AN ABSTRACT OF THE THESIS OF

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Title: Meadowfoam Oil Yield as Influenced by Dry Matter Production and Partitioning, Flower Number, and Honey Bee Density

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Abstract Approved: ______________ Dr. Gary D. Jolliff ____________.

Meadowfoam (*Limnanthes alba* Hartw. ex Benth. ssp. *alba* cv. Mermaid) seed yield, and consequently oil yield, varies considerably among years. Stable and high oil yield is needed to encourage profitable commercialization. Reports in the literature indicate that a negative relationship exists between seed yield (and thus oil yield) and total above-ground dry matter (phytomass) and that pollination may be limiting seed yield. The objective of this research was to create differing phytomass production, phytomass partitioning, flower phenology, and number of open flowers to determine the association of oil yield and its components with the cumulation and partitioning of phytomass, and pollination.

Transparent floating crop cover and shade cloth were used on field plots to alter light and temperature. Cover Early, Cover Early Plus Late and Shade treatments were applied 22 Jan. 1988 and 24 Jan. 1989. Shade and Cover Early were removed at the beginning of rapid elongation of stems 29 Mar. 1988 and 28 Mar. 1989; and Cover Early Plus Late was removed two weeks later, 12 and 11 April, respectively.

Oil yield was consistently increased by the Shade and the Cover Early treatments. Increases in oil yield were related primarily to increases in flower number and seed number. Eighty-seven percent of the treatment variation in seed number was explained by cumulated

foraging bee density, cumulated open flowers and the synchronous occurrence of both. No relationship was apparent between phytomass two weeks after the beginning of rapid elongation of stems and seed yield. However, phytomass two weeks after the beginning of rapid elongation of stems did have a negative relationship with the weight $seed^{-1}$, but the magnitude of the effect was small. The number of open flowers was found to be correlated with the percent of phytomass in stem tissue at the beginning of flowering. Fewer but heavier primary stems during rapid reproductive development were traits associated with higher yields. Leaf area development was accelerated by covering or shading, and partitioning to leaf tissue declined during rapid stem development.

Improvement in meadowfoam seed yield may be accomplished through increases in flower number via switching phytomass partitioning from vegetative to reproductive tissue during rapid stem development and through better pollination.

Meadowfoam Oil Yield as Influenced by Dry Matter Production and Partitioning, Flower Number, and Honey Bee Density

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIX FIGURES

LIST OF APPENDIX TABLES

(Continued)

LIST OF APPENDIX TABLES (Continued)

PREFACE

The data included in the thesis were collected in 1987-1988 and 1988-1989. Tim Fiez assisted me in the planning, hiring of labor, and conducting of the experiments. The work was accomplished in cooperative manner, since our experiments were intermingled. The amount of work involved between both degree programs was tremendous.

Dr. Gary D. Jolliff's contribution to these experiments included 1) generating research funding, 2) providing equipment and facilities, 3) recruiting me to identify limiting factors to yield, 4) advising during the research, 5) critical review and guidance in the writing of scientific results.

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Because of many years of working with meadowfoam, Jim Crane was able to help me identify problems with prior experiments and, if possible, ways to avoid them. Jim's personal experience in the field gave me a better understanding of the influence of the environment on meadowfoam, which was helpful since little has been published in this area.

Chapter I has been submitted to Agronomy Journal. Chapter II is currently in Departmental Review and will be submitted to Crop Science for publication. Chapter III will soon be submitted for Departmental Review and then be submitted to Crop Science.

Meadowfoam Oil Yield as Influenced by Dry Matter Production and Partitioning, Flower Number, and Honey Bee Density

INTRODUCTION

This thesis is written in manuscript format. It reports the following three studies: 1) "Shading and Crop Cover Effects On Meadowfoam Oil Yield", 2) "Flower Production and Honey Bee Density Effects On Meadowfoam Seed Yield", 3) "Meadowfoam Phytomass Development Effects On Flower Production".

Meadowfoam (*Limnanthes alba* Hartw. ex Benth.) is a native to the west coast of North America, more specifically to California, southern Oregon, and Vancouver Island, British Columbia. Its native environment changes from flooded in the winter to arid in the summer. In some locations the lack of winter precipitation may inhibit germination. Meadowfoam has evolved many mechanisms which enable it to compete and survive under these conditions. Our interest focuses on increasing oil yield and decreasing production costs, thereby stimulating the commercialization of a profitable alternative crop. Our objective is to domesticate meadowfoam into an agronomic crop for the purpose of optimizing profitable oil yield. However, this places meadowfoam in an environment considerably different and from that of wild meadowfoam, and the life cycle strategy of native genotypes most likely will not maximize oil production.

Previous work has provided indirect evidence that phytomass production has a negative relationship with oil yield (Pearson and Jolliff, 1986b; Krebs and Jain, 1985) and led to speculation that pollination was limiting oil yield (Calhoun and Crane, 1978; Gentry and Miller, 1965). More recent work has shown that seeds $flower^{-1}$ is related to measures of honey bee density (Pearson and Jolliff, 1986a; Jahns and Jolliff, 1990). Chapter I explores the negative relationship between oil yield and phytomass production. Chapter II looks at seed set as influenced by pollination and flowering. Finally, Chapter III looks at flower production as influenced by phytomass production and phytomass partitioning.

CHAPTER I

SHADING AND CROP COVER EFFECTS ON MEADOWFOAM OIL YIELD

ABSTRACT

Meadowfoam (*Limnanthes alba* Hartw. ex Benth. ssp. *alba* cv. Mermaid) seed yield, and consequently oil yield, has varied considerably among years. Stable and high oil yields are needed to encourage profitable commercialization. This experiment tested the hypothesis that phytomass (total above-ground dry matter) at the beginning of rapid elongation of stems (early April) is negatively associated with seed yield. Shade cloth and a transparent floating crop cover were used to alter light and temperature, compared to the Control. Cover Early, Cover Early Plus Late and Shade treatments were applied on 22 Jan. 1988 and 24 Jan. 1989. Shade and Cover Early were removed at 29 Mar. 1988 and 28 Mar. 1989; and Cover Early Plus Late was removed after an additional two weeks. Shade increased oil yield an average of 47% through higher (35%) seed yield and higher (8%) percent oil content. Seed yield and oil content were positively correlated with seed number area^{-1}. The shaded plants had 24% less phytomass, 28% fewer stems, and 27% more open flowers than the Control. Cover Early increased seed and oil yield in both years while Cover Early Plus Late was inconsistent. In 1987-1988, Cover Early Plus Late increased oil yield 97% with fewer (14%) but heavier (63%) stems, 83% more seed number area^{-1}, and 21% higher percent oil content than the Control. Seed yield improvement by all treatments was associated with fewer primary stems, more flowers that opened, and greater seed number area^{-1}. These results suggest that environmental and management practices which result in a reduced number of primary stems per plant would both increase and stabilize oil yield.

INTRODUCTION

Meadowfoam is a herbaceous winter annual domesticated at Oregon State University (Jolliff, 1981) for its unique seed oil (Earle, et al., 1959; Nikolava-Damyanova, et al., 1990). Seed yield, and consequently oil yield, has varied significantly among years. Higher and more stable oil yields are needed to increase economic attractiveness.

There is little information available on meadowfoam growth as related to oil yield. Also, no growth stage definitions have been developed for the crop. Averaged over treatments, Pearson and Jolliff (1986b) reported a large variation between years in total aboveground dry matter (phytomass) in mid-April. Oil yield in the low-phytomass year was 181% greater than when phytomass was high, suggesting a negative relationship between phytomass in mid-April and oil yield. In California, Krebs and Jain (1985) found oil yield of *L. alba* accessions to be negatively correlated with both crop growth rate and leaf area at 88 days after sowing. Weather data from the Oregon State University Hyslop Research Farm for 1984-1987 showed large variations in precipitation and diurnal fluctuation in temperature from year to year during winter months which may create considerable differences in phytomass production. All these factors led to the hypothesis that phytomass at the beginning of rapid elongation of stems (early April) is negatively associated with seed yield. The beginning of rapid elongation of meadowfoam stems generally occurs in late March in the Willamette Valley of Oregon.

Floating crop covers have been used to alter air temperature (Hall, 1971; Shadbolt and McCoy, 1960; Wells and Loy, 1985). In strawberry (*Fragaria x ananassa* Duch.), time of flowering, fruit set, and fruit ripening were hastened in direct relation to the length of time row covers were left in place in the spring (Gent, 1990). Growth rates of cucumber [*Cucumis sativus* (L.)] were increased by use of covers (Wolfe et al., 1989). Shade cloth reduces the amount of light received by a crop, suppresses dry matter production, and may influence partitioning of assimilates within crop canopies (Early et al., 1967; Egli, 1988; Hang et al., 1984).

The objective of this experiment was to create differing phytomass development before the beginning of rapid elongation of stems, and to determine: (*i*) phytomass production at two weeks after the beginning of rapid elongation of stems, (*ii*) oil yield and yield components, and (*iii*) the association of *i* with *ii*.

MATERIALS AND METHODS

Field experiments were conducted at Oregon State University Schmidt Research Farm (44° and 38'N, 123° and 12'W) near Corvallis, OR in 1987-1988 and 1988-1989 on an Amity silt loam (fine-silty, mixed, mesic Argiaquic Xeric Agialboll). A fallow year preceded planting each season. Prior to planting, the concentrations of N, P, and K in the top 30 cm of soil were determined. Nitrogen, P, and K levels were 7, 36, and 160 mg kg^{-1} in 1987-1988 and 6, 44, and 218 mg kg^{-1} in 1988-1989, respectively. Soil pH was 5.6 in 1987-88 and 5.8 in 1988-1989. Fifty-four kg ha^{-1} of N and 29 kg ha^{-1} of P were incorporated pre-planting both seasons. Fifty-six kg ha^{-1} N was broadcasted on 23 Feb. 1988 and on 28 Feb. 1989. The meadowfoam cultivar 'Mermaid' was planted in 15-cm rows on 1 Oct. 1987 and 6 Oct. 1988 at 280 seeds m^{-2}. Plots were 12 rows and 6.1 by 1.2 m. For weed control, Propachlor [2-chloro-N-(1-methylethyl)-N-phenylacetamide] at 2.24 kg a.i. ha^{-1} was sprayed preemergence both years and, in 1988-89, paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) was sprayed preemergence at 0.56 kg a.i. ha^{-1}. Emergence dates (50% emergence) were 13 Nov. 1987 and 14 Nov. 1988.

The cover treatments, Cover Early (CE) and Cover Early Plus Late (CE+L) were created by laying a flexible transparent cover (extruded polypropylene and polyamid net; trade name Agronet, type M, Beghin Say, Kaysersberg, France) directly on the crop. A Shade treatment was created by suspending shade cloth (47% shade, Nicolon Inc. Norcross, GA) on a wooden frame approximately 20 cm above the soil surface. Treatments were applied 22 Jan. 1988 and 24 Jan. 1989. The CE and Shade treatments were removed on 29 Mar. 1988 and 28 Mar. 1989 when Control plants had stems 1 cm long. The CE+L treatment was removed 2 weeks later.

Photosynthetically active photon flux density (PPFD) transmitted through the crop cover and through the shading material was measured hourly on two clear days, using a Model-191S Quantum Sensor (Li-Cor Inc., Lincoln, NE). Air temperature above the plots was measured with 4 copper-constantan thermocouples $plot^{-1}$ placed 5 cm above the soil surface and shaded from direct sunlight. Readings for each treatment were recorded hourly by an electronic data logger (CR5 in 1988 and CR10 in 1989; Campbell Scientific, Logan, UT). Daily and 30-year mean maximum and minimum temperatures were from measurements taken at Hyslop Field Laboratory located 3 km from the plots (Fig. I.1; Tables I.1 and I.2).

The Oct.-May mean air temperature at 105 cm above the plots averaged across years was 6.5°C and was approximately equal to the 30-year mean which was 6.6°C. However, temperatures were abnormally low during the second and third weeks following treatment application in 1989. The mean air temperature under the shade cloth was slightly less than in the Control plots. However, the major effects of shading were a decrease in diurnal fluctuation of 2.0°C (Table I.2) and a 54% reduction in PPFD. Crop covers increased mean maximum and minimum temperature approximately 1°C and decreased incident light by 18%.

At two weeks after the beginning of rapid elongation of stems, total phytomass from 0.1 m^2 was collected from all plots. Plants in the sample were counted and separated into leaves, stems (including the crown), and flower buds. Leaves which were more than 50 percent green were measured using a LI 3100 leaf area meter (Li-Cor, Lincoln, NE). Stems originating or appearing to originate from the crown or branched less than 2 cm from root tissue were counted and referred to as primary stems. The plant parts were dried at 60°C to a constant weight.

For pollination, honey bee hives were placed next to the experimental plots during flowering at a density of approximately five hives ha^{-1}. At flowering, a 0.1-m^2 area was selected randomly in each plot and the flowers which opened by 1100 h were counted and removed each day. Visible physical damage to parts of some flowers occurred both years and apparently was caused by a maggot of a small fly identified to be in the genus *Scaptomyza* (M. R. Wheeler, 1990, personal communication). The number of damaged opened flowers was recorded daily. A concurrent study also addressed this insect damage and the relatively low oil yields (Fiez et al., 1991a).

After flowering was complete, the unopened flower buds in the flower-counting area were removed, counted, and added to the total flower number to give the total number of buds produced. On 15 July 1988, a 2.8 m^2 area of each plot was flail-harvested (Carter Manufacturing, Brookston, IN); on 27 June 1989, a 5.6 m^2 was harvested. In both years, the plants were dried 24 hours at 38 °C, threshed (Kurt Pelz thresher, Bonn-Bad Godesberg, Germany), cleaned (Clipper cleaner; Ferrell-Ross, Saginaw, MI) and the seed dried at 60 °C to a constant weight. Two random 0.14 m^2 areas were vacuumed in each flail-harvested area to determine harvest loss. In 1988, the vacuum-samples were threshed and cleaned in the same manner as the flail-harvested samples. In 1989, the vacuum-samples were hand-threshed. Seed yield was determined by adding harvest loss to the flail-harvested seed. The oil content of a random sample of 1000 seeds was determined using a Bruker Minispec PC 120 pulsed nuclear magnetic resonance spectroscope equipped with an 18-mm RTa absolute probe head and an EDM 311 program module (Bruker Spectrospin Canada Limited, Milton, Ontario).

The experimental design was a randomized block with four replications in 1987-1988 and six replications in 1988-1989. Error variances were determined to be homogeneous by use of an F-test (Snedecor and Cochran, 1980). Data for years were combined for analysis of variance (Federer, 1955) or analysis of covariance. Year was considered a fixed effect. Analysis of covariance was conducted to determine treatment significance and to adjust the measured seed weight for the effect caused by insect feeding on flowers. Seed number area^{-1} was calculated by dividing seed yield by the weight seed^{-1}. Seeds flower^{-1} was determined by dividing seed number area^{-1} by the number of open flowers. Phytomass samples taken on 12 April 1988 and 11 April 1989 also were analyzed using analysis of covariance with the covariate being number of plants per 0.1 m^2. Treatment means were compared using a set of non-orthogonal contrasts. The alpha level was 0.05 for all response variables and 0.10 for determining covariate significance on response variables.

RESULTS AND DISCUSSION

Shade increased oil yield an average of 47% (Table I.3). The increase in oil yield was a result of higher seed yield (35%) and higher oil content (8%)(Table I.3). Seed yield, oil content, and consequently oil yield, were positively correlated with seed number area^{-1} (Table I.4). Two weeks after the beginning of rapid elongation of stems, shade had produced 24% less phytomass and 28% fewer stems than the Control (Table I.5). The shade treatment had no effect on stem weight, leaf area index, and seeds per flower (Tables I.3 and I.5). There were also 27% more open flowers in the shade. Cover Early increased seed and oil yield in both years while Cover Early Plus Late was inconsistent. In 1987-1988, CE+L increased oil yield 97% with fewer (14%) but heavier (63%) stems, 83% more seed number area^{-1}, and 21% higher percent oil content than the Control. Also in 1987-1988, CE+L had fewer primary stems (14%) but heavier stem (63%) and bud (20%) dry weights than the Control.

Contrary to the hypothesis, correlations between phytomass 2 weeks after the beginning of rapid elongation of stems and yield were not significant. However, weight seed^{-1} was negatively correlated with phytomass, stem weight, and bud dry weight at removal of CE+L both years (Table I.4). But differences in weight seed^{-1} between treatments were small both years in comparison to the influence on seed number area^{-1} (Table I.3). Weight seed^{-1} was decreased in both years by covering, whereas the effect of shading was inconsistent between years. Seed yield improvement by all treatments was associated with fewer primary stems, more flowers that opened, and greater seed number area^{-1}. Similar results have been reported for strawberry where early shading decreased the number of runners, but increased fruit number and total berry yield (Ferree, 1988). Apparently, when excess numbers of stems are produced, intra-plant competition for assimilate causes cessation of development of some flower buds. Thus, environmental conditions which favor development of excess primary stems may decrease Mermaid seed and oil yields. This agrees with Krebs and Jain (1985), who used stepwise multiple regression on 12 independent plant growth characters to predict meadowfoam seed yield. They reported a negative association between seed yield and the number of basal branches plant^{-1}, whereas the correlation between seed yield and flower number was positive. Similarly, the primary effect of N fertilizer -- when applied at favorable rates and times -- on meadowfoam oil yield is through increased number of opened flowers, and consequently, increased seed number area^{-1} (Pearson and Jolliff, 1986b; Jolliff, et al., 1991).

In both years, seeds flower^{-1} was positively correlated with seed number area^{-1} and oil yield. Seeds flower^{-1} was an important component of oil yield in a concurrent study (Fiez et. al., 1991a). It has also been shown that pollination can play an important role in determining seeds flower^{-1} (Jahns and Jolliff, 1990; Jahns et al., 1991). These findings support future investigations of management practices and genetic selection to reduce the number of primary stems per plant as a means of increasing the number of open flowers, and consequently increasing and stabilizing oil yield.

Table I.1. Mean monthly maximum and minimum temperatures, precipitation, and monthly means of daily mean (hourly measurements) for light intensity, November through June in 1987-1988 and 1988-1989.

Month	Mean air temperature				Precipitation		Mean light intensity	
	Maximum		Minimum					
	87-88	88-89	87-88	88-89	87-88	88-89	87-88	88-89
	°C				mm		$\mu mol.\ m^{-2}\ s^{-1}\ day^{-1}$	
November	13.5	12.6	4.5	4.3	99	276		199
December	7.3	8.7	1.1	1.2	290	101	179	198
January	7.7	9.7	0.5	1.1	181	106	226	210
February	12.4	6.7	1.2	-0.7	43	82	427	362
March	15.3	13.4	1.8	3.0	99	173	548	401
April	18.0	20.7	5.5	6.0	85	36	583	625
May	20.0	21.6	5.9	6.1	98	37	658	595
June	24.4	26.7	8.8	10.0	46	29	792	721

Table I.2. Deviations from the Control for mean air temperatures in the plant canopy for Shade, Cover Early (CE), and Cover Early Plus Late (CE+L) in 1987-1988 and 1988-1989, and the two-year means.

	1987-1988	1988-1989	2-yr Mean
Mean Max.		°C	
Shade	-2.1	-0.2	-1.1
CE	0.5	2.1	1.3
CE+L	0.1	2.0	1.1
Mean Min.			
Shade	0.8	0.9	0.9
CE	1.1	1.1	1.1
CE+L	1.1	1.0	1.1
Mean Diurnal Change			
Shade	-2.9	-1.1	-2.0
CE	-0.6	1.0	0.2
CE+L	-1.0	1.0	0.0

Table I.3. Means, analyses of variance or analyses of covariance, and contrasts for yield and yield components of Mermaid meadowfoam as influenced by treatments, Cover Early (CE), Cover Early Plus Late (CE+L), Shade, and Control, in 1987-1988 and 1988-1989.

