	3065 a	1320 a	37 a	-	-
1:5	2782 a	1866 a	49 a	12.0 a	65 a
1:7	3021 a	1605 a	43 a	23.1 a	71 a
1:11	3222 a	1503 a	39 a	31.2 a	76 a
1:28	2764 a	1596 a	43 a	54.8 b	77 a
1:46	2947 a	1664 a	46 a	87.5 a	76 a

α/ Treatment differences are based on Duncan's Bayes lsd. Any two means followed by the same letter are not significantly different at 5% level.

Figure 3.5. Effect of specific densities of pure stands of E. javanica type Red on the fruit weights of transplanted tomato 'N-52' (2nd crop). Treatments with the same letter with the same subscript are not significantly different based on Duncan's Bayes LSD at 5% level.


TOTAL FRUIT HARVEST
TOMATO FRUIT WT/HARVEST (kg/10 plants)
TOTAL TOMATO FRUIT WT (kg/10 plants)
A
B
B
C
1 2 3 4 5
HARVEST AT WEEKLY INTERVAL
1:0
1:80
1:126
1:171
CROP:WEED RATIO AT HARVEST

reduction of 37 percent.

The dry weight of the weeds did not show any significant difference with an increase in stand count (Table 3.8). There was no significant difference in plant height although the weeds became slightly shorter as density increased.

These results indicate that the effect of the weeds on tomato yields started to appear after the second week of harvest. The dry weight of the weeds was poorly correlated with yield reductions, since the dense weed population that got established with the crop failed to gain more dry matter with increasing densities. This indicated that the optimum weed density for maximum dry matter production might have already been attained or exceeded. However, a good correlation between crop yield and Emilia stand count was evident. The reduction of tomato fruit yield by Emilia might have resulted from competition during the early stages of both crop and weeds. Since the tomato plants were already established before the weeds emerged so that the weeds never shaded the crop, competition between transplanted tomato and Emilia was probably mainly for nutrients, possibly, nitrogen. At the early growth stages, there was less intraspecific competition for light among the weeds so that the weeds were in a better condition to compete for nutrients.

Correlation and regression analyses were done to compare the relative effects of the specific densities of Emilia on the different vegetable crops. To determine the best correlation between crop and weed relationship, linear, quadratic and square root functions of the data were compared. The function that gave the highest correlation coeffi-

Table 3.8. Harvest data of pure stands of E. javanica type Red grown at specific weed densities with transplanted tomato 'N-52' (2nd crop).

Crop:weed ratio	E. javanica type Red α/		
	Stand count	Dry weight	Plant height
	(no/0.36 sq m)	(g/0.36 sq m)	(cm)
1:80	80 a	179 a	92 a
1:130	126 b	188 a	88 a
1:180	171 c	173 a	85 a

α/ Data collected after the 5th tomato fruit harvest.

cient was used to show the specific crop-weed relationship. The correlation coefficients indicated that the weed dry weights and stand counts were negatively correlated with crop yields (Table 3.9). With the exceptions of the Emilia dry weight and the Emilia stand count in the second crops of mustard cabbage and transplanted tomato, respectively, the square root functions gave the best correlation coefficients. The square root function indicate a curvilinear relationship between crop yields and the weed parameters. The effect of Emilia on the dry weight of lettuce was better correlated with the weed dry weight ($r = 0.938$) than the weed stand count ($r = -0.864$) although both were significant. The correlation coefficients in both crops of mustard cabbage indicate that either the weed dry weights or the weed stand counts can be used to evaluate the effect of weed density on the crop. Transplanted tomato fruit yield was better correlated with the weed stand count ($r = -0.812$) than with the weed dry weight ($r = -0.713$).

The slopes of the regression equations manifest the degree of reduction caused by a particular unit of weed characteristic. A comparison of the slopes between the lettuce and the second crop of mustard cabbage point out that the Emilia stand counts had similar effects on either crop. Although there was a slightly greater reduction of the mustard cabbage dry weight at a specific weed density in contrast with lettuce, mustard cabbage produced greater amounts of dry matter than was reduced by the weeds. The intercepts and the slopes of the regression equations of transplanted tomato were very different from that of either lettuce or mustard cabbage. The large value of the intercept relative to the slope denoted that high weed densities or high weed weights were

Table 3.9. Summary of the correlation coefficients and regression equations between crop yields and weed dry weights and stand counts.