Year or treatment	Total flower buds /1000	Open flowers /1000	Seeds flower^{-1}	Seeds /1000	Weight seed^{-1}	Seed yield	Oil con-tent	Oil yield
1988	----- No. m^{-2} ---		- No.--	No. m^{-2}	mg	Mg ha^{-1}	%	Mg ha^{-1}
Control (C)	11.0	4.86	1.23	5.81	8.56	0.554	23.0	0.127
CE	9.5	5.21	1.56	8.16	7.95	0.699	26.7	0.187
CE+L	10.7	6.78	1.64	10.64	8.13	0.890	27.9	0.250
Shade (S)	9.7	6.57	1.24	7.80	9.41	0.794	26.1	0.210
1989								
Control	8.9	4.49	1.49	6.65	8.72	0.546	25.8	0.142
CE	8.8	6.26	1.41	8.53	7.93	0.631	26.4	0.167
CE+L	8.8	4.81	1.62	7.63	8.07	0.565	26.2	0.148
Shade	9.8	5.32	1.79	8.43	8.52	0.696	26.6	0.185

(Continued)

Table I.3. (Continued)

Year or treatment	df	Total flower buds /1000	Open flowers /1000	Seeds $flower^{-1}$	Seeds /1000	Weight $seed^{-1}$	Seed yield	Oil content	Oil yield
Year (Y)	1	*	NS	NS	NS	NS	NS	NS	NS
Rep (Y)†	8								
Treatment(T)	3	NS	NS	NS	**	***	*	**	**
Y x T	3	NS	*	NS	NS	NS	**	*	*
Residual	24‡								
C.V.		17	20	29	19	5	18	5	21
R^2		0.52	0.65	0.43	0.63	0.93	0.67	0.64	0.72
<u>Contrast</u>									
C vs CE		NS	*	NS	**	**	*	**	*
C vs CE+L		NS	*	NS	***	*	**	***	***
C vs Shade		NS	*	NS	*	NS	**	**	***
Y vs C vs CE		NS	NS	NS	NS	NS	NS	*	NS
Y vs C vs CE+L		NS	NS	NS	**	NS	**	**	**
Y vs C vs S		NS	NS	NS	NS	*	NS	NS	NS

+, *, **, *** Significant at the 0.10, 0.05, 0.01, and 0.001 levels, respectively.
† Replication within year.
‡ Since analysis of covariance was conducted on weight $seed^{-1}$, and total number of buds, only 23 df was left for the residual.

Table I.4. Correlation of growth parameters at 2 weeks after the beginning of rapid elongation of stems with yield and yield components, and correlations between yield components of meadowfoam in 1987-1988 and 1988-1989.

	Year	Phyto-mass	Leaf weight	Stem weight	Bud weight	Leaf area	Stems plant^{-1}	Open flower number	Seeds flower^{-1}	Seed number area^{-1}	Weight seed^{-1}
Open flower number	1988	-0.17	-0.04	0.06	-0.21	0.26	-0.46				
	1989	-0.18	-0.21	-0.06	-0.22	-0.24	-0.19				
Seeds flower^{-1}	1988	0.36	0.08	0.39	0.45	-0.21	0.25	-0.35			
	1989	0.13	0.32	0.06	0.20	0.46*	0.06	-0.65*			
Seed number area^{-1}	1988	0.26	0.08	0.45	0.30	0.00	-0.13	0.42	0.69*		
	1989	0.03	0.22	0.11	0.05	0.31	-0.08	0.32	0.45		
Weight seed^{-1}	1988	-0.73*	-0.56*	-0.72*	-0.61*	-0.50*	-0.31	-0.31	0.13	-0.41	
	1989	-0.47*	-0.38	-0.67*	-0.58*	-0.26	-0.02	0.01	-0.17	-0.35	
Seed yield	1988	-0.12	-0.21	0.09	0.00	-0.24	-0.34	0.26	0.68	0.82*	0.13
	1989	-0.18	0.09	-0.17	-0.19	0.27	-0.13	0.35	0.43	0.91*	0.01
Oil content	1988	0.12	-0.09	0.35	0.21	-0.01	-0.39	0.02	0.66*	0.60*	-0.03
	1989	-0.06	-0.08	-0.06	-0.02	0.08	-0.17	0.09	0.27	0.42*	0.02
Oil yield	1988	-0.06	-0.20	0.16	0.06	-0.21	-0.33	0.19	0.72*	0.81*	0.12
	1989	-0.18	0.06	-0.17	-0.18	0.24	-0.15	0.33	0.44*	0.89*	0.02

* Significant at 0.05 level (n=16 and 24 in 1988 and 1989, respectively).

Table I.5. Analyses of covariance, contrasts, and adjusted treatment means for some growth parameters measured at two weeks after the beginning of rapid elongation of stems as influenced by Cover Early (CE), Cover Early Plus Late (CE+L), Shade, and Control, in 1987-1988 and 1988-1989.

Year or treatment		Phyto- mass	Dry weights Leaf	Stem	Bud	Leaf area index	Primary stems $plant^{-1}$
1987-1988		---------- Mg ha^{-1}	---------				No.
Control		3.73	2.76	0.72	0.25	3.6	7.1
CE		4.34	2.98	1.07	0.30	4.0	6.7
CE+L		4.18	2.73	1.17	0.28	4.0	6.1
Shade		2.79	2.12	0.52	0.16	3.8	4.9
1988-1989							
Control		2.49	1.96	0.39	0.14	3.0	6.3
CE		2.77	2.02	0.58	0.17	3.3	5.7
CE+L		2.73	1.92	0.64	0.17	3.6	6.1
Shade		1.91	1.51	0.30	0.10	2.9	4.8
Year (Y)	1	***	***	***	***	**	NS
Replication (Y)†	8						
Treatment	3	***	**	***	***	NS	***
Y X T	3	NS	NS	NS	NS	NS	NS
Covariate‡	1	*	**	+	**	**	**
Residual	23						
C.V.		18	16	27	18	16	11
R^2		0.83	0.82	0.84	0.90	0.69	0.81
Contrast		----------------------		PR>F	-------------		
Control vs CE		NS	NS	**	*	NS	NS
Control vs CE+L		NS	NS	***	*	NS	*
Control vs Shade		**	**	NS	***	NS	***
Year vs Control vs CE		NS	NS	NS	NS	NS	NS
Year vs Control vs CE+L		NS	NS	NS	NS	NS	NS
Year vs Control vs Shade		NS	NS	NS	NS	NS	NS

+, *, **, *** Significant at the 0.10, 0.05, 0.01, and 0.001 levels, respectively.
† Replication within year.

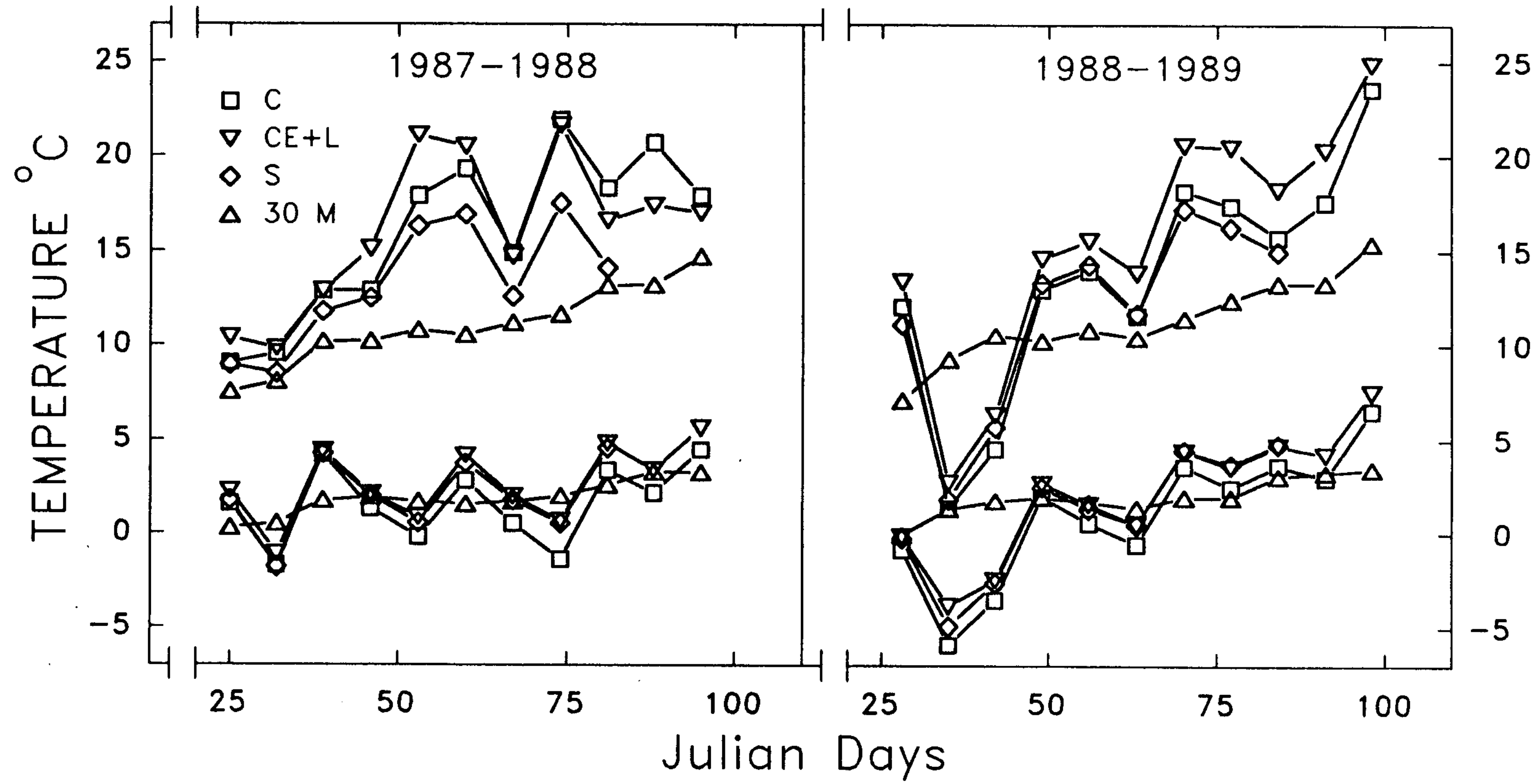

Figure I.1. Mean maximum and mean minimum temperatures (approximately weekly) recorded at 5 cm above the soil surface, under transparent crop cover (CE+L), shade cloth (S), and Control (C) in 1987-1988 and 1988-1989; as compared to the 30-year means (30 M) (measured at 105 cm above the soil surface). The Cover Early treatment is included within CE+L; CE and S were removed the same day.

CHAPTER II

FLOWER PRODUCTION AND HONEY BEE DENSITY EFFECTS ON MEADOWFOAM SEED YIELD

ABSTRACT

Meadowfoam (*Limnanthes alba* Hartw. ex Benth. ssp. *alba* cv. Mermaid) is protandrous and entomophilous. Flower number and phenology, stigma receptivity, and timely honey bee pollination are highly weather-dependent and were hypothesized to cause much seed yield variation. The objective was to use a synchrony index -- an estimate of flower receptivity and pollination timing synchrony -- to relate variation in seed yield to number of open flowers and foraging honey bee (*Apis mellifera* L.) density. Transparent floating crop-cover and shade cloth were used to alter flower number and flower phenology. Cumulated open flowers and cumulated foraging bee density were derived from daily counts of flowers and foraging honey bees, respectively. Flower receptivity for each day was estimated using maximum air temperature for that day. Number of receptive flowers for each day was multiplied by the number of foraging bees for that day and summed for the bloom period to form cumulated synchrony index. A multiple regression model (R^2=0.47, P=0.001) indicated a linear positive association of seeds flower^{-1} with cumulated foraging bee density, and a quadratic negative (within the experiment range) association with cumulated open flowers. A simple linear regression explained 87% (P=0.001) of the variation in seed number area^{-1} by differences in cumulated synchrony index. This confirms the importance of pollination timing, foraging honey bee activity, and total number of flowers for achieving high seed and oil yield and emphasizes the need for careful management and monitoring of these variables. Yield may be increased and stabilized by consistent high levels of pollination.

INTRODUCTION

Limnanthes alba flowers are self-compatible, protandrous, and entomophilous (Devine and Johnson, 1978; Mason, 1952). Cultivated meadowfoam flowers profusely, is indeterminate, and is pollinated primarily by honey bees (*Apis mellifera* L.)(Kalin, 1971). It has been speculated for several years that seed yield may be limited by inadequate pollination (Calhoun and Crane, 1978; Gentry and Miller, 1965), but no data were provided to relate pollinator foraging to seed yield. More recently, data have been reported which relate seeds flower^{-1} is related to measures of bee density (Jahns and Jolliff, 1990; Jahns, et al., 1991; Pearson and Jolliff, 1986a). The critical aspect of proper pollination timing also has been demonstrated in a greenhouse study. Stigmas pollinated at 48 h postanthesis produced almost 3 times as many seeds flower^{-1} as those pollinated at 24 and 72 h (Jahns, 1990).

In a recent field study, as bee visits increased from 1 to 11 flower^{-1}, the seeds flower^{-1} increased from 1.6 to 3.3, suggesting that multiple bee visits are required for maximum seed set (Jahns and Jolliff, 1990). In strawberry (*Fragaria x ananassa* Duch.), 20 to 25 visits may be required for optimal fruit set (Skrebtsova, 1957). More recent work with strawberry, however, indicates that length of visits is also important (Chagnon et al., 1989). If 11 bee visits flower^{-1} are required for maximum seed set in meadowfoam (Jahns and Jolliff, 1990), and 4 210 flowers m^{-2} opened in 1 day (Pearson and Jolliff, 1986b), 46 310 bee visits m^{-2} day^{-1} would be needed (at maximum bloom) to realize the potential seed set. This illustrates the high demand for adequate bee foraging at maximum bloom and the importance of matching flower opening and foraging bee activity for meadowfoam seed production. Pollination of flowers by foraging honey bees is dependent on many things, including the number, strength, and placement of honey bee colonies, and environmental conditions, including rain, light, temperature, and wind speed (Burgett et al., 1984; Jahns et al., 1991). Further, Burgett (1976) and Pearson and Jolliff (1986b) showed that foraging honey bees can be attracted away from meadowfoam to other flowering plants. This diversion of foraging bees to other plants can occur in as few as 2 to 4 days after bee hives have been delivered to a meadowfoam field. Thus, it becomes apparent that meadowfoam flower phenology and factors influencing pollinator activity during a few critical days during the bloom period may have major impacts on meadowfoam seed yield.

To test the importance of flower production and pollinator activity and the synchronous occurrence of flower receptivity and pollinator activity on seed number area^{-1} it was necessary to apply treatments to cause differences in these variables. Two synthetic cloth-like materials were used to provide the needed treatments. A transparent floating crop cover was selected since it has been shown to advance flowering in strawberry (Gent, 1990). Shade cloth was also selected since it suppresses dry matter production and may influence partitioning of assimilates within crop canopies, which may alter flower production (Early et al., 1967; Egli, 1988; Hang et al., 1984). These materials were used to modify flower number and flower phenology in field-grown meadowfoam with the objectives of determining if: *i.* a measure of flower number and pollinator activity can be used to estimate seed set and seed yield, and *ii.* the estimate in seed set area^{-1} could be improved by adjusting for stigma receptivity and pollination timing.

MATERIALS AND METHODS

Field experiments were conducted at Oregon State University Schmidt Research Farm near Corvallis, Oregon (44° and 38'N, 123° and 12'W) in 1987-1988 and 1988-1989 on an Amity silt loam (fine-silty, mixed, mesic Argiaquic Xeric Agialboll). Detailed methods are given elsewhere (Materials and Methods, Chapter I). Meadowfoam cv. Mermaid was planted in 15-cm rows on 1 Oct. 1987 and 6 Oct. 1988, at 279 seeds m^{-2}. Dates of 50% emergence were 13 Nov. 1987 and 14 Nov. 1988. Three treatments and a Control were studied. The Cover Early (CE) and the Cover Early Plus Late (CE+L) treatments were created by laying a transparent floating crop cover (trade name Agronet, type M, Beghin Say, Kaysersberg, France) directly on the crop. The Shade treatment was created by placing shade cloth (47% shade, Nicolon Inc., Norcross, Georgia) suspended on a wooden frame approximately 20 cm above the soil surface. Treatments were applied 22 Jan. 1988 and 24 Jan. 1989. Shade and CE treatments were removed at the beginning of rapid elongation of stems -- defined as the time when Control plants had approximately 1 stem, 1 cm in length -- which occurred on 29 Mar. 1988 and 28 Mar. 1989. The CE+L was removed 2 weeks after the beginning of rapid elongation of stems.

Honey bee hives were placed next to the experimental plots during flowering, at a density of approximately five hives ha^{-1}. Foraging honey bee counts were made daily during flowering between 1200 and 1300 h in a marked 0.25 m^2 area in each plot. That count is referred to as the foraging bee density for each day during the flowering period. All bees foraging in the marked area at the first instant of observation were counted. Cumulated foraging bee density (CBD) was the summation of daily foraging bee densities for the flowering period. A 0.1 m^2 area was randomly selected in each plot to determine number of open flowers each day. Flowers were considered open if a honey bee could physically enter the flower. Flowers open by 1100 h were removed and counted each day, and summed to generate cumulated open flowers (COF).

A regression model was used (Table II.1) to relate seeds $flower^{-1}$ to COF and CBD. The equation was:

$$\text{Seeds flower}^{-1}\ (SPF) = a - b\ (COF) + c\ (COF)^2 + d\ (CBD) \qquad (i)$$

Where 'a' is the intercept and 'b', 'c', and 'd' are the coefficients (Table II.1). Total seed number $area^{-1}$ was then calculated:

$$\text{Seed number area}^{-1}\ (SNA) = COF \times SPF \qquad (ii)$$

Substituting equation *i* for SPF in *ii* gives:

$$SNA = a\ (COF) - b\ (COF)^2 + c\ (COF)^3 + d\ (CBD)(COF), \qquad (iii)$$

where SNA, COF, and CBD are expressed in numbers per unit land area.

A "synchrony index" was calculated by multiplying the number of receptive flowers by the foraging bee density for the day of optimum receptivity. Cumulated synchrony index (CSI) for each treatment is the summation of daily calculated synchrony indexes. Stigma receptivity in *Limnanthes alba* occurs 1 to 4 days after anthesis, depending on air temperature (Guerrant, 1984; Kalin, 1971). Similar to earlier work with meadowfoam, we considered anthesis as occurring simultaneously with flower opening (Franz and Jolliff, 1989). The optimum receptivity was then estimated, using the daily maximum air temperature (Jahns, 1990; Franz, 1990). If the maximum temperature for the day the flowers opened was less than or equal to 24.4 °C, the day of optimum receptivity was 2 days following flower opening; if it was greater, the optimum receptivity was the day after opening.

The experimental design was a randomized block with four replications in 1987-1988 and six replications in 1988-1989. Error variances were homogeneous (Federer, 1955) therefore, data for 1987-1988, and 1988-1989 were combined for analysis of variance. An F-test was used to test the equality of error variances (Snedecor and Cochran, 1980). Year was considered a fixed effect. The alpha level was 0.05 for all response variables.

RESULTS

Considerable variation in flower phenology occurred among treatments and years (Fig. II.1, a-b). All treatments had greater cumulated open flowers than the Control (Table II.2). Foraging bee density averaged over treatments, varied between days of bloom, and was considerably larger in 1987-1988 than in 1988-1989 (Fig. II.1, c-d; Table II.2). In 1987-1988, CBD varied among treatments, whereas in 1988-1989 it did not (Figure II.1e-f and Table II.2). The CSI varied among treatments both years (Fig. II.1, g-h).

A multiple regression model, which included COF and CBD, predicted 47% (R^2=0.47) of the total variation in seeds flower^{-1} (Table II.1). Seeds flower^{-1} was linearly (positive) related with CBD and quadratically (negative within the range of experiment observation) related with COF (Table II.1; Fig. II.2). Seeds flower^{-1} was the highest at the lowest COF and highest CBD (Fig. II.2).

Seed number area^{-1} produced was a cubic function of COF and a linear function of CBD (Fig. II.3). Consequently, although seeds flower^{-1} decreased as flower number increased (Fig. II.2), seed number area^{-1} was improved when flower number increased, especially at higher levels of CBD (Fig. II.3).

Using the treatment means for each year and simple linear regression analysis, CBD and COF explained 59 and 55% of the variation in seed number area^{-1}, respectively (regressions not shown). Cumulated synchrony index, however, explained 87% of the variation in seed number area^{-1} produced by the treatments (Fig. II.4). A close investigation of flower phenology, foraging bee densities, and air temperature indicated that only on a few days did high foraging bee densities coincide with the days of optimum stigma receptivity (Fig. II.1, g-h). Consequently, substantially larger variations in seeds flower^{-1} as a function of COF and CBD were explained when the synchrony for stigma receptivity and pollination timing were accounted for, using CSI.

Weight seed^{-1} was not correlated with flower number (r=-0.01; n=40) or seed number area^{-1} (r=-0.27; n=40). However, seed yield was correlated with seed number area^{-1} (r=0.84; n=40). Furthermore, oil content was positively correlated with seed number area^{-1} (r=0.56; n=40), indicating that improvements in seed number area^{-1} will increase oil yield.

DISCUSSION AND CONCLUSION

The importance of flower production in meadowfoam as the major yield component has been discussed in several reports (Jolliff, et al., 1991; Pearson and Jolliff, 1986b; and CHAPTER I). Results of this experiment provide strong evidence that meadowfoam seed yield is vulnerable to the synchrony of stigma receptivity and honey bee pollination. Therefore, genetic, cultural, and environmental variables which influence flower production and opening, or pollinator activity may affect the crop yield. Further research is needed to determine when CSI no longer increases seed number $area^{-1}$ or yield.

Cumulated foraging bee density was positively correlated with COF (r=0.46; n=40), while bloom duration was not greatly influenced. Therefore, this correlation indicates that increasing bloom intensity increases CBD. This agrees with Ribbands' (1949) observation that profuse flowering might be advantageous for attracting foraging honey bees and improving pollination. Pearson and Jolliff (1986a) also reported a positive relationship between numbers of open flowers and foraging bee densities in meadowfoam. Proper timing and placement of honey bee colonies are critical for successful meadowfoam pollination (Burgett et al., 1984; Jahns et al., 1991). Because of the relative attractiveness of competing flowers to foraging honey bees, meadowfoam pollen collection can decline from 100% at first placement of hives, to almost no pollen collected after 7 days (Burgett, 1976). Therefore, introducing new colonies at 3 to 5 day intervals has been recommended (Jolliff et al., 1981; Jahns et al., 1991).

In natural habitat, *Limnanthes* species can have a bloom period which is in a high degree of synchrony with foraging activity of an oligolectic bee *Andrena (Hesperandrena) limnanthis* (Thorp, 1990). Possible benefits for using native insects such as *limnanthis* warrants further investigation. Another bee species, *Osmia lignaria propinqua* Cresson, has also shown promise for pollinating meadowfoam (Jahns, 1990; Jahns and Jolliff, 1991). Suggested benefits of *O. l. propinqua* include reducing the effects of inclement weather on pollinator activity, and the possibility of a developing a large local population, which could be managed to synchronize foraging bee emergence with meadowfoam bloom.

Development of self-pollinating meadowfoam has been suggested (Jolliff, 1981) as a means of decreasing vulnerability to pollinator effects. Potential for development of a self-pollinating meadowfoam cultivar exists (Jolliff et al., 1984; Kalin, 1971). However, inbreeding depression has been substantial (unpublished data, 1990, New-Crops Research Project, Oregon State University), which detracts from development of such cultivars. Meadowfoam oil yield may also be increased and stabilized by increased attractiveness to foraging honey bees and by increased duration of flower receptivity.

Table II.1. Analysis of variance, parameter estimates, and standard error of the estimates for seeds flower^{-1} in 1988 and 1989 as influenced by cumulated open flowers (COF) and cumulated foraging bee density (CBD).

Source or parameter	df	Mean square †	Estimate	Standard error of the estimate	R^2 gain
Model	3	1.265***			
Intercept			3.897	0.739	
COF (Linear)	1	2.470***	-7.294×10^{-4}	2.51×10^{-4}	0.30
COF (Quadratic)	1	0.533*	4.117×10^{-8}	2.00×10^{-8}	0.07
CBD	1	0.794*	8.146×10^{-3}	3.17×10^{-3}	0.10
Error	36	0.120			
Model R^2=0.47					

*, *** Significant at 0.5, 0.01 and 0.001 levels, respectively.
† Mean squares are from sequential sum of squares entered into the model from the top to the bottom of the table.

Table II.2. Means and analysis of variance for cumulated open flowers, and cumulated foraging bee density means for Mermaid meadowfoam as influenced by treatments in 1987-1988 and 1988-1989, and the analysis of variance for these variables.

Year or treatment	Cumulated open flowers	Cumulated bee density
1987-1988	no. m^{-2}	no. m^{-2} $instant^{-1}$
Control	4,855	5.0
CE	5,205	12.0
CE+L	6,777	18.0
Shade	6,570	11.8
1988-1989		
Control	4,487	8.3
CE	6,260	7.7
CE+L	4,810	6.0
Shade	5,322	6.7

Table II.2. (Continued)

Source	df	Cumulated open flowers	Cumulated bee density
Year	1	NS	*
Replication (Year)	8	*	**
Treatment	3	+	*
Year x Treatment	3	*	***
Residual	24		
C.V.		19.7	29.8
R^2		0.65	0.82
Contrast	**df**	**PR>F**	**PR>F**
Control vs. CE	1	*	†**, NS
Control vs. CE+L	1	*	†***, NS
Control vs. Shade	1	*	†**, NS
Year vs. Control vs. CE	1	NS	0.0044
Year vs. Control vs. CE+L	1	NS	0.0001
Year vs. Control vs. Shade	1	NS	0.0021

+, *, **, *** Significance at the 0.1, 0.05, 0.01, and 0.001 levels, respectively.
† Contrasts were done within year since years interacted, PR>F value represents 1987-1988 and 1988-1989, respectively.

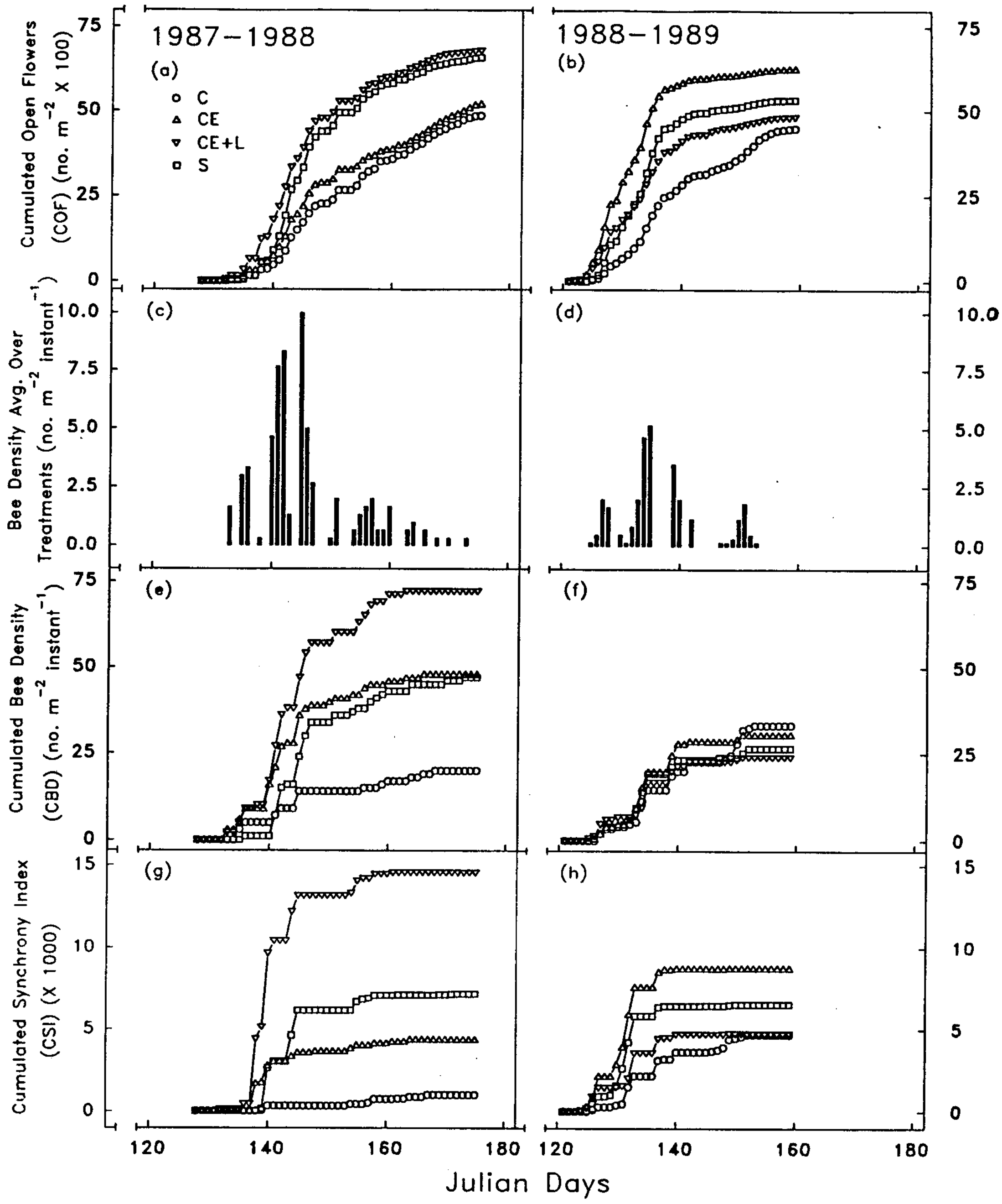

Figure II.1. Cumulated open flowers (a) and (b), foraging bee density for Mermaid meadowfoam averaged over treatments during bloom in 1987-1988 (c) and 1988-1989 (d), cumulated foraging bee density (e) and (f), and cumulated synchrony index (g) and (h) as influenced by treatments during Mermaid meadowfoam bloom in 1987-1988 and 1988-1989 respectively. The treatments include the Control (C), transparent crop cover applied early (CE), transparent crop cover applied early plus late (CE+L), and shade cloth (S).

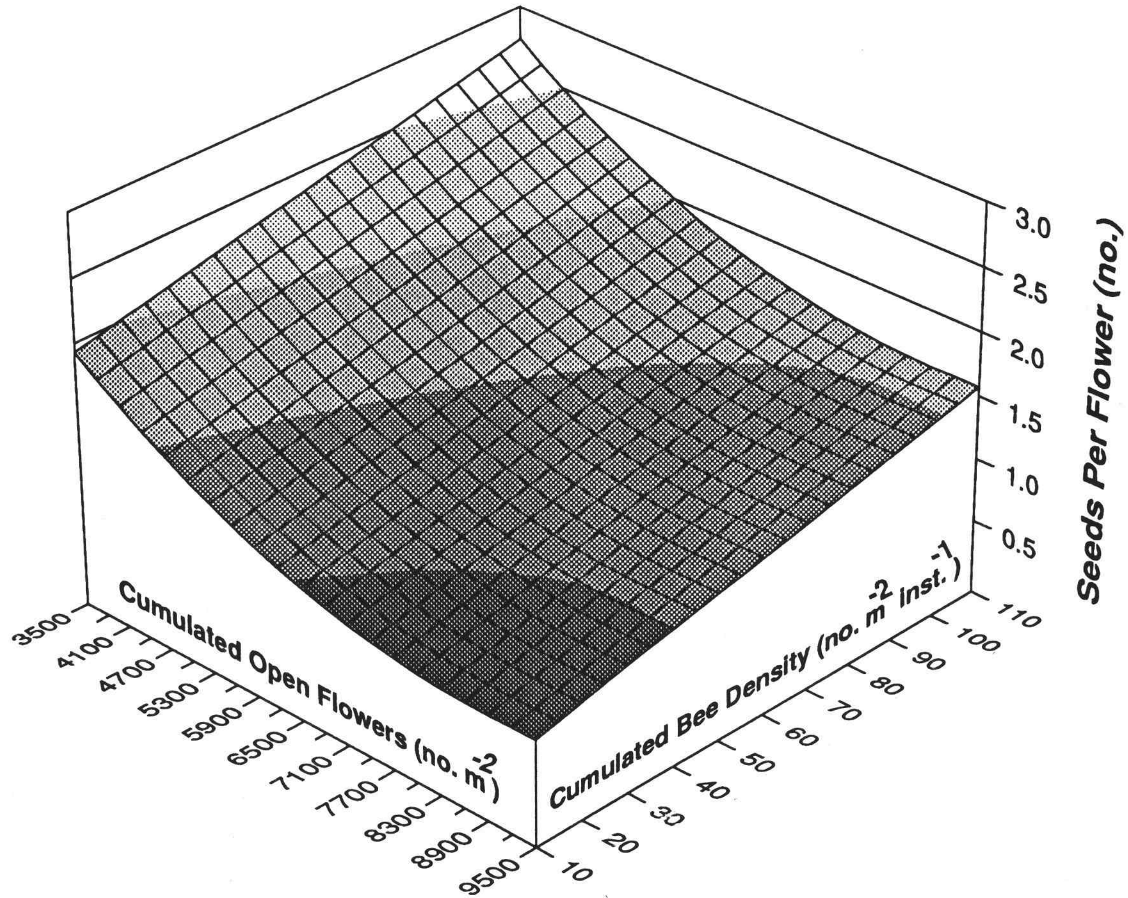

Figure II.2. The influence of cumulated open flowers (COF) and cumulated foraging bee density (CBD) on seeds $flower^{-1}$ (SF) of Mermaid meadowfoam from the combined data collected in 1987-1988 and 1988-1989. The multiple regression model was: $SF = 3.897 - [7.294 \times 10^{-4} \times (COF)] + [4.117 \times 10^{-8} \times (COF^2)] + [8.146 \times 10^{-3} \times (CBD)]$; ($R^2$=0.47).

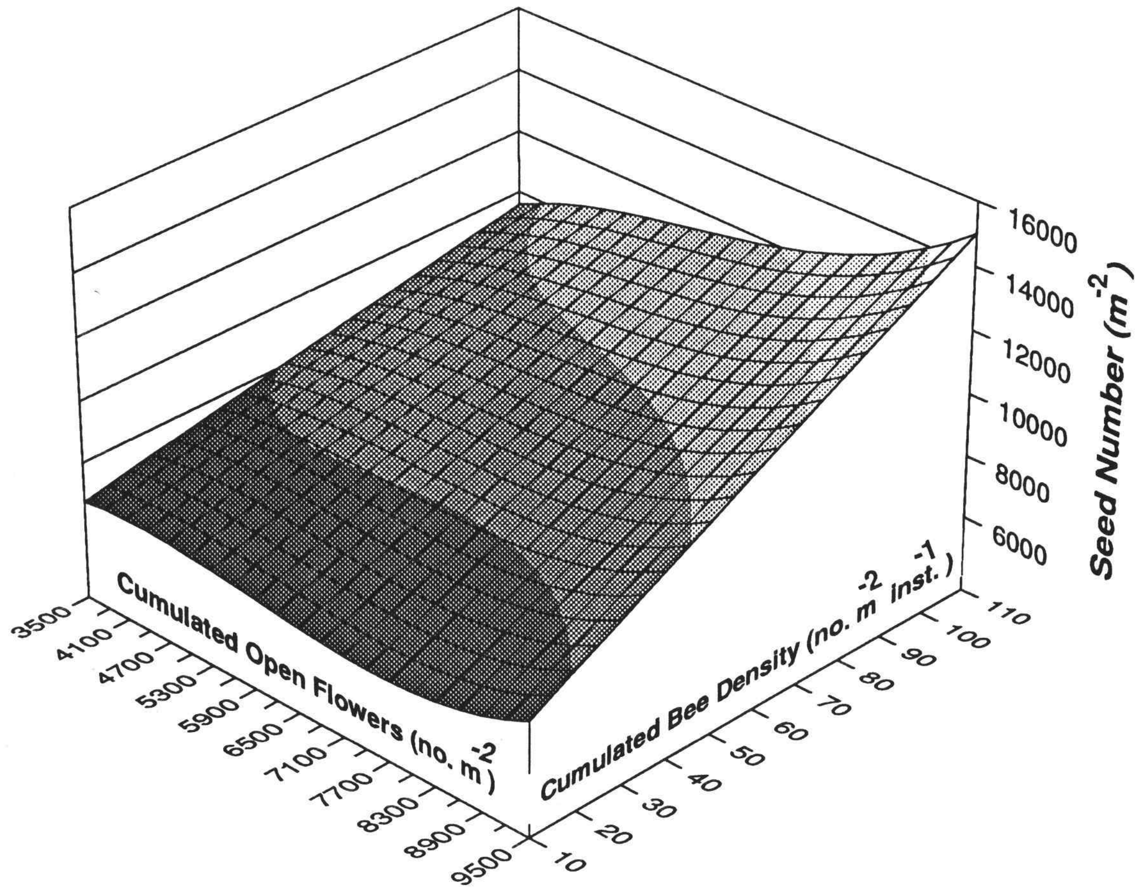

Figure II.3. The influence of cumulated open flowers (COF) and cumulated foraging bee density (CBD) on seed number area^{-1} (SNA) of Mermaid meadowfoam from the combined data collected in 1987-1988 and 1988-1989. The multiple regression equation determined was: SNA = [3.897 (COF)] - [$7.294 \times 10^{-4} \times (COF^2)$] + [$4.117 \times 10^{-8} \times (COF^3)$] + [$8.146 \times 10^{-3} \times (CBD) \times (COF)$].

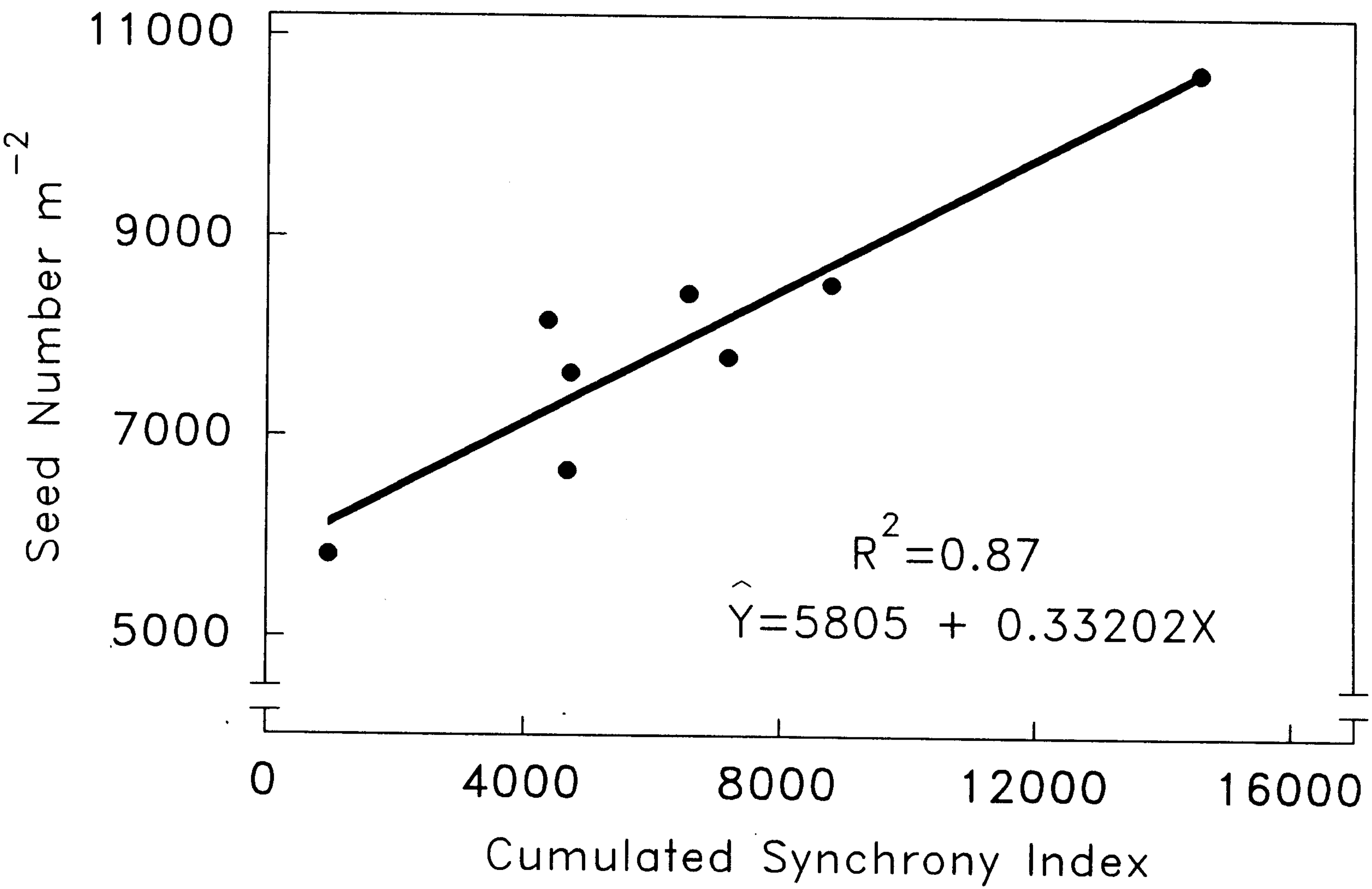

Figure II.4. The relationship between cumulated synchrony index (CSI) for treatment means with seed number area^{-1} from the combined data collected in 1987-1988 and 1988-1989.

CHAPTER III

MEADOWFOAM PHYTOMASS DEVELOPMENT EFFECTS ON FLOWER PRODUCTION

ABSTRACT

Meadowfoam (*Limnanthes alba* Hartw. ex Benth. ssp. *alba* cv. Mermaid) seed yield, and consequently oil yield, has varied considerably among years. High stable oil yield is needed to enhance commercialization. Reports in the literature indicate a negative relationship between seed yield and phytomass production. The objective of this research was to determine the association between flower production and phytomass cumulation and partitioning. Treatments of a transparent floating crop cover (Cover) and shade cloth (Shade) were used to alter phytomass production. Cover and Shade treatments were applied 22 Jan. 1988 and 24 Jan. 1989 and removed 28 Mar. 1988 and 29 Mar. 1989, respectively. Measurements of phytomass production and distribution, leaf area index, crop growth rate, and net assimilation rate were made. Flower production was not significantly correlated with total phytomass produced at two weeks after the beginning of rapid elongation of stems or at the beginning of flowering. However, flower production and seed yield were correlated with the percent of phytomass in stems at the beginning of flowering (r=0.76, n=8; for both correlations). Flower production and seed yield were not associated with greater partitioning to leaves. Therefore, improvement in yield might be realized by increasing flower production through manipulation of cultural practices, environment, or genetics, which would hasten partitioning to stems.