Variables α/ (Crop vs weed)	Correlation coefficient (r)	Regression equation ($\hat{Y} = a + b X_1$)
1. Lettuce dry weight (Y) vs		
a. Emilia dry weight ($X^{\frac{1}{2}}$)	- 0.938	$\hat{Y}_{1a} = 18.2 - 2.1 (X^{\frac{1}{2}})$
b. Emilia stand count ($X^{\frac{1}{2}}$)	- 0.864	$\hat{Y}_{1b} = 14.9 - 2.3 (X^{\frac{1}{2}})$
2. Mustard cabbage dry weight (Y) vs		
(1st crop)		
a. Emilia dry weight ($X^{\frac{1}{2}}$)	- 0.822	$\hat{Y}_{2a} = 39.2 - 3.0 (X^{\frac{1}{2}})$
b. Emilia stand count ($X^{\frac{1}{2}}$)	-0.820	$Y_{2b} = 39.5 - 4.6 (X^{\frac{1}{2}})$
(2nd crop)		
c. Emilia dry weight (X)	- 0.732	$\hat{Y}_{2c} = 30.2 - 0.4 (X)$
d. Emilia stand count ($X^{\frac{1}{2}}$)	- 0.745	$\hat{Y}_{2d} = 30.6 - 2.8 (X^{\frac{1}{2}})$
3. Transplanted tomato fruit weight (Y) vs		
(2nd crop)		
a. Emilia dry weight ($X^{\frac{1}{2}}$)	- 0.713	$\hat{Y}_{3a} = 12661 - 220 (X^{\frac{1}{2}})$
b. Emilia stand count (X)	- 0.812	$\hat{Y}_{3b} = 12562 - 22 (X)$

α/ Lettuce, mustard cabbage and corresponding weeds are in g per 0.09 sq m while transplanted tomato and corresponding weeds are in g per 0.36 sq m.

required before yield reductions occurred in the transplanted tomato.

The preceding results demonstrate clearly that the different vegetable crops tested were differentially affected by pure stands of specific densities of the Red type of Emilia javanica. Both lettuce and mustard cabbage were adversely affected at relatively low weed densities although the yield reduction caused by the weeds were greater in lettuce than in mustard cabbage. Sweet corn was unaffected by the highest weed densities tested whereas relatively high weed populations of Emilia were required before appreciable decline in fruit yields in transplanted tomato was noted.

SUMMARY AND CONCLUSIONS

Field experiments were conducted to evaluate the effects of specific densities of pure stands of Emilia javanica type Red on the growth and yield of lettuce 'Anuenue', mustard cabbage 'Waianae', sweet corn 'H-68', and transplanted tomato 'N-52'.

The four crops varied in degree of tolerance to Emilia competition. Relatively low densities of Emilia affected both lettuce and mustard cabbage. However, mustard cabbage was less severely affected by competition with specific densities of the weed. For example, infestations of 11 weeds per crop plant (WPCP) decreased the dry weights of lettuce by 70% and mustard cabbage by 30%. The shorter height and slower growth rate (in terms of dry matter production) of lettuce in contrast to mustard cabbage resulted in the former crop to be more severely subjected to competition by Emilia. The weeds grew taller and accumulated more dry matter than lettuce. However, when Emilia was grown with mustard

cabbage, the weeds produced less dry matter than when Emilia grew with lettuce at comparable crop:weed density ratios. The stunting of lettuce, its reduced nitrogen uptake at high weed densities, and the greater percentage of dry matter reduction at comparable crop:weed ratios in contrast with mustard cabbage can be attributed to competition for light and probably, nitrogen. Since both mustard cabbage and Emilia were relatively taller at high weed densities than at low weed densities, it is therefore likely that both crop and weed competed primarily for light. Because mineral composition analysis for both mustard cabbage and Emilia was not done, competition for nutrients between them can not be discounted.

The growth and yield of sweet corn were not affected by Emilia infestation during the entire crop season even at Emilia densities of 150 WPCP. However, the corn plants were adequately fertilized, particularly with nitrogen. Corn competed more vigorously than Emilia for light and nutrients. The competitive ability of corn can be attributed to its early establishment and greater growth rate in contrast with the late germination and slow growth of Emilia. The height advantage of corn made it impossible for Emilia to compete for light. This lower level of light available to Emilia at higher densities may have weakened the weeds' ability also to compete for nutrients.

Fruit yields of transplanted tomato required relatively much higher densities of Emilia infestations than both lettuce and mustard cabbage before yield reductions resulted. An 18% reduction in tomato fruit yield required 80 to 126 WPCP. The tolerance of transplanted tomato to Emilia infestations could be due to its more developed root system,

greater growth rate, and earlier establishment (transplanted at 5 weeks after sowing) relative to Emilia. Although the tomato plants were taller than Emilia throughout the crop season, the Emilia weeds were only slightly shaded by the trellised tomato. Although both tomato and weeds were not analyzed for mine l composition, the very dense growth of the high population of Emilia may have required the uptake of relatively large amounts of nutrients. It is therefore possible that the Emilia may have affected the tomato by competition for nutrients.

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