INTRODUCTION

Meadowfoam is a herbaceous winter annual domesticated at Oregon State University (Jolliff, 1981) for its unique seed oil (Earle, et al., 1959; Nikolava-Damyanova, 1990). Seed yield has varied significantly among years. High and stable oil yield is needed to make meadowfoam a more attractive commercial crop.

Little research was found on meadowfoam growth and development. Pearson and Jolliff (1986b) reported a large variation in total above-ground dry matter (phytomass) in mid-April between the two years. Oil yield in the low-phytomass year was 181% greater than when phytomass was high, suggesting that a negative relationship exists between phytomass in mid-April and oil yield at maturity. In California, Krebs and Jain (1985) found yield of *L. alba* accessions to be negatively correlated with both crop growth rate and leaf area at 88 days after sowing. Native *Limnanthes alba* has a relatively high-risk life history/cycle strategy (Ritland and Jain, 1984) and responds quickly to resource availability (Zedler, 1990). Therefore, under the mild and wet cultivated conditions of western Oregon during November through March, it is suspected that *L. alba* may tend to produce excess vegetative dry matter at the expense of seed yield.

Number of flowers has been shown to be an important yield component in meadowfoam, and the most consistent indicator of seed yield (Krebs and Jain, 1985; Jolliff and Seddigh, 1991; Jolliff, et al., 1991; and Pearson and Jolliff, 1986b). Application of 50, 100, and 200 kg N ha^{-1} resulted in 38, 72, and 92% increases in flower production and, consequently, increased seed number $area^{-1}$ (Jolliff, et al., 1991). The increased flower number was also shown to have a positive linear relationship to total dry matter produced. Krebs and Jain (1985) suggested that improvement in seed number $area^{-1}$ in *L. alba* may be possible by selection for increased number of primary stems and, thus, the number of flowers produced.

Early season control of phytomass distribution may be a key element in determining meadowfoam flower production. Therefore, the hypothesis this work was based on is that modification of early biomass production may improve meadowfoam oil yield.

The hypothesis was tested in the field by use of transparent floating crop cover (Cover), and shade cloth (Shade) treatments, which modified early phytomass distribution. Floating crop covers have been used to increase air temperatures (Hall, 1971; Shadbolt and McCoy, 1960; Wells and Loy, 1985). In strawberry (*Fragaria* x *ananassa* Duch.), time of flowering, fruit set, and fruit ripening were hastened in direct relation to the duration row covers were in place in the spring (Gent, 1990). Growth rates of cucumber [*Cucumis sativus* (L.)] were increased by use of covers (Wolfe et al., 1989).

Shade cloth reduces the amount of light received by a crop, suppresses dry matter production, and may influence flower production and partitioning of assimilates within crop canopies (Early et al., 1967; Egli, 1988; Hang et al., 1984).

MATERIALS AND METHODS

Field experiments were conducted at Oregon State University Schmidt Research Farm (44° and 38'N, 123° and 12'W) in 1987-1988 and 1988-1989 on an Amity silt loam (fine-silty, mixed, mesic Argiaquic Xeric Agialboll). Mermaid meadowfoam was planted in 15-cm rows on 1 Oct. 1987 and 6 Oct. 1988 at 280 seeds m^{-2}. Emergence date (50% emergence) was 13 Nov. 1987 and 14 Nov. 1988. The experimental design was a randomized block with four replications in 1987-1988 and six replications in 1988-1989 with a plot size of 3.6 by 6.1 m. The alpha level was 0.05 for all response variables. Three treatments and a Control were studied.

The Cover Early and Cover Early Plus Late treatments were created by laying a transparent floating crop-cover (trade name Agronet, type M, Beghin Say, Kaysersberg, France) directly on the crop. The Shade treatment was created by suspending shade cloth (47% shade, Nicolon Inc., Norcross, Georgia) on a wooden frame approximately 20 cm above the soil surface. All treatments were applied 22 Jan. 1988 and 24 Jan. 1989. Cover Early and Shade treatments were removed at the beginning of rapid elongation of stems -- determined visually, and defined as when Control-plants had approximately 1 stem 1 cm in length. Treatment removal was 29 Mar. 1988 and 28 Mar. 1989. Both years, Cover Early Plus Late was removed 2 weeks after the beginning of rapid elongation of stems. Detailed research methods and weather data were given elsewhere (Chapter I).

To evaluate dry matter accumulation and partitioning, plant samples, including abscised material, were taken at random on thirteen dates between Julian days 7 and 192 in 1987-1988. In 1988-1989, plant samples from 0.10-m^2 areas were taken on eleven dates between Julian days 24 and 173 for leaf area and dry matter determinations. Sample size was 0.15 m^2. Plants were divided into leaves (including petiole), stems (including crown), and buds plus flowers. The dry weight of leaves, stems, and flower buds plus flowers were determined. Leaf area index (LAI) was measured on 0.10-m^2 portion of the sample area. Leaf area was determined using a LI 300 leaf area meter (Li-Cor, Lincoln, NE). Only leaves that were more than 50% green (determined visually) were included in leaf area.

For pollination, honey bee hives were placed next to the experimental plots during flowering at a density of approximately five hives ha^{-1}. At flowering, a 0.1-m^2 area was selected randomly in each plot, and the flowers which opened by 1100 h were counted and removed each day.

Plots were flail-harvested (Carter Manufacturing, Brookston, IN) on 15 July 1988 and 27 June 1989 (Julian days 197 and 178 respectively), and dried 24 hours at 38 °C to a constant weight. Harvested areas of plots were 2.8 m^2 in 1988 and 5.6 m^2 in 1989. Two random 0.14 m^2 areas were vacuumed in each flail-harvested area to determine harvest loss. In 1988, the vacuum-collected samples were threshed and cleaned the same as the flail-harvested samples. In 1989, the vacuum-collected samples were hand-threshed. Seed yield was determined by adding vacuumed seed to the flail-harvested seed.

Polynomial regression equations were fitted to natural logarithm transformations of data to describe changes over time for each response variable in each treatment (Hunt, 1982). Actual measurements were used to compare treatments at selected times (Table III.1). Crop growth rate (CGR) and net assimilation rate (NAR) were derived from regression equations for dry weight and LAI (Hunt, 1982).

RESULTS

Treatment effects of Cover Early and Cover Early Plus Late were similar. Therefore, for ease of graphic interpretation only data for Cover Early (Cover), along with the Control and Shade treatment, are presented. For the majority of the growing season in 1987-1988, Cover increased phytomass whereas shading decreased it. However in 1988-1989 smaller differences in phytomass were created by covering and shading, and maximum phytomass achieved by all treatments was less (Fig. III.1a and III.1b). Averaged over years, the number of open flowers m^{-2} for the Control, Cover, Cover Early plus Late, and Shade were 4634, 5838, 5597, and 5821. A positive correlation ($r=0.76$, $P=0.029$) was found between flower number and the percent of phytomass in stems at the beginning of flowering (Fig. III.2a). Seed yield was also positively correlated ($r=0.76$, $P=0.028$) with the percent of phytomass in stems at the beginning of flowering (approx. first bloom)(Fig. III.2b, Fig. III.3e and Fig. III.3f). Flower number was not significantly correlated with any other response variable at treatment removal or the beginning of flowering (correlations not shown).

Leaf area development in the Cover and Shade treatments tended to increase and decline earlier than in the Control (Fig. III.1c and III.1d). On Julian day 46 in 1988 the Cover and Shade treatments had 41 and 7 % higher leaf area than the Control, respectively (Table III.1). On day 51 in 1989 the Cover and Shade treatments had 138 and 152% more leaf area than the Control, respectively. However, in both years the Cover and Shade had less leaf area than the Control later in the season (Table III.1).

Treatment effects on CGR, like phytomass, was increased by covering and decreased by shading in 1987-1988 and there were only small differences in 1988-1989 which provided little explanation for changes in flower production (Fig. III.3a and III.3b). In both years CGR for all treatments reached its maximum near early bloom and dropped precipitously to near zero by the end of bloom.

Net assimilation rate was lower for the Cover and Shade treatments than in the Control during application of the treatments, whereas the situation was reversed during flowering (Fig. III.3c and III.3d). For all treatments and in both years, NAR was the highest at near peak bloom and decreased sharply to near zero by the end of bloom.

The percent of phytomass in stems was greater in both the Cover and Shade treatments as compared to the Control (III.3e and III.3f). This trend was first apparent after treatment removal. Phytomass distribution to stems for Cover and Shade was more than the Control by 32 and 11% on Julian day 116 in 1988, and by 19 and 17% on Julian day 114 in 1989, respectively (Table III.1). Furthermore, phytomass distribution to buds and flowers for Cover and Shade treatments was higher than the Control by 33 and 35 % on Julian day 130 in 1988, and by 18 and 22 % on Julian day 128 in 1989, respectively (Table III.1). Partitioning to buds plus seeds also was increased for the covered and shaded treatments than the Control (Fig. III.3e and III.3f).

The increased partitioning to stems and buds plus seeds by the Cover and Shade treatments was at the expense of leaf production (Fig. III.3e and III.3f). Phytomass distribution to leaves for Cover and Shade was 21 and 9% less than the Control on Julian day 116 in 1988, and 15 and 18% less on Julian day 114 in 1989, respectively (Table III.1).

DISCUSSION AND CONCLUSION

At the beginning of flowering, percent phytomass in stem tissue was the only measured variable associated with treatment induced increases in flower number. One attribute of stem tissue is carbohydrate storage. In a concurrent study (Fiez, et al., 1991b) stems contained 354 and 94% more ethanol soluble carbohydrates than leaves or flowers, respectively. Also, the level of potentially remobilizable carbohydrate was positively associated with seed yield. Thus, the increase in flowers in this study may have been the result of more potentially remobilizable carbohydrate in stems to support flower bud development.

Cover and Shade reduced the number of primary stems plant^{-1} at 2 weeks after the beginning of rapid elongation of stems (time of CE+L removal) (Chapter I). Perhaps the Cover and Shade treatments had early initiation of fewer stems plant^{-1}, which apparently were stronger sinks than competing stems (or stem primordia), thereby limiting the growth of other axillary stem primordia and providing fewer more robust stems. Larger diameter stems were visually apparent in the Shade treatment. Also visually apparent at time of treatment removal was increased elongation of stems by the Cover and Shade treatments.

In *Limnanthes alba*, seed yield has been shown, by a stepwise multiple regression model, to be associated with fewer basal stems, supporting our results (Krebs and Jain, 1985). However, in the same experiment simple correlations of flower number was positively associated with basal branches plant^{-1}, which is not consistent with our results. Krebs and Jain (1985) measured genetic variation between *Limnanthes alba* genotypes whereas, in this study shading and covering induced variation with one cultivar, which may provide different results. Pierce and Jain (1976) also reported a positive association of basal branches plant^{-1} and flower number of meadowfoam plants grown in pots in the phytotron. However, flower production of single plants grown in pots may react considerably different as compared to solid stand in the field.

Native *Limnanthes alba* has a relatively high-risk life history/cycle strategy (Ritland and Jain, 1984), and responds quickly to resource availability (Zedler, 1990). The result can be an excess commitment to development of leaf mass and numbers of primary stems if resources are available early in the season. Then, increased intra-plant competition may cause some flower buds to senesce resulting in fewer open flowers. The mild and wet climate of western Oregon with more available resources than in native meadowfoam habitat may frequently result in growth over-commitment. High nitrogen fertility might be expected to accentuate such a tendency (Jolliff and Seddigh, 1991).

Observations in the laboratory indicated that Mermaid seedlings have little or no juvenility and may be initiated soon after germination. We have dissected plants from the field as early as December and found reproductive buds. Numerous primordia form on meadowfoam crowns. These buds often develop during winter months if temperatures are mild. Usually, growth of these buds is increased by late February. Ultimately this primordia would develop into the number of buds produced. The total number of flower buds produced in this study was not influenced and numbers were low in comparison to the number of developed flowers in high yielding years (Chapter I)(unpublished data, 1990, New Crop Project, Oregon State University). This supports a hypothesis that determination of the number of flower buds occurred early in plant development and before shading and covering had a major impact on plant parameters in this experiment. Further research is needed to confirm the timing of reproductive initiation in meadowfoam and its influence on flower production.

In conclusion, meadowfoam flower production and seed yield may be increased by avoiding over-commitment to production of leaf mass and excessive number of primary stems. Stored carbohydrates in the stems of the shade and cover treatments possibly provided nutritional support for the higher rate of flower bud development compared to the Control. Genetic and management manipulation to avoid over-commitment may be fruitful.

Table III.1. Treatment means for leaf area index and phytomass distribution (leaves, stems, and buds and flowers) at different Julian days in 1987-1988 and 1988-1989.

Treatments	Leaf Area Index				Phytomass Distribution (%)					
					Leaves		Stems		Buds and Flowers	
	87-88		88-89		87-88	88-89	87-88	88-89	87-88	88-89
Julian Day	46	130	51	114	116	114	116	114	130	128
Control	0.59	2.72	0.21	2.71	52.2	51.1	36.7	38.3	11.6	12.4
Cover Early	0.83	2.13	0.50	2.38	41.1	43.2	48.5	45.6	15.4	14.7
Shade	0.63	2.30	0.53	2.25	47.0	42.1	40.6	45.1	15.7	15.1

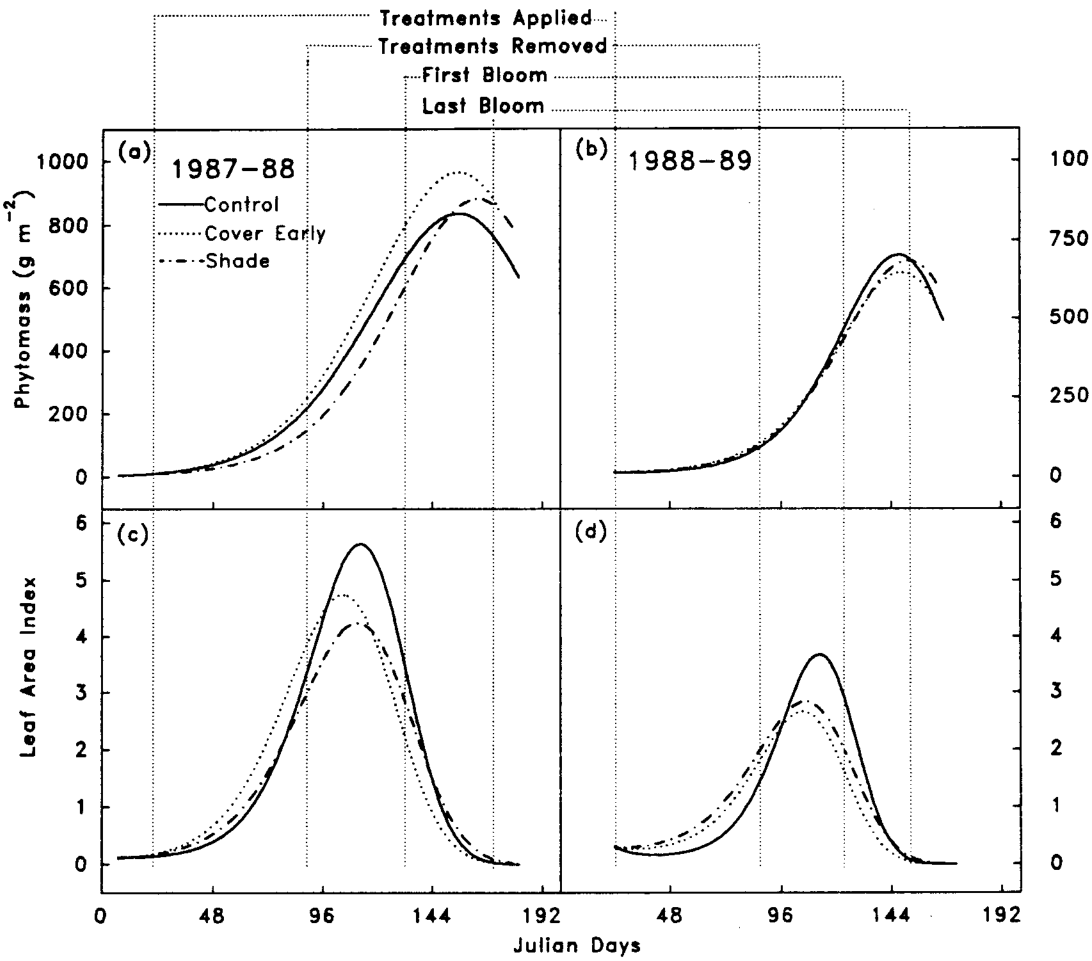

Figure III.1. Phytomass and leaf area index for Cover Early, Shade and Control in 1987-1988 and 1988-1989.

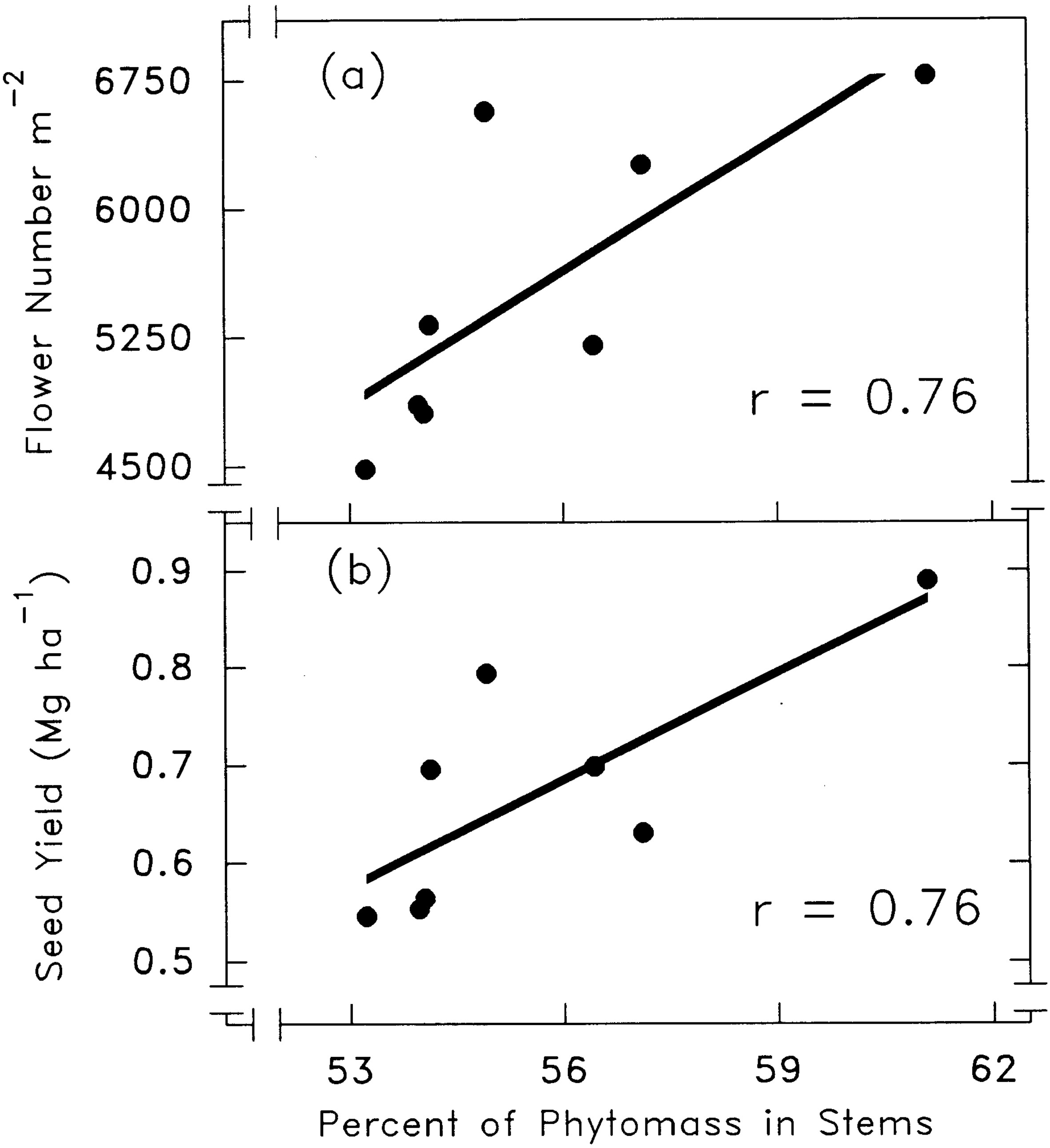

Figure III.2. Correlations of percent of total phytomass in stems at the beginning of flowering with the cumulated open flowers and seed yield.

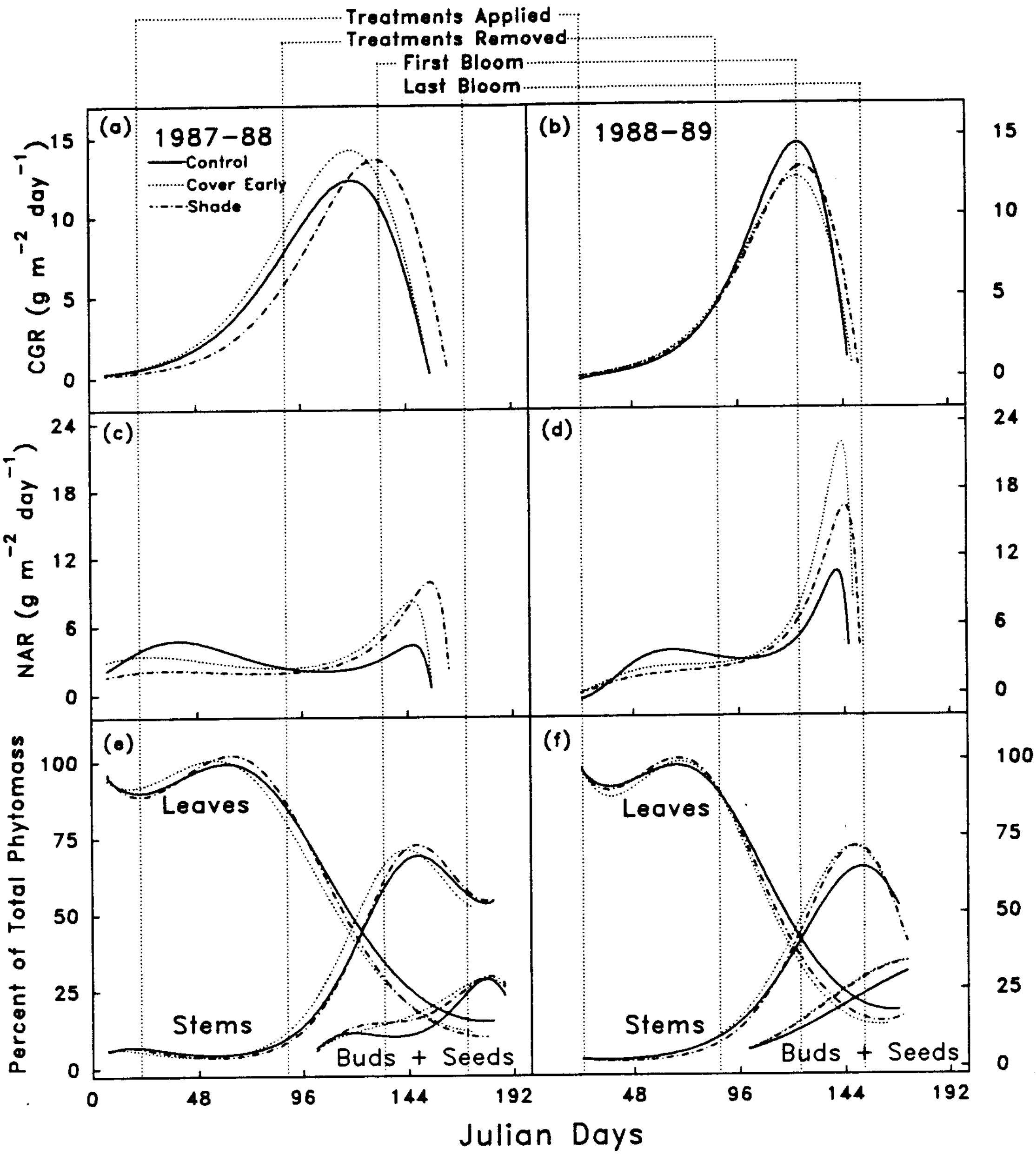

Figure III.3. Crop growth rate (CGR), net assimilation rate (NAR), and percent of total phytomass in leaves, stems, and buds + seeds in 1987-1988 and 1988-1989.

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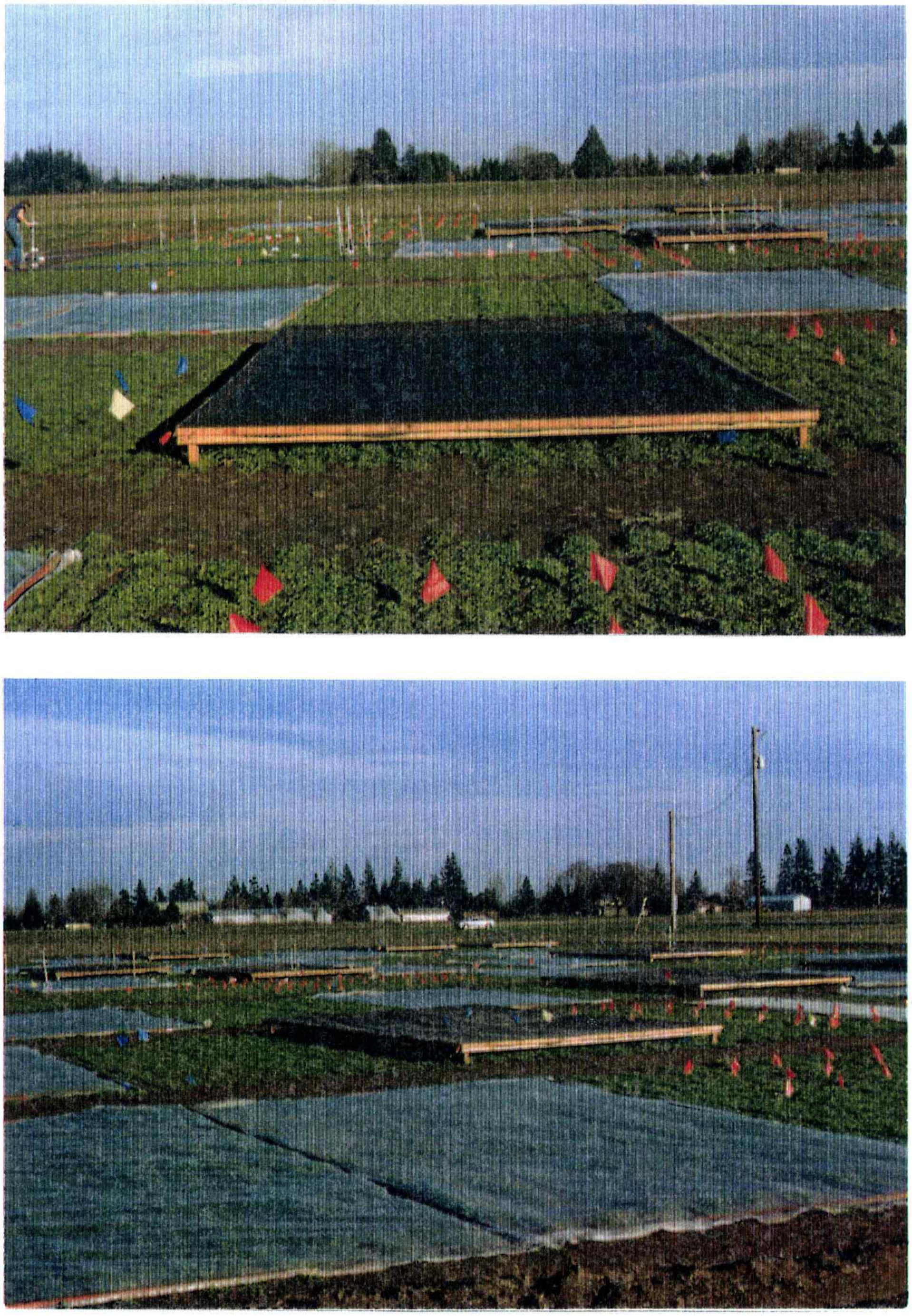
APPENDIX



Appendix Figure I.1. Pictures of shade cloth (black) and transparent floating crop cover (white) during application.

Appendix Figure I.2. Pictures of Mermaid meadowfoam plants with leaves removed. Top picture shows differences in stem elongation of single plants from the Control as influenced by Cover Early (Agronet 67 Day), Cover Early Plus Late (Agronet 81 Day), and Shade on 11 April 1988. Bottom picture contrasts 0.1 m^2 samples from the Control with Cover Early (Agronet 63 Day), Cover Early Plus Late (Agronet 71 Day), and Shade on 10 April 1989.

Appendix Table I.1. Average, maximum and minimum temperatures (°C) from Julian day 7 to 102 for the Control (C) and during treatment application for Cover Early Plus Late (CE+L) and Shade (S) in 1988.

Julian Day in 1988	Avg. temp.			Max. temp.			Min. temp.		
	C	CE+L	S	C	CE+L	S	C	CE+L	S
7	2.59			5.50			1.80		
8	4.18			7.70			1.60		
9	7.28			10.30			4.10		
10	5.20			6.70			3.60		
11	5.13			10.30			1.60		
12	3.41			7.70			0.50		
13	6.62			9.50			3.70		
14	8.93			11.43			4.43		
15	4.37			6.77			2.17		
16	4.57			11.10			2.13		
17	2.19			5.83			-0.03		
18	2.97			6.33			0.43		
19	5.13			14.83			0.07		
20	6.57			15.03			0.10		
21	2.60			6.60			-0.30		
22	4.51	4.85	3.78	6.65	7.50	7.78	2.10	2.50	1.08
23	5.49	5.84	3.78	10.13	11.63	7.78	2.65	2.73	1.08
24	3.03	3.67	3.78	8.18	9.60	7.78	-0.85	-0.08	1.08
25	2.18	3.54	3.78	8.28	9.83	7.78	-0.03	1.10	1.08
26	3.29	3.98	3.78	5.96	7.97	7.78	0.17	1.55	1.08
27	5.71	6.58	5.60	10.97	13.53	11.07	3.10	3.77	2.93
28	8.20	8.46	7.93	13.23	13.00	12.63	3.83	4.03	3.87
29	7.08	7.14	6.95	11.67	11.90	11.67	1.13	1.40	1.07
30	3.42	3.94	3.50	7.90	8.13	7.83	-1.20	-0.47	-1.00
31	3.46	4.04	3.66	6.97	9.60	8.13	0.47	1.40	0.93
32	-0.14	0.45	-0.51	7.00	7.27	4.43	-3.77	-3.50	-4.40
33	0.88	1.52	0.33	13.07	12.10	9.97	-4.63	-4.03	-4.63
34	3.83	3.82	2.60	15.70	13.93	12.03	-1.53	-1.00	-1.93
35	0.88	1.68	1.05	4.57	5.83	5.37	-2.63	-2.07	-2.90
36	2.53	3.01	2.71	9.73	9.20	8.50	0.00	0.33	0.20
37	6.25	6.29	5.95	12.23	12.10	11.70	1.80	2.03	1.97
38	7.75	7.78	7.42	11.70	11.50	11.13	4.13	4.23	4.00
39	9.78	9.71	9.50	12.60	12.43	11.93	7.37	7.47	7.23
40	8.81	8.83	8.74	10.13	10.10	10.00	7.60	7.53	7.50
41	10.69	10.42	9.78	21.20	19.40	16.50	4.13	4.37	4.17
42	7.50	8.48	7.74	12.87	16.23	13.00	4.37	4.77	4.67
43	7.52	7.73	7.53	11.80	12.47	11.43	5.33	5.00	5.27
44	6.18	6.58	6.03	11.67	12.87	11.00	1.73	2.10	2.37
45	6.52	7.29	6.62	12.90	15.07	12.93	0.27	1.40	1.13
46	7.03	7.60	7.10	13.47	16.23	14.37	2.67	3.63	3.13
47	6.13	7.56	5.88	15.00	19.70	14.30	-0.17	1.10	0.87
48	3.87	4.27	3.93	11.70	12.83	11.07	-0.77	0.47	0.13
49	6.24	7.23	6.11	14.13	16.97	13.07	0.10	0.87	0.97
50	8.84	9.33	7.94	16.03	19.77	14.83	2.03	2.27	2.60
51	4.48	5.38	4.46	12.20	14.43	11.53	-0.43	0.67	0.20
52	6.96	8.07	6.78	21.00	23.00	17.17	0.53	1.70	1.27
53	5.86	6.75	5.33	15.30	17.40	12.47	-0.27	0.73	0.23
54	5.46	6.37	5.66	18.03	21.00	18.57	-1.83	-0.13	-0.77
55	7.17	8.92	7.03	19.13	26.43	19.63	-1.43	-0.50	-0.47

(Continued)

Appendix Table I.1. (Continued)

Julian Day in 1988	Avg. temp. C	Avg. temp. CE+L	Avg. temp. S	Max. temp. C	Max. temp. CE+L	Max. temp. S	Min. temp. C	Min. temp. CE+L	Min. temp. S
56	8.13	9.20	7.87	23.63	25.87	20.57	-0.27	1.10	0.70
57	9.94	10.63	9.18	22.10	23.30	18.20	3.40	4.27	4.03
58	9.67	10.78	9.30	21.30	24.80	20.23	1.77	3.10	2.77
59	9.53	10.44	9.24	21.67	22.03	19.13	1.40	3.23	2.57
60	10.13	10.73	10.01	19.97	20.73	17.33	4.97	5.70	5.27
61	9.03	9.90	9.04	17.97	19.53	15.90	4.20	5.63	5.17
62	7.76	8.35	7.93	12.20	12.27	10.90	3.27	4.77	4.30
63	8.91	9.88	8.76	20.17	21.27	17.27	0.43	2.40	1.93
64	8.52	9.09	8.68	12.83	12.77	11.37	0.23	2.27	2.07
65	5.43	6.23	5.99	10.47	10.97	9.97	0.33	2.30	2.10
66	6.62	7.53	6.73	19.17	19.03	15.93	0.07	2.00	1.77
67	7.56	7.67	6.24	18.67	17.87	15.23	-1.17	0.13	0.13
68	5.59	6.32	5.99	9.40	10.00	9.37	0.57	2.33	1.67
69	6.52	6.93	6.41	13.50	13.07	10.97	3.43	3.80	3.90
70	6.50	7.05	6.25	20.90	19.33	16.00	0.13	0.83	0.57
71	6.89	7.35	6.24	20.27	21.17	16.73	-2.90	-0.60	-0.50
72	7.39	8.09	6.80	22.30	22.03	17.90	-3.10	-0.43	-0.43
73	7.52	8.25	6.88	20.23	19.57	16.97	-2.20	0.27	0.10
74	7.72	8.51	7.15	22.63	21.90	18.17	-2.43	0.87	-0.50
75	9.38	8.89	7.77	21.43	20.97	16.83	0.37	1.10	1.43
76	11.90	10.27	9.19	23.97	22.93	18.53	2.33	2.30	2.80
77	9.57	10.02	8.15	22.63	23.03	17.43	-2.03	1.03	0.70
78	11.25	10.97	8.57	31.13	25.90	20.30	-1.77	1.23	0.50
79	11.39	11.08	9.43	26.57	24.23	20.07	-0.13	2.33	1.57
80	11.32	11.06	10.47	13.80	13.30	12.17	7.87	8.20	8.17
81	9.15	9.49	8.67	18.17	16.73	14.00	2.77	5.00	4.03
82	9.08	8.98	8.59	15.63	14.03	12.00	5.23	5.83	6.00
83	8.40	8.40	8.03	15.10	14.03	12.17	4.80	5.50	5.73
84	6.68	7.07	7.04	8.23	8.27	8.23	4.67	5.70	5.87
85	10.75	10.61	10.18	17.27	15.73	13.63	7.63	8.27	8.23
86	8.01	8.27	7.99	11.97	11.93	11.50	2.27	3.20	3.47
87	7.79	8.14	6.80	20.63	18.53	13.90	0.80	2.63	2.43
88	8.49	8.36	7.63	23.37	19.73	17.00	-0.40	1.30	1.03
89	8.28	8.11		17.90	14.40		2.00	3.40	
90	8.68	8.49		26.60	20.27		1.30	2.60	
91	11.85	10.77		27.23	21.80		1.20	2.27	
92	14.47	13.07		32.20	25.27		2.20	3.83	
93	9.81	10.26		11.67	11.80		8.40	9.07	
94	7.41	8.44		13.47	12.73		4.00	5.37	
95	8.84	9.42		18.73	19.20		3.23	4.70	
96	10.85	10.97		21.47	21.03		6.47	6.83	
97	8.78	9.19		11.30	12.17		4.53	5.77	
98	7.28	8.05		16.83	17.07		2.43	3.90	
99	7.43	7.28		17.47	15.37		-0.37	2.07	
100	12.11	10.58		20.90	18.90		5.07	4.43	
101	14.44	13.20		27.33	24.80		3.53	3.60	
102	6.64	6.83		11.23	10.80		4.80	5.37	

Appendix Table I.2. Average, maximum and minimum temperatures (°C) of the Control (C), Cover Early Plus Late (CE+L), and Shade (S) during treatment application in 1989.

Julian Day in	Avg. temp.			Max. temp.			Min. temp.		
1989	C	CE+L	S	C	CE+L	S	C	CE+L	S
25	2.17	2.43	2.45	6.59	8.26	7.12	-1.21	-1.10	-1.05
26	2.19	2.81	2.63	9.06	10.62	8.49	-1.70	-1.58	-1.08
27	2.38	3.27	3.02	5.36	6.80	5.92	0.41	1.06	0.92
28	4.13	4.56	4.27	12.12	13.50	11.66	-2.22	-1.48	-1.45
29	3.80	4.91	3.79	15.94	18.42	13.60	-3.09	-2.06	-1.99
29	7.49	7.81	6.48	20.27	20.11	16.40	0.87	2.03	1.38
30	7.43	7.91	7.50	15.12	16.08	14.67	0.93	2.15	1.48
31	4.20	4.96	4.57	11.20	14.36	11.49	0.15	0.85	0.78
32	0.02	1.83	1.43	2.35	4.46	2.12	-1.86	0.45	0.42
33	-2.13	0.23	0.20	0.30	1.68	1.61	-6.41	-4.31	-5.65
34	-4.58	-2.50	-1.91	-1.59	-0.59	-0.02	-9.47	-6.40	-9.06
35	-4.92	-3.33	-4.71	-2.02	-1.18	-2.04	-9.29	-5.75	-10.23
36	-3.49	-2.98	-3.29	-0.70	-0.24	-0.66	-8.04	-6.35	-5.74
37	-2.51	-2.49	-2.88	0.01	0.55	0.09	-6.53	-5.36	-4.98
38	-3.88	-2.73	-2.80	0.17	1.66	0.94	-7.87	-6.06	-5.63
39	-3.02	-2.02	-2.44	0.26	1.26	0.97	-8.09	-5.93	-6.40
40	-1.39	-1.00	-0.70	5.00	4.61	5.89	-5.03	-3.89	-3.63
41	0.48	1.02	0.95	4.15	5.80	5.87	-2.09	-1.45	-1.38
42	1.49	2.86	1.81	5.78	9.71	7.13	-0.57	-0.43	-0.39
43	2.54	4.42	3.03	10.00	13.33	12.44	-1.53	-0.99	-1.85
44	2.74	3.99	3.24	6.42	8.16	6.60	0.51	1.71	1.06
45	3.03	4.52	3.74	16.30	19.50	16.75	-2.46	-1.14	-1.81
46	2.54	3.93	3.20	12.93	15.16	13.09	-3.87	-2.83	-2.95
47	6.22	6.38	6.30	8.81	9.09	8.86	3.14	3.73	3.42
48	7.77	7.84	7.75	10.25	10.62	10.35	6.54	6.66	6.64
49	6.59	7.11	6.91	9.89	11.00	10.48	4.95	5.09	5.16
50	6.89	7.87	7.28	15.23	17.66	15.80	2.72	3.34	3.25
51	8.50	9.36	8.71	17.53	19.36	17.87	2.67	3.88	3.53
52	6.66	7.50	7.07	10.79	12.68	11.43	2.46	3.48	3.11
53	7.35	7.68	7.43	12.29	12.69	11.51	1.76	2.30	2.38
54	5.27	5.89	5.63	9.33	9.88	9.60	0.36	1.45	1.00
55	4.21	5.60	4.92	15.97	18.18	16.49	-1.90	-0.21	-0.87
56	6.64	7.89	7.14	17.94	21.07	19.21	0.68	2.20	1.50
57	4.05	5.05	4.65	14.51	15.05	14.37	-0.26	0.14	0.46
58	5.45	6.88	6.23	16.94	19.32	17.48	0.79	1.46	1.44
59	4.93	6.36	5.72	17.64	20.04	18.28	-2.30	-0.22	-1.11
60	4.89	5.56	5.44	9.25	10.58	9.44	0.12	1.50	1.38
61	2.27	3.42	3.08	9.63	15.06	10.64	-2.68	-1.69	-1.47
62	2.59	4.33	3.58	14.54	19.01	13.60	-1.85	-1.06	-0.77
63	1.45	2.52	2.28	3.07	4.68	4.05	-0.62	-0.02	0.23
64	7.08	7.33	7.19	12.81	12.91	12.63	2.44	3.06	2.96
65	7.86	8.09	7.98	14.25	14.70	13.23	0.86	1.67	2.06
66	6.78	7.89	7.24	17.94	20.51	17.03	0.00	1.21	1.45
67	8.69	10.42	9.01	23.15	27.30	22.06	-0.33	1.03	0.92
68	10.61	11.43	10.70	21.39	24.42	20.77	7.03	7.61	7.32
69	10.29	11.24	10.44	17.85	20.67	17.21	4.65	5.35	5.24

(Continued)

Appendix Table I.2. (Continued)

Julian Day in 1989	Avg. temp.			Max. temp.			Min. temp.		
	C	CE+L	S	C	CE+L	S	C	CE+L	S
70	10.84	11.25	10.85	19.47	21.89	18.80	6.11	6.91	7.00
71	9.07	9.86	9.43	16.42	17.92	15.10	5.62	6.30	6.30
72	4.77	5.57	5.32	10.91	11.35	9.42	1.99	2.61	2.89
73	6.17	6.99	6.57	11.57	13.36	11.41	1.80	2.18	2.35
74	10.76	12.02	11.05	23.14	26.74	22.15	5.75	6.48	6.25
75	8.47	9.72	9.03	17.48	20.54	17.29	4.06	5.36	5.67
76	6.96	8.23	7.45	12.58	16.53	11.83	3.52	4.33	4.45
77	7.54	8.76	8.03	16.43	19.47	15.23	0.60	1.89	2.42
78	9.32	10.98	9.27	22.56	27.78	19.77	2.35	3.67	3.87
79	8.19	9.14	8.41	18.00	18.81	15.91	-1.04	0.83	0.70
80	9.56	10.60	9.76	18.05	20.57	16.62	3.73	5.31	5.33
81	8.88	10.48	9.08	21.68	26.09	20.21	3.80	4.36	4.70
82	8.53	9.71	8.42	17.90	22.03	16.21	0.96	1.72	2.15
83	9.24	10.34	9.64	13.16	14.60	13.15	6.39	7.66	7.19
84	8.04	9.34	8.69	18.26	21.31	17.12	1.49	3.10	3.12
85	5.92	6.75	6.58	9.21	10.29	9.40	2.60	4.01	4.04
86	8.16	8.64		11.81	12.70		6.43	6.73	
87	8.89	10.03		20.08	23.54		5.06	6.17	
88	8.37	10.19		21.37	25.69		2.86	4.01	
89	6.75	7.97		10.82	11.81		2.81	4.33	
90	8.91	10.49		20.44	23.20		1.63	3.01	
91	7.43	8.23		14.48	15.98		3.25	4.22	
92	7.32	8.80		17.54	20.77		2.10	3.57	
93	8.96	10.53		18.34	21.08		2.89	4.23	
94	10.44	11.43		16.57	18.45		6.68	8.08	
95	14.96	15.84		28.16	29.29		8.60	9.38	
96	15.37	16.07		27.52	29.01		6.57	7.63	
97	13.98	14.69		24.15	25.43		8.08	8.97	
98	13.40	13.94		24.98	25.63		6.88	7.41	
99	14.05	13.79		25.28	25.39		6.06	6.84	

Appendix I.3. Accumulated Growing Degree Days (GDD) from emergence to physiological maturity for the Control (C), Cover Early (CE), Cover Early Plus Late (CE+L), and Shade (S) in 1987-1988 and 1988-1989. If mean temperature for the day was > 0 °C then: GDD = Max. temp + Min. temp / 2. If mean temperature for day was < 0 °C then GDD = 0.

Year	Julian	Accum. GDD				Year	Julian	Accum. GDD			
	Day	C	CE	CE+L	S		Day	C	CE	CE+L	S
87	317	15	15	15	15	88	318	7	7	7	7
87	318	24	24	24	24	88	319	15	15	15	15
87	319	32	32	32	32	88	320	25	25	25	25
87	320	38	38	38	38	88	321	32	32	32	32
87	321	48	48	48	48	88	322	39	39	39	39
87	322	55	55	55	55	88	323	44	44	44	44
87	323	63	63	63	63	88	324	50	50	50	50
87	324	71	71	71	71	88	325	59	59	59	59
87	325	81	81	81	81	88	326	69	69	69	69
87	326	91	91	91	91	88	327	78	78	78	78
87	327	98	98	98	98	88	328	84	84	84	84
87	328	107	107	107	107	88	329	89	89	89	89
87	329	113	113	113	113	88	330	94	94	94	94
87	330	118	118	118	118	88	331	100	100	100	100
87	331	122	122	122	122	88	332	106	106	106	106
87	332	125	125	125	125	88	333	113	113	113	113
87	333	129	129	129	129	88	334	117	117	117	117
87	334	132	132	132	132	88	335	120	120	120	120
87	335	142	142	142	142	88	336	125	125	125	125
87	336	151	151	151	151	88	337	128	128	128	128
87	337	161	161	161	161	88	338	130	130	130	130
87	338	169	169	169	169	88	339	133	133	133	133
87	339	177	177	177	177	88	340	141	141	141	141
87	340	186	186	186	186	88	341	151	151	151	151
87	341	193	193	193	193	88	342	158	158	158	158
87	342	201	201	201	201	88	343	164	164	164	164
87	343	209	209	209	209	88	344	173	173	173	173
87	344	219	219	219	219	88	345	180	180	180	180
87	345	226	226	226	226	88	346	187	187	187	187
87	346	230	230	230	230	88	347	195	195	195	195
87	347	233	233	233	233	88	348	200	200	200	200
87	348	234	234	234	234	88	349	205	205	205	205
87	349	237	237	237	237	88	350	211	211	211	211
87	350	238	238	238	238	88	351	214	214	214	214
87	351	238	238	238	238	88	352	218	218	218	218
87	352	240	240	240	240	88	353	222	222	222	222
87	353	241	241	241	241	88	354	228	228	228	228
87	354	243	243	243	243	88	355	232	232	232	232
87	355	246	246	246	246	88	356	239	239	239	239
87	356	251	251	251	251	88	357	243	243	243	243
87	357	255	255	255	255	88	358	247	247	247	247
87	358	257	257	257	257	88	359	249	249	249	249
87	359	257	257	257	257	88	360	251	251	251	251
87	360	257	257	257	257	88	361	254	254	254	254
87	361	257	257	257	257	88	362	257	257	257	257
87	362	257	257	257	257	88	363	261	261	261	261

(Continued)

Appendix I.3. (Continued)

Year	Julian Day	Accum. GDD C	CE	CE+L	S	Year	Julian Day	Accum. GDD C	CE	CE+L	S
87	363	258	258	258	258	88	364	267	267	267	267
87	364	262	262	262	262	88	365	271	271	271	271
87	365	265	265	265	265	89	1	276	276	276	276
88	1	268	268	268	268	89	2	283	283	283	283
88	2	269	269	269	269	89	3	291	291	291	291
88	3	269	269	269	269	89	4	300	300	300	300
88	4	269	269	269	269	89	5	306	306	306	306
88	5	269	269	269	269	89	6	309	309	309	309
88	6	270	270	270	270	89	7	313	313	313	313
88	7	272	272	272	272	89	8	316	316	316	316
88	8	274	274	274	274	89	9	322	322	322	322
88	9	279	279	279	279	89	10	328	328	328	328
88	10	287	287	287	287	89	11	335	335	335	335
88	11	292	292	292	292	89	12	339	339	339	339
88	12	298	298	298	298	89	13	344	344	344	344
88	13	303	303	303	303	89	14	347	347	347	347
88	14	311	311	311	311	89	15	351	351	351	351
88	15	318	318	318	318	89	16	359	359	359	359
88	16	323	323	323	323	89	17	368	368	368	368
88	17	327	327	327	327	89	18	376	376	376	376
88	18	330	330	330	330	89	19	384	384	384	384
88	19	333	333	333	333	89	20	391	391	391	391
88	20	339	339	339	339	89	21	399	399	399	399
88	21	344	344	344	344	89	22	402	402	402	402
88	22	349	350	350	350	89	23	404	404	404	404
88	23	355	359	359	356	89	24	404	404	404	404
88	24	359	366	366	362	89	25	407	408	408	407
88	25	363	372	372	367	89	26	411	412	412	411
88	26	366	378	378	373	89	27	413	416	416	414
88	27	373	388	388	381	89	28	418	422	422	419
88	28	381	399	399	392	89	29	425	430	430	425
88	29	388	409	409	401	89	30	435	441	441	434
88	30	391	415	415	407	89	31	443	451	451	442
88	31	395	422	422	413	89	32	449	458	458	448
88	32	396	425	425	415	89	33	449	461	461	450
88	33	401	432	432	420	89	34	449	461	461	450
88	34	408	441	441	427	89	35	449	461	461	450
88	35	409	445	445	430	89	36	449	461	461	450
88	36	414	451	451	436	89	37	449	461	461	450
88	37	421	460	460	445	89	38	449	461	461	450
88	38	428	470	470	454	89	39	449	461	461	450
88	39	438	481	481	465	89	40	449	461	461	450
88	40	447	490	490	474	89	41	449	461	461	451
88	41	460	505	505	487	89	42	450	463	463	453
88	42	469	518	518	497	89	43	453	468	468	456
88	43	477	528	528	507	89	44	457	474	474	462
88	44	484	537	537	515	89	45	461	479	479	465
88	45	490	549	549	525	89	46	468	488	488	473
88	46	499	560	560	536	89	47	472	494	494	478
88	47	506	574	574	546	89	48	478	501	501	484
88	48	511	583	583	554	89	49	486	509	509	493
88	49	519	595	595	563	89	50	494	517	517	500

(Continued)

Appendix I.3. (Continued)

Year	Julian Day	Accum. GDD C	CE	CE+L	S	Year	Julian Day	Accum. GDD C	CE	CE+L	S
88	50	528	609	609	575	89	51	503	528	528	510
88	51	533	619	619	583	89	52	513	539	539	521
88	52	544	635	635	595	89	53	520	548	548	528
88	53	552	647	647	603	89	54	527	555	555	535
88	54	560	661	661	616	89	55	531	561	561	540
88	55	569	678	678	629	89	56	538	570	570	548
88	56	580	696	696	643	89	57	548	581	581	558
88	57	593	713	713	657	89	58	555	589	589	566
88	58	605	730	730	672	89	59	564	599	599	575
88	59	616	747	747	686	89	60	571	609	609	584
88	60	629	762	762	699	89	61	576	615	615	589
88	61	640	777	777	712	89	62	580	622	622	594
88	62	647	787	787	721	89	63	586	631	631	600
88	63	658	803	803	734	89	64	587	633	633	602
88	64	664	814	814	744	89	65	595	641	641	610
88	65	670	823	823	752	89	66	602	649	649	618
88	66	679	836	836	764	89	67	611	660	660	627
88	67	688	849	849	774	89	68	623	674	674	639
88	68	693	857	857	782	89	69	637	690	690	653
88	69	702	867	867	791	89	70	648	703	703	664
88	70	712	880	880	802	89	71	661	718	718	677
88	71	721	894	894	813	89	72	672	730	730	687
88	72	730	909	909	826	89	73	678	737	737	694
88	73	739	923	923	838	89	74	685	745	745	700
88	74	749	938	938	850	89	75	700	761	761	715
88	75	760	953	953	863	89	76	710	774	774	726
88	76	773	970	970	876	89	77	718	785	785	734
88	77	784	986	986	889	89	78	727	795	795	743
88	78	798	1005	1005	904	89	79	739	811	811	755
88	79	812	1023	1023	918	89	80	748	821	821	763
88	80	823	1035	1035	930	89	81	759	834	834	774
88	81	833	1048	1048	941	89	82	771	849	849	787
88	82	843	1059	1059	951	89	83	781	861	861	796
88	83	853	1071	1071	961	89	84	791	872	872	806
88	84	860	1078	1078	969	89	85	801	884	884	816
88	85	872	1091	1091	981	89	86	806	891	891	823
88	86	879	1102	1102	991	89	87	816	901	901	832
88	87	890	1115	1115	1001	89	88	828	913	916	845
88	88	902	1129	1129	1013	89	89	840	925	931	857
88	89	912	1139	1140	1023	89	90	847	932	939	863
88	90	925	1153	1155	1037	89	91	858	943	952	874
88	91	940	1167	1171	1052	89	92	867	952	962	883
88	92	957	1184	1190	1069	89	93	877	962	974	893
88	93	967	1194	1201	1079	89	94	887	972	987	904
88	94	976	1203	1212	1087	89	95	899	984	1000	915
88	95	987	1214	1226	1098	89	96	917	1002	1020	934
88	96	1001	1228	1242	1112	89	97	934	1019	1038	951
88	97	1009	1236	1253	1120	89	98	951	1036	1055	967
88	98	1018	1245	1265	1130	89	99	967	1052	1072	983
88	99	1027	1254	1276	1139	89	100	982	1067	1088	999

(Continued)

Appendix I.3. (Continued)

Year	Julian Day	Accum. GDD C	CE	CE+L	S	Year	Julian Day	Accum. GDD C	CE	CE+L	S
88	100	1040	1267	1291	1152	89	101	996	1081	1101	1012
88	101	1055	1282	1310	1167	89	102	1010	1095	1116	1027
88	102	1070	1297	1325	1182	89	103	1026	1111	1132	1043
88	103	1087	1314	1342	1199	89	104	1044	1129	1149	1060
88	104	1105	1332	1360	1216	89	105	1061	1146	1167	1077
88	105	1117	1344	1372	1229	89	106	1074	1159	1179	1090
88	106	1127	1355	1382	1239	89	107	1087	1172	1192	1103
88	107	1142	1369	1397	1253	89	108	1102	1187	1208	1119
88	108	1153	1381	1409	1265	89	109	1121	1206	1226	1137
88	109	1163	1391	1419	1275	89	110	1138	1223	1244	1154
88	110	1176	1404	1431	1288	89	111	1148	1233	1254	1165
88	111	1189	1416	1444	1301	89	112	1160	1245	1266	1177
88	112	1202	1429	1457	1313	89	113	1171	1256	1276	1187
88	113	1210	1437	1465	1322	89	114	1183	1268	1289	1199
88	114	1219	1446	1474	1331	89	115	1196	1281	1301	1212
88	115	1231	1458	1486	1343	89	116	1207	1292	1312	1223
88	116	1238	1465	1493	1350	89	117	1213	1298	1319	1229
88	117	1251	1479	1506	1363	89	118	1225	1310	1330	1241
88	118	1268	1495	1523	1380	89	119	1241	1326	1346	1257
88	119	1285	1512	1540	1397	89	120	1257	1342	1363	1274
88	120	1298	1525	1553	1409	89	121	1269	1354	1374	1285
88	121	1306	1534	1561	1418	89	122	1283	1368	1389	1300
88	122	1315	1542	1570	1426	89	123	1298	1383	1404	1314
88	123	1324	1551	1579	1436	89	124	1313	1398	1419	1330
88	124	1333	1560	1588	1444	89	125	1334	1419	1439	1350
88	125	1342	1570	1597	1454	89	126	1354	1439	1459	1370
88	126	1353	1580	1608	1464	89	127	1372	1457	1478	1389
88	127	1361	1589	1616	1473	89	128	1389	1474	1495	1405
88	128	1371	1598	1626	1483	89	129	1406	1491	1512	1423
88	129	1385	1612	1640	1496	89	130	1416	1501	1522	1432
88	130	1395	1622	1650	1506	89	131	1429	1514	1534	1445
88	131	1407	1634	1662	1518	89	132	1439	1524	1545	1455
88	132	1424	1651	1679	1536	89	133	1449	1534	1555	1465
88	133	1443	1670	1698	1555	89	134	1463	1548	1568	1479
88	134	1460	1687	1715	1572	89	135	1478	1563	1584	1494
88	135	1473	1700	1728	1584	89	136	1494	1579	1600	1510
88	136	1488	1715	1743	1600	89	137	1510	1595	1616	1526
88	137	1506	1733	1761	1618	89	138	1520	1605	1625	1536
88	138	1517	1744	1772	1629	89	139	1531	1616	1636	1547
88	139	1531	1758	1786	1643	89	140	1543	1628	1648	1559
88	140	1543	1771	1799	1655	89	141	1558	1643	1663	1574
88	141	1557	1785	1812	1669	89	142	1571	1656	1676	1587
88	142	1573	1800	1828	1685	89	143	1584	1669	1689	1600
88	143	1593	1820	1848	1704	89	144	1594	1679	1699	1610
88	144	1604	1831	1859	1716	89	145	1605	1690	1710	1621
88	145	1615	1843	1870	1727	89	146	1619	1704	1724	1635
88	146	1628	1855	1883	1740	89	147	1633	1718	1738	1649
88	147	1642	1869	1897	1754	89	148	1646	1731	1752	1662
88	148	1658	1885	1913	1770	89	149	1660	1745	1765	1676
88	149	1672	1900	1927	1784	89	150	1672	1757	1777	1688
88	150	1684	1912	1939	1796	89	151	1687	1772	1792	1703
88	151	1695	1922	1950	1806	89	152	1706	1791	1811	1722
88	152	1709	1936	1964	1821	89	153	1725	1810	1831	1741

(Continued)

Appendix I.3. (Continued)

Year	Julian Day	Accum. GDD C	CE	CE+L	S
88	153	1722	1949	1977	1833
88	154	1736	1963	1991	1848
88	155	1749	1977	2004	1861
88	156	1764	1991	2019	1876
88	157	1776	2003	2031	1888
88	158	1790	2017	2045	1902
88	159	1806	2033	2061	1918
88	160	1821	2048	2076	1933
88	161	1837	2064	2092	1949
88	162	1851	2079	2106	1963
88	163	1867	2094	2122	1979
88	164	1882	2109	2137	1994
88	165	1898	2125	2153	2010
88	166	1917	2144	2172	2029
88	167	1940	2167	2195	2052
88	168	1960	2187	2215	2071
88	169	1978	2205	2233	2090
88	170	1997	2224	2252	2109
88	171	2015	2242	2270	2126
88	172	2032	2260	2287	2144
88	173	2051	2279	2306	2163
88	174	2073	2300	2328	2185
88	175	2091	2319	2346	2203
88	176	2109		2364	2221
88	177	2129			2241
88	178	2147			2259
88	179	2165			2277
88	180	2179			2291
88	181	2192			2304
88	182	2207			
88	183	2223			
88	184	2244			

Year	Julian Day	Accum. GDD C	CE	CE+L	S
89	154	1744	1829	1850	1761
89	155	1768	1853	1874	1784
89	156	1789	1874	1894	1805
89	157	1809	1894	1915	1826
89	158	1826	1911	1931	1842
89	159	1842	1927	1947	1858
89	160	1859	1944	1964	1875
89	161	1874	1959	1980	1890
89	162	1891	1976	1997	1907
89	163	1910	1995	2015	1926
89	164	1926	2011	2031	1942
89	165	1946		2051	1962
89	166	1961			1977
89	167	1976			
89	168	1991			

Appendix I.4. Data collected during growth analysis in 1988. Measurements include: julian days; block (Blk); treatment (Trt); number of plants in 0.1-m^2 sampling area (converted to $meter^2$); total above-ground dry weight (phytomass), leaf area index (LAI), dry leaf, stem, bud (without seed), and seed weights, and the number of primary stems per area.

Julian Days	Blk	Trt †	no. plts # m^{-2}	phyto- mass g m^{-2}	leaf area index LAI	leaf wt.	stem wt.	bud wt.	seed wt.	prim. stems # m^{-2}
						--------- g m^{-2}	----------			
7	1	3	260	8.5	0.11	8.0	0.5			
7	2	3	200	7.5	0.08	7.0	0.5			
7	3	3	253	10.3	0.10	9.7	0.6			
7	4	3	247	10.4	0.13	9.8	0.6			
21	1	3	133	8.8	0.15	8.4	0.4			
21	2	3	147	5.0	0.08	4.7	0.4			
21	3	3	153	8.4	0.15	7.9	0.5			
21	4	3	240	11.4	0.18	10.5	0.8			
46	1	3	240	47.4	0.73	44.9	2.5			
46	1	11	187	49.9	0.89	47.2	2.7			
46	1	13	127	24.5	0.55	23.3	1.2			
46	2	3	173	26.1	0.30	23.3	2.8			
46	2	11	167	27.9	0.58	26.6	1.3			
46	2	13	153	22.1	0.53	20.9	1.1			
46	3	3	180	27.6	0.51	26.0	1.6			
46	3	11	220	40.3	0.87	38.7	1.6			
46	3	13	180	25.7	0.70	24.4	1.3			
46	4	3	267	40.2	0.82	38.2	2.0			
46	4	11	193	43.7	0.98	42.6	1.1			
46	4	13	213	27.2	0.74	26.4	0.8			
60	1	3	187	73.1	0.99	69.9	3.3			
60	1	11	233	135.3	2.65	129.2	6.1			
60	1	13	173	57.2	1.37	55.2	2.0			
60	2	3	160	44.3	0.49	42.9	1.4			
60	2	11	153	77.6	1.24	74.6	3.0			
60	2	13	167	32.4	0.79	31.1	1.4			
60	3	3	213	62.3	0.83	59.7	2.6			
60	3	11	233	54.1	0.96	51.1	2.9			
60	3	13	260	60.4	1.42	57.9	2.4			
60	4	3	293	71.5	1.52	67.9	3.7			
60	4	11	193	46.3	0.92	44.7	1.6			
60	4	13	227	41.1	0.90	39.2	1.9			
77	1	3	353	214.4	2.93	204.5	9.9			
77	1	11	233	230.7	3.27	215.9	14.8			
77	1	13	200	128.0	2.71	122.5	5.5			
77	2	3	207	151.5	2.11	143.8	7.8			
77	2	11	247	141.4	2.18	134.7	6.6			
77	2	13	220	90.7	1.81	86.8	3.9			
77	3	3	153	133.5	1.68	127.2	6.3			
77	3	11	247	203.1	3.10	191.6	11.5			
77	3	13	193	96.6	1.89	92.0	4.6			
77	4	3	247	173.3	1.86	163.9	9.4			
77	4	11	220	175.7	2.62	164.3	11.4			
77	4	13	207	85.0	1.62	81.1	3.9			

† Treatment numbers 3, 11, 12, and 13 refer to Control, Cover Early, Cover Early Plus Late, and Shade respectively.
(Continued)

Appendix I.4. (Continued)

Julian Days	Blk	trt	no. plts # m^{-2}	Phyto-mass g m^{-2}	leaf area index LAI	leaf wt.	stem wt.	bud wt.	seed wt.	prim. stems # m^{-2}
						----------	g m^{2}	----------		
88	1	3	160	206.1	2.44	181.2	24.9			
88	1	11	213	363.2	4.97	299.8	63.4			
88	1	13	227	180.4	3.65	165.9	14.5			
88	2	3	253	246.3	3.06	218.2	28.1			
88	2	11	227	341.0	4.45	293.3	47.7			
88	2	13	307	153.1	3.20	140.2	12.9			
88	3	3	267	251.5	3.10	225.5	26.0			
88	3	11	193	199.4	2.78	179.5	19.9			
88	3	13	193	135.1	2.73	126.2	8.9			
88	4	3	173	262.9	3.46	238.2	24.8			
88	4	11	213	222.7	3.10	193.5	29.2			
88	4	13	113	140.9	2.49	131.3	9.5			
102	1	3	320	448.0	4.78	325.1	88.9	34.01		1660
102	1	11	187	465.4	3.92	324.4	111.3	29.70		1270
102	1	12	253	452.4	3.98	289.9	129.6	32.84		1440
102	1	13	193	286.7	4.01	214.4	53.9	18.33		1030
102	2	3	193	412.8	3.86	299.4	88.3	25.04		1460
102	2	11	247	421.7	4.64	298.7	93.5	29.51		1470
102	2	12	227	450.2	3.87	310.3	111.6	28.32		1250
102	2	13	240	338.1	4.75	250.9	68.6	18.55		1160
102	3	3	240	404.6	3.73	298.3	80.7	25.59		1320
102	3	11	167	352.3	3.17	237.9	92.1	22.27		1370
102	3	12	220	528.3	5.03	337.9	156.4	34.08		1230
102	3	13	147	206.2	3.29	156.1	37.9	12.18		830
102	4	3	247	351.0	3.67	266.9	58.8	25.36		1750
102	4	11	227	512.3	4.38	340.6	133.8	37.89		1400
102	4	12	207	307.5	3.75	200.1	83.5	23.88		1250
102	4	13	253	308.0	3.44	238.3	52.2	17.51		1030
116	1	3	227	526.3	3.45	262.7	189.2	74.45		1100
116	1	11	187	715.9	3.16	314.7	325.5	75.67		1470
116	1	12	327	737.2	3.77	317.5	338.3	81.33		1380
116	1	13	227	432.0	3.20	186.8	192.7	52.56		1240
116	2	3	193	483.9	2.88	246.1	190.2	47.53		1410
116	2	11	273	659.6	2.94	236.9	355.7	67.03		1500
116	2	12	273	604.4	3.68	247.5	286.6	70.29		1130
116	2	13	240	373.9	2.38	177.8	148.4	47.70		910
116	3	3	240	557.0	3.32	324.7	177.3	54.99		1550
116	3	11	247	525.3	3.16	210.9	259.5	54.87		1530
116	3	12	207	677.0	4.11	267.2	328.3	81.45		1320
116	3	13	180	388.3	2.90	181.4	157.2	49.73		800
116	4	3	160	544.3	4.09	269.7	216.2	58.35		1540
116	4	11	173	605.2	3.75	269.4	273.4	62.40		1470
116	4	12	227	553.8	3.70	226.5	267.3	60.02		1490
116	4	13	200	430.3	2.81	217.2	162.3	50.73		770

(Continued)

Appendix I.4. (Continued)

Julian Days	Blk	trt	no. plts # m⁻²	Phyto- mass g m⁻²	leaf area index LAI	leaf wt.	stem wt.	bud wt.	seed wt.	prim. stems # m⁻²
						---------	g m²	----------		
130	1	3	280	739.0	2.84	231.2	422.8	84.97		1640
130	1	11	147	609.4	1.45	187.7	340.5	81.11		1130
130	1	12	140	663.1	1.79	152.7	428.7	81.75		1270
130	1	13	140	593.4	2.61	186.5	323.3	83.62		970
130	2	3	187	608.6	2.36	206.5	325.5	76.67		1480
130	2	11	93	715.0	2.58	205.8	362.1	147.12		590
130	2	12	147	811.8	2.42	206.7	468.8	136.35		1300
130	2	13	160	577.7	2.74	165.2	320.4	92.09		950
130	3	3	247	700.4	2.98	264.9	361.6	73.87		2010
130	3	11	153	712.1	2.17	190.7	425.0	96.33		890
130	3	12	287	798.5	1.73	200.0	472.3	126.25		1520
130	3	13	273	459.5	1.94	120.5	260.9	78.10		560
130	4	3	247	527.2	2.68	182.8	282.3	62.08		2160
130	4	11	207	767.7	2.30	201.6	456.9	109.09		1150
130	4	12	140	653.7	1.73	162.3	410.7	80.65		1140
130	4	13	147	548.4	1.88	172.1	290.5	85.88		630
144	1	3	240	826.7	1.18	187.3	532.7	106.36	0.37	1830
144	1	11	140	925.5	0.99	196.5	538.8	188.53	1.74	930
144	1	12	153	911.4	0.80	170.0	580.1	155.54	5.79	880
144	1	13	113	851.5	1.81	159.9	527.3	163.50	0.83	650
144	2	3	160	533.3	1.10	125.3	350.5	57.47	0.00	1330
144	2	11	240	1022.6	1.00	195.6	664.5	160.54	1.99	1060
144	2	12	140	759.1	0.94	127.9	504.1	121.83	5.17	1090
144	2	13	220	654.7	1.66	130.9	444.7	78.65	0.42	670
144	3	3	300	758.2	1.67	170.6	516.1	71.16	0.37	1280
144	3	11	253	849.7	1.35	171.7	570.7	106.39	1.02	1330
144	3	12	160	733.5	1.32	131.7	497.0	103.66	1.14	710
144	3	13	153	602.7	1.07	100.1	421.1	80.53	1.07	780
144	4	3	193	792.2	2.37	241.5	489.9	60.70	0.17	1320
144	4	11	113	908.3	1.87	169.0	600.0	135.62	3.71	830
144	4	12	220	901.2	1.43	161.1	604.9	128.95	6.25	1420
144	4	13	833	715.1	1.70	151.9	474.1	88.88	0.19	830
152	1	3						149.60	23.95	
152	1	11						113.40	32.28	
152	1	12						107.00	26.51	
152	1	13						106.20	20.65	
152	2	3						108.60	16.98	
152	2	11						195.80	41.75	
152	2	12						192.40	47.96	
152	2	13						147.20	23.67	
152	3	3						128.00	10.81	
152	3	11						120.20	24.96	
152	3	12						89.80	18.69	
152	3	13						82.60	9.74	
152	4	3						94.40	8.45	
152	4	11						91.60	20.62	
152	4	12						85.40	29.49	
152	4	13						115.60	16.06	

(Continued)

Appendix I.4. (Continued)

Julian Days	Blk	trt	no. plts # m^{-2}	Phyto-mass g m^{-2}	leaf area index LAI	leaf wt. g m^2	stem wt. g m^2	bud wt. g m^2	seed wt. g m^2	prim. stems # m^{-2}
158	1	3	180	826.2	0.41	161.7	502.9	150.38	11.22	1120
158	1	11	180	845.4	0.08	167.5	497.0	152.09	28.84	980
158	1	12	207	914.0	0.17	171.3	560.2	156.24	26.23	920
158	1	13	166.66	998.0	0.84	159.9	613.5	190.55	33.98	730
158	2	3	166.66	781.3	0.78	133.6	534.0	109.53	4.20	980
158	2	11	180	911.8	0.51	138.1	576.1	173.01	24.59	990
158	2	12	140	794.7	0.05	123.2	479.1	156.71	35.75	1290
158	2	13	186.66	794.4	1.02	128.1	515.2	134.05	17.09	640
158	3	3	240	759.9	0.47	149.5	500.4	104.18	5.75	1360
158	3	11	193.33	938.1	0.79	161.2	595.0	174.09	7.78	1260
158	3	12	180	874.4	0.71	124.1	572.9	157.88	19.52	820
158	3	13	120	832.0	0.87	123.9	545.5	149.02	13.51	1000
158	4	3	213.33	776.4	0.69	166.5	494.0	110.70	5.16	1110
158	4	11	120	855.4	0.58	123.1	548.3	158.84	25.16	810
158	4	12	193.33	819.6	0.71	133.7	528.2	128.17	29.56	1420
158	4	13	160	882.7	0.95	121.4	565.2	170.27	25.86	910
165	1	3						114.20	39.63	
165	1	11						84.60	62.87	
165	1	12						98.80	97.10	
165	1	13						170.20	87.88	
165	2	3						74.60	26.52	
165	2	11						107.80	69.03	
165	2	12						124.00	94.14	
165	2	13						227.20	135.09	
165	3	3						112.40	54.66	
165	3	11						185.00	64.94	
165	3	12						108.60	96.03	
165	3	13						128.40	59.34	
165	4	3						144.80	19.30	
165	4	11						189.60	130.45	
165	4	12						139.60	79.58	
165	4	13						132.60	24.05	
172	1	3	226.66	670.1	0.04	117.9	370.6	109.67	72.00	1180
172	1	11	206.66	634.1	0.00	70.9	360.5	128.93	73.80	900
172	1	12	233.33	878.9	0.00	123.5	496.3	146.13	113.00	680
172	1	13	133.33	718.2	0.04	80.7	436.8	104.73	96.00	600
172	2	3	180	583.1	0.05	85.6	359.3	86.07	52.20	930
172	2	11	133.33	661.7	0.02	79.6	412.0	88.13	82.00	1010
172	2	12	126.66	645.8	0.02	67.7	375.0	92.13	111.00	530
172	2	13	193.33	687.8	0.08	63.5	422.4	112.93	89.00	690
172	3	3	153.33	504.9	0.05	73.7	291.6	92.87	46.73	900
172	3	11	173.33	720.4	0.03	76.9	429.6	115.87	98.00	820
172	3	12	200	510.9	0.01	76.5	345.4	47.93	41.00	820
172	3	13	193.33	611.4	0.12	73.5	425.1	75.80	37.00	1000
172	4	3	166.66	626.9	0.08	123.8	357.8	100.07	45.27	1160
172	4	11	266.66	705.7	0.07	95.7	427.0	87.00	96.00	1350
172	4	12	166.66	843.5	0.08	73.2	511.3	121.00	138.00	1140
172	4	13	166.66	917.5	0.18	92.9	556.3	161.40	107.00	1290

(Continued)

Appendix I.4. (Continued)

Julian Days	Blk	trt	no. plts	Phyto-mass	leaf area index	leaf wt.	stem wt.	bud wt.	seed wt.	prim. stems
			# m^{-2}	g m^{-2}	LAI	---------	g m^{2}	----------	#	m^{-2}
179	1	3						94.00	64.00	
179	1	11						198.00	94.00	
179	1	12						172.00	126.00	
179	1	13						183.00	124.00	
179	2	3						78.00	48.00	
179	2	11						147.00	114.00	
179	2	12						115.00	108.00	
179	2	13						141.00	116.00	
179	3	3						98.00	65.00	
179	3	11						95.00	72.00	
179	3	12						76.00	79.00	
179	3	13						60.00	25.00	
179	4	3						126.00	69.00	
179	4	11						70.00	80.00	
179	4	12						105.00	132.00	
179	4	13						98.00	62.00	
188	1	11	300	808.5	0.00	101.4	474.3	156.06	76.70	
188	1	12	272	804.0	0.00	119.0	446.5	190.06	48.50	
188	1	13	220	890.0	0.00	113.7	512.3	209.08	55.00	
188	2	11	276	811.2	0.00	108.8	482.4	147.40	72.60	
188	2	12	212	788.5	0.00	95.7	442.0	161.94	88.90	
188	2	13	252	727.7	0.00	77.4	445.2	138.92	66.20	
188	3	11	256	742.4	0.00	77.1	496.3	120.30	48.70	
188	3	12	208	741.1	0.00	56.7	477.7	136.62	70.10	
188	3	13	208	764.8	0.01	76.5	459.3	111.40	60.40	
188	4	11	252	775.8	0.01	96.2	484.8	119.62	83.90	
188	4	12	196	871.9	0.01	75.7	481.2	134.88	88.80	
188	4	13	228	719.8	0.01	66.7	439.4	111.02	102.70	
193	1	3	93.333	690.7	0.00	56.9	379.7	144.60	109.53	
193	2	3	153.33	700.3	0.00	121.2	419.3	105.73	54.07	
193	3	3	100	708.4	0.00	122.7	430.7	104.80	50.20	
193	4	3	220	639.7	0.00	152.1	384.5	76.20	26.93	

Appendix I.5. Data collected during growth analysis in 1989. Measurements include: julian days; block (Blk); treatment (trt); number of plants in 0.1-m^2 sampling area (converted to $meter^2$); total above-ground dry weight (phytomass), leaf area index (LAI), dry leaf, stem, bud (without seed), and seed weights, and the number of primary stems per area.

Julian Days	Blk	trt	no. plts # m^{-2}	Phyto-mass g m^{-2}	leaf area index LAI	leaf wt.	stem wt.	bud wt.	seed wt.	prim. stems # m^{-2}
						---------	g m^2	----------		
24	1	3	130	14.4	0.24	13.8	0.6			
24	2	3	160	18.7	0.34	18.5	0.3			
24	3	3	150	12.7	0.25	12.5	0.2			
24	4	3	170	21.0	0.38	20.2	0.8			
24	5	3	160	17.0	0.31	16.3	0.6			
24	6	3	220	13.7	0.25	13.2	0.5			
51	1	3	150	18.5	0.25	17.8	0.7			
51	1	11	250	25.2	0.39	24.5	0.7			
51	1	13	150	26.2	0.52	25.4	0.8			
51	2	3	180	20.0	0.17	19.4	0.7			
51	2	11	120	19.6	0.36	19.1	0.5			
51	2	13	160	24.3	0.52	23.8	0.6			
51	3	3	150	22.4	0.38	21.8	0.6			
51	3	11	170	36.5	0.64	35.8	0.7			
51	3	13	200	33.9	0.66	32.9	1.0			
51	4	3	140	20.2	0.17	19.6	0.6			
51	4	11	220	32.2	0.51	31.5	0.8			
51	4	13	240	30.4	0.60	29.8	0.7			
51	5	3	200	21.8	0.16	20.8	1.1			
51	5	11	250	27.1	0.33	26.6	0.5			
51	5	13	170	17.1	0.33	16.8	0.3			
51	6	3	140	12.6	0.10	12.1	0.4			
51	6	11	260	48.0	0.77	47.3	0.7			
51	6	13	160	30.8	0.57	30.3	0.5			
65	1	3	170	26.4	0.37	24.8	1.5			
65	1	11	240	27.1	0.44	25.9	1.2			
65	1	13	210	36.3	0.86	35.3	1.0			
65	2	3	160	29.8	0.46	28.6	1.2			
65	2	11	310	24.6	0.43	23.0	1.6			
65	2	13	200	39.9	0.81	38.6	1.3			
65	3	3	150	33.8	0.48	32.5	1.3			
65	3	11	180	41.8	0.73	40.2	1.7			
65	3	13	140	41.7	0.88	40.4	1.3			
65	4	3	170	31.7	0.44	30.4	1.3			
65	4	11	230	42.1	0.74	40.3	1.8			
65	4	13	160	31.6	0.69	30.6	0.9			
65	5	3	200	18.6	0.27	17.7	0.9			
65	5	11	210	29.7	0.54	28.1	1.5			
65	5	13	190	34.3	0.68	33.1	1.2			
65	6	3	260	31.7	0.55	30.5	1.2			
65	6	11	240	29.9	0.55	28.5	1.4			
65	6	13	250	34.9	0.77	33.8	1.0			

(Continued)

Appendix I.5. (Continued)

Julian Days	Blk	trt	no. plts # m^{-2}	Phyto-mass g m^{-2}	leaf area index LAI	leaf wt.	stem wt.	bud wt.	seed wt.	prim. stems # m^{-2}
						---------- g m^{2}	----------	----------		
74	1	3	160	49.0	0.79	45.9	3.1			
74	1	11	180	48.6	0.87	45.3	3.3			
74	1	13	260	52.5	1.08	50.5	2.0			
74	2	3	150	59.3	0.95	56.2	3.1			
74	2	11	170	34.0	0.59	32.0	2.0			
74	2	13	150	53.6	1.21	51.9	1.7			
74	3	3	200	49.5	0.80	46.5	3.0			
74	3	11	140	69.7	1.27	66.2	3.5			
74	3	13	240	60.7	1.30	57.5	3.2			
74	4	3	160	30.1	0.48	28.2	1.9			
74	4	11	210	61.7	1.24	58.5	3.2			
74	4	13	190	63.4	1.42	60.6	2.8			
74	5	3	200	31.8	0.57	29.5	2.3			
74	5	11	200	52.5	1.13	49.1	3.4			
74	5	13	180	40.6	0.97	38.9	1.7			
74	6	3	150	38.4	0.70	36.5	1.9			
74	6	11	200	48.7	1.06	46.0	2.7			
74	6	13	160	44.5	1.04	42.4	2.1			
86	1	3	210	107.4	1.63	98.0	9.4			
86	1	11	120	100.7	1.80	91.4	9.3			
86	1	13	190	82.5	1.94	77.9	4.6			
86	2	3	150	114.8	1.87	105.3	9.6			
86	2	11	140	98.6	1.83	89.6	8.9			
86	2	13	220	116.2	2.74	109.9	6.3			
86	3	3	240	142.1	2.58	131.2	10.9			
86	3	11	170	121.9	2.15	110.6	11.3			
86	3	13	230	98.8	2.53	91.9	6.9			
86	4	3	120	117.4	1.81	106.4	11.0			
86	4	11	130	69.9	1.33	64.2	5.7			
86	4	13	270	109.4	2.91	103.6	5.8			
86	5	3	170	110.2	1.74	102.0	8.2			
86	5	11	170	115.8	2.38	105.4	10.4			
86	5	13	230	91.6	2.22	85.7	5.9			
86	6	3	220	69.9	1.34	64.9	4.9			
86	6	11	210	179.4	3.75	161.2	18.2			
86	6	13	180	117.5	3.76	108.8	8.7			
100	1	3	230	253.4	2.78	202.0	37.5	13.82		1270
100	1	11	170	242.2	3.03	178.8	48.7	14.69		1000
100	1	12	170	301.6	3.57	201.6	80.4	19.60		1160
100	1	13	180	137.9	1.70	109.5	20.6	7.80		670
100	2	3	120	241.8	2.50	190.8	37.7	13.36		1020
100	2	11	150	220.8	2.71	166.7	41.8	12.31		990
100	2	12	330	307.5	4.11	214.6	69.9	22.99		1360
100	2	13	230	296.6	4.51	230.8	49.8	16.04		1400
100	3	3	180	319.3	3.88	247.9	55.8	15.55		1470
100	3	11	200	280.9	3.02	212.9	52.9	15.13		1170
100	3	12	160	276.5	3.65	202.4	59.4	14.73		1220
100	3	13	170	175.0	2.58	139.6	26.9	8.53		970

(Continued)

Appendix I.5. (Continued)

Julian Days	Blk	trt	no. plts # m^{-2}	Phyto-mass g m^{-2}	leaf area index LAI	leaf wt.	stem wt.	bud wt.	seed wt.	prim. stems # m^{-2}
						---------- g m^{2}		----------		
100	4	3	160	156.0	1.96	125.3	21.6	9.05		1120
100	4	11	160	253.4	2.82	179.8	59.4	14.21		1180
100	4	12	250	345.5	4.54	232.3	92.4	20.74		1470
100	4	13	250	200.6	3.16	155.8	34.1	10.76		1180
100	5	3	170	190.3	2.73	152.5	27.3	10.43		1060
100	5	11	80	191.3	2.26	141.5	37.1	12.71		860
100	5	12	160	232.9	3.11	166.7	51.9	14.29		990
100	5	13	210	194.1	3.03	152.6	31.6	9.96		740
100	6	3	230	260.9	3.38	206.3	41.2	13.41		1600
100	6	11	150	291.7	3.37	204.2	68.6	18.91		1160
100	6	12	150	186.4	2.84	142.6	34.5	9.30		1270
100	6	13	190	160.9	2.86	130.0	22.6	8.34		920
114	1	3	250	420.7	3.21	225.0	143.0	52.70		1720
114	1	11	280	348.3	2.23	159.6	145.8	42.90		1620
114	1	12	130	353.1	2.23	141.5	168.0	43.60		1050
114	1	13	130	314.7	1.83	131.0	143.8	39.90		950
114	2	3	170	458.0	3.73	236.2	177.2	44.60		1140
114	2	11	150	366.8	2.22	143.7	178.5	44.60		950
114	2	12	140	343.6	2.01	130.8	169.9	42.90		870
114	2	13	200	395.2	2.70	171.5	165.4	58.30		1100
114	3	3	120	405.6	2.40	196.2	166.6	42.80		1190
114	3	11	240	424.9	2.91	202.9	178.3	43.70		1630
114	3	12	180	443.8	2.45	169.0	220.7	54.10		1170
114	3	13	190	418.3	3.18	192.5	179.8	46.00		1490
114	4	3	120	319.6	2.27	161.9	126.9	30.80		1030
114	4	11	200	347.1	2.37	153.4	154.3	39.40		1340
114	4	12	260	375.4	1.86	131.4	188.6	55.40		1570
114	4	13	140	356.4	2.24	136.8	170.1	49.50		1160
114	5	3	90	338.7	2.54	173.3	132.9	32.50		840
114	5	11	180	424.3	2.84	167.3	210.0	47.00		1470
114	5	12	130	338.1	1.45	133.9	167.3	36.90		850
114	5	13	200	291.1	1.52	117.3	137.8	36.00		1010
114	6	3	200	358.2	2.09	184.5	133.2	40.50		1470
114	6	11	120	359.2	1.71	153.2	168.8	37.20		1090
114	6	12	170	330.3	1.74	144.9	151.9	33.50		1220
114	6	13	90	360.2	2.00	154.2	162.7	43.30		750
128	1	3	210	534.3	0.92	182.4	277.1	74.80		1440
128	1	11	280	615.9	1.04	164.9	368.3	82.70		1330
128	1	12	110	488.2	0.67	146.3	270.1	71.80		1040
128	1	13	110	505.6	1.30	177.9	248.8	78.90		800
128	2	3	170	438.2	0.85	152.7	232.8	52.70		1360
128	2	11	190	543.2	1.14	162.0	289.2	92.00		1350
128	2	12	160	470.0	0.72	122.2	273.0	74.80		780
128	2	13	190	531.4	0.93	169.7	281.4	80.30		1000
128	3	3	190	592.3	1.45	210.8	311.8	69.70		1600
128	3	11	160	501.2	0.77	141.0	292.8	67.40		950
128	3	12	100	461.1	0.49	112.9	231.2	117.00		600
128	3	13	160	499.8	0.94	150.8	270.9	78.10		810

(Continued)

Appendix I.5. (Continued)

Julian Days	Blk	trt	no. plts # m-2	Phyto-mass g m-2	leaf area index LAI	leaf wt.	stem wt.	bud wt.	seed wt.	prim. stems # m-2
						--------- g m2		----------		
128	4	3	130	414.6	1.02	150.7	223.0	40.90		1390
128	4	11	180	440.6	0.53	127.4	251.2	62.00		1050
128	4	12	150	518.1	0.84	153.6	278.1	86.40		1000
128	4	13	190	529.0	0.94	166.3	290.0	72.70		950
128	5	3	160	439.5	1.05	150.7	235.9	52.90		1260
128	5	11	190	476.4	0.68	126.3	279.0	71.10		1310
128	5	12	120	487.5	0.92	149.9	264.7	72.90		890
128	5	13	210	414.1	0.73	118.8	234.4	60.90		940
128	6	3	130	373.4	0.89	115.1	202.6	55.70		1050
128	6	11	130	354.8	0.44	102.2	197.4	55.20		990
128	6	12	200	448.9	0.65	129.4	237.0	82.50		1020
128	6	13	240	586.1	1.41	161.2	333.9	91.00		1170
135	1	3	200					88.10	2.97	
135	1	11	230					73.80	11.18	
135	1	12	110					64.40	5.61	
135	1	13	160					72.40	3.83	
135	2	3	220					77.60	1.94	
135	2	11	120					94.80	1.14	
135	2	12	50					77.20	10.04	
135	2	13	270					108.90	6.76	
135	3	3	160					86.40	3.69	
135	3	11	130					77.00	7.65	
135	3	12	130					96.90	15.49	
135	3	13	100					81.00	5.19	
135	4	3	160					64.70	2.07	
135	4	11	120					57.10	6.10	
135	4	12	120					94.40	10.24	
135	4	13	200					94.00	6.93	
135	5	3	220					80.30	4.16	
135	5	11	210					57.30	3.11	
135	5	12	150					56.20	5.20	
135	5	13	130					93.30	4.61	
135	6	3	240					55.30	2.27	
135	6	11	170					80.20	3.72	
135	6	12	200					73.20	6.80	
135	6	13	160					104.70	5.07	
142	1	3	280	771.7	1.01	200.6	431.6	117.50	21.94	1680
142	1	11	120	423.1	0.19	65.7	247.7	81.10	28.63	740
142	1	12	140	418.9	0.14	81.1	263.9	54.90	19.03	980
142	1	13	110	558.0	0.39	134.6	302.3	95.70	25.35	840
142	2	3	210	603.8	0.45	169.8	343.8	77.00	13.17	1550
142	2	11	140	556.8	0.30	98.9	326.6	91.40	39.89	1130
142	2	12	70	528.4	0.22	96.7	312.9	85.80	33.00	420
142	2	13	260	551.8	0.32	121.7	328.8	74.20	27.15	1000
142	3	3	150	702.0	0.63	192.9	355.6	127.70	25.80	1070
142	3	11	90	667.6	0.27	150.8	366.0	110.00	40.78	500
142	3	12	140	499.5	0.14	72.1	301.0	83.30	43.06	800
142	3	13	110	532.0	0.44	103.7	321.4	83.10	23.78	870
142	4	3	110	568.0	0.47	155.9	316.1	83.20	12.78	1010
142	4	11	120	592.6	0.37	105.7	357.6	84.40	44.85	920
142	4	12	190	472.7	0.27	106.5	279.6	63.30	23.34	920

(Continued)

Appendix I.5. (Continued)

Julian Days	Blk	trt	no. plts # m^{-2}	Phyto-mass g m^{-2}	leaf area index LAI	leaf wt.	stem wt.	bud wt.	seed wt.	prim. stems # m^{-2}
						---------- g m^{2}	----------	----------		
142	4	13	200	789.9	0.86	152.9	451.9	142.40	42.74	710
142	5	3	90	485.6	0.45	105.2	259.3	96.00	25.09	710
142	5	11	90	514.1	0.41	90.8	288.1	105.40	29.79	640
142	5	12	130	556.0	0.18	110.2	327.9	87.40	30.46	700
142	5	13	220	605.5	0.57	122.1	350.2	101.70	31.51	730
142	6	3	220	475.3	0.41	128.3	276.3	62.40	8.31	1380
142	6	11	100	493.9	0.18	79.8	273.6	102.60	37.90	630
142	6	12	150	568.0	0.43	102.0	349.8	87.40	28.83	1110
142	6	13	70	523.9	0.45	111.0	301.1	89.80	22.05	680
149	1	3	120					67.80	22.98	0
149	1	11	180					69.20	56.21	0
149	1	12	100					79.30	55.31	0
149	1	13	160					93.30	63.57	0
149	2	3	100					88.80	29.54	0
149	2	11	170					66.50	51.06	0
149	2	12	100					92.40	69.65	0
149	2	13	180					147.60	91.74	0
149	3	3	110					103.20	51.49	0
149	3	11	170					90.20	69.15	0
149	3	12	20					166.70	122.83	0
149	3	13	150					77.50	44.68	0
149	4	3	190					77.40	18.72	0
149	4	11	130					107.50	70.88	0
149	4	12	130					94.80	62.76	0
149	4	13	120					170.90	91.60	0
149	5	3	90					99.40	38.56	0
149	5	11	130					67.90	36.37	0
149	5	12	160					105.60	77.64	0
149	5	13	170					95.40	64.45	0
149	6	3	250					83.80	22.97	0
149	6	11	160					66.50	48.85	0
149	6	12	110					72.30	45.62	0
149	6	13	80					76.00	40.61	0
156	1	3	190	574.6	0.09	123.2	307.1	85.60	58.66	1370
156	1	11	110	497.3	0.05	59.6	226.2	99.50	111.94	570
156	1	12	170	564.4	0.04	79.9	294.7	91.60	98.21	770
156	1	13	150	449.3	0.07	69.5	258.6	59.20	62.02	670
156	2	3	180	540.2	0.10	119.9	304.0	68.90	47.40	1320
156	2	11	160	468.3	0.03	52.3	241.7	87.10	87.20	630
156	2	12	130	483.3	0.05	74.1	266.5	76.10	66.61	590
156	2	13	240	731.9	0.15	111.9	380.9	122.30	116.88	800
156	3	3	130	586.1	0.18	97.4	315.5	90.00	83.15	1220
156	3	11	190	558.5	0.01	86.7	309.4	81.50	80.87	420
156	3	12	110	551.9	0.07	67.3	264.8	102.60	117.24	560
156	3	13	90	557.8	0.22	74.9	288.6	93.10	101.13	510
156	4	3	190	507.1	0.17	89.2	278.1	80.10	59.75	1120
156	4	11	100	679.4	0.10	76.4	326.6	137.10	139.36	530
156	4	12	180	498.2	0.06	57.0	254.5	83.00	103.68	860
156	4	13	100	631.1	0.21	79.4	341.8	103.90	105.98	610

(Continued)

Appendix I.5. (Continued)

Julian Days	Blk	trt	no. plts # m^{-2}	Phyto- mass g m^{-2}	leaf area index LAI	leaf wt.	stem wt.	bud wt.	seed wt.	prim. stems # m^{-2}
						---------	g m^2	----------		
156	5	3	300	747.9	0.23	144.3	360.0	137.30	106.32	1320
156	5	11	180	469.4	0.06	76.7	258.2	67.70	66.80	680
156	5	12	170	461.6	0.10	67.0	229.3	89.20	76.10	820
156	5	13	130	522.3	0.13	69.1	268.2	87.40	97.66	530
156	6	3	100	541.5	0.13	98.6	281.9	98.80	62.24	680
156	6	11	120	553.9	0.03	77.3	299.9	88.50	88.17	620
156	6	12	120	500.4	0.10	57.1	251.1	100.00	92.19	760
156	6	13	90	715.2	0.23	127.2	301.1	143.20	143.78	320
163	1	3	170					87.60	69.50	
163	1	11	120					63.00	61.90	
163	1	12	110					82.30	60.90	
163	1	13	180					50.40	55.00	
163	2	3	170					72.90	38.30	
163	2	11	100					98.80	95.60	
163	2	12	130					57.80	68.00	
163	2	13	190					76.20	79.40	
163	3	3	100					108.50	87.60	
163	3	11	160					99.30	102.00	
163	3	12	210					105.20	133.00	
163	3	13	150					79.30	88.20	
163	4	3	140					99.20	66.40	
163	4	11	140					98.40	108.80	
163	4	12	200					165.90	177.90	
163	4	13	140					102.10	89.60	
163	5	3	230					101.90	94.60	
163	5	11	130					105.50	99.30	
163	5	12	110					76.90	84.00	
163	5	13	180					87.50	94.20	
163	6	3	220					59.80	42.60	
163	6	11	150					53.50	59.00	
163	6	12	80					72.10	87.70	
163	6	13	220					64.40	69.60	
174	1	3	60	422.0	0.00	59.6	223.8	73.50	65.09	
171	1	11	210	533.9	0.00	106.9	260.1	84.80	82.11	
171	1	12	110	470.7	0.00	94.5	228.0	73.80	74.40	
171	1	13	230	590.3	0.00	120.7	250.9	94.80	123.89	
174	2	3	80	456.4	0.00	96.2	244.6	71.10	44.46	
171	2	11	110	467.1	0.00	95.0	225.6	72.80	73.68	
171	2	12	140	516.1	0.00	115.4	256.7	66.10	77.89	
171	2	13	150	548.7	0.00	134.2	256.2	78.50	79.77	
178	3	3	90	509.0	0.00	111.5	232.5	85.70	79.34	
171	3	11	80	498.6	0.00	119.7	244.7	68.70	65.54	
171	3	12	150	646.9	0.01	127.9	302.2	113.20	103.58	
171	3	13	140	598.9	0.04	106.9	322.7	87.10	82.16	
178	4	3	130	474.2	0.00	95.1	235.1	79.60	64.41	
171	4	11	70	470.9	0.00	64.3	241.9	74.10	90.57	
171	4	12	130	449.5	0.00	69.1	219.3	80.30	80.76	
171	4	13	90	438.9	0.01	77.5	228.2	77.80	55.43	

(Continued)

Appendix I.5. (Continued)

Julian Days	Blk	trt	no. plts # m^{-2}	Phyto-mass g m^{-2}	leaf area index LAI	leaf wt.	stem wt.	bud wt.	seed wt.	prim. stems # m^{-2}
						--------- g m^{2}		----------		
178	5	3	110	443.5	0.00	81.2	223.9	70.90	67.46	
171	5	11	110	430.3	0.00	61.3	235.1	74.30	59.53	
171	5	12	170	411.3	0.00	59.9	212.7	69.00	69.72	
171	5	13	210	564.3	0.00	69.9	286.9	93.70	113.73	
178	6	3	120	448.3	0.00	82.5	247.1	71.40	47.30	
171	6	11	140	542.7	0.00	76.6	265.3	99.30	101.48	
171	6	12	190	493.9	0.00	80.4	273.0	71.40	69.13	
171	6	13	210	578.6	0.00	75.5	273.0	92.50	137.65	

Appendix I.6. Average (of 4 replications) cumulated foraging bee density and average cumulated open flowers as influenced by the Control (C), Cover Early (CE), Cover Early Plus Late (CE+L), and Shade (S) in 1988.

Julian	Cumulated bee density				Cumulated open flowers			
Days	C	CE	CE+L	S	C	CE	CE+L	S
	------------------- no. m^{-2} -------------------							
128	0	0	0	0	0	0	0	0
129	0	0	0	0	0	0	3	0
130	0	0	0	0	0	0	3	0
131	0	0	0	0	3	3	3	0
132	0	0	0	0	8	10	58	3
133	0	3	2	0	30	63	143	10
134	0	3	2	0	30	63	143	10
135	3	6	5	0	83	138	325	40
136	5	9	9	1	160	328	643	158
137	5	9	9	1	160	328	643	158
138	5	9	10	1	323	565	1208	563
139	5	9	10	1	348	578	1280	585
140	5	16	17	1	478	750	1783	893
141	7	21	27	7	608	1003	2158	1303
142	9	27	36	15	878	1315	2720	1908
143	9	28	38	16	1260	1795	3305	2655
144	9	28	38	16	1480	1950	3560	2923
145	14	36	47	24	1703	2185	3880	3308
146	14	38	54	30	1958	2555	4370	3908
147	14	39	57	34	2168	2813	4655	4203
148	14	39	57	34	2250	2875	4755	4373
149	14	39	57	34	2250	2875	4755	4373
150	14	40	57	34	2355	2978	4920	4538
151	14	41	60	36	2650	3253	5250	4930
152	14	41	60	36	2650	3253	5250	4930
153	14	41	60	36	2650	3253	5250	4930
154	14	42	60	37	2768	3350	5333	5055
155	14	42	63	38	3053	3530	5583	5328
156	15	44	65	38	3190	3643	5733	5470
157	15	45	68	40	3270	3680	5793	5543
158	15	45	69	41	3493	3798	5928	5720
159	16	45	69	42	3523	3848	5970	5778
160	17	46	71	43	3568	3873	5993	5803
161	17	46	71	43	3683	3978	6090	5910
162	17	46	71	43	3700	3990	6115	5913
163	17	47	72	43	3848	4110	6238	6005
164	18	47	72	45	3953	4228	6300	6085
165	18	47	72	45	4028	4303	6375	6135
166	19	48	72	45	4175	4438	6475	6263
167	19	48	72	45	4298	4555	6545	6320
168	20	48	72	45	4388	4678	6618	6360
169	20	48	72	45	4470	4763	6655	6395
170	20	48	72	46	4560	4848	6683	6438
171	20	48	72	46	4620	4915	6703	6458
172	20	48	72	46	4723	5005	6725	6490
173	20	48	72	47	4788	5095	6743	6525
174	20	48	72	47	4835	5170	6760	6555
175	20	48	72	47	4855	5205	6778	6570

Appendix I.7. Average (of 6 replications) cumulated foraging bee density and average cumulated open flowers as influenced by the Control (C), Cover Early (CE), Cover Early Plus Late (CE+L), and Shade (S) in 1989.

Julian	Cumulated bee density				Cumulated open flowers			
Days	C	CE	CE+L	S	C	CE	CE+L	S
	no. m^{-2}							
121	0	0	0	0	0	2	8	0
122	0	0	0	0	0	30	30	0
123	0	0	0	0	0	62	57	0
124	0	0	0	0	8	212	152	7
125	0	0	1	0	42	568	372	78
126	0	1	1	1	93	938	573	190
127	2	2	5	2	238	1605	978	558
128	3	4	6	4	453	2268	1432	1072
129	3	4	6	4	533	2383	1550	1187
130	4	5	7	4	678	2927	1797	1602
131	4	5	7	5	805	3245	1955	1920
132	5	6	7	6	977	3580	2188	2262
133	5	9	7	9	1172	3938	2398	2565
134	11	15	9	14	1567	4647	2833	3180
135	15	20	17	19	1932	5105	3198	3768
136	15	20	17	19	2227	5453	3503	4205
137	15	20	17	19	2465	5653	3765	4478
138	15	20	17	19	2527	5700	3805	4512
139	19	25	20	21	2667	5780	3942	4637
140	20	28	21	23	2835	5850	4107	4772
141	20	28	21	23	3015	5932	4233	4868
142	23	29	23	23	3093	5958	4282	4927
143	23	29	23	23	3132	5973	4288	4950
144	23	29	23	23	3147	5978	4292	4955
145	23	29	23	23	3250	6010	4387	5015
146	23	29	23	23	3310	6032	4448	5033
147	23	29	23	24	3375	6050	4482	5062
148	23	29	23	24	3415	6055	4492	5075
149	25	29	23	24	3537	6068	4528	5100
150	28	29	23	24	3648	6097	4568	5130
151	32	31	24	25	3830	6128	4610	5178
152	33	31	24	27	3975	6152	4650	5210
153	33	31	24	27	4162	6185	4688	5245
154	33	31	24	27	4265	6207	4730	5270
155	33	31	24	27	4363	6227	4767	5298
156	33	31	24	27	4427	6243	4788	5310
157	33	31	24	27	4453	6250	4798	5317
158	33	31	24	27	4475	6258	4807	5320
159	33	31	24	27	4487	6260	4810	5322

Appendix I.8. Mean (of four replications) seed yield and total above-ground dry matter produced (Phytomass) by meadowfoam lines 75-765 and 75-729 as influenced by covering and shading in 1987-1988.

Treatment	Seed Yield	Phytomass at maturity
765	----------- kg ha^{-1}	---------
Control	692	7153
Cover Early	1120	7893
Cover Early Plus Late	1214	8668
Shade	1049	7493
729		
Control	528	5704
Cover Early	622	7568
Cover Early Plus Late	785	7726
Shade	771	7282

Appendix I.9. Mean (of four replications) seed yield and total above-ground dry matter produced (Phytomass) by 85-765 as influenced by covering from December 2 to the begining of rapid elongation of stems (CDE), from December 2 to 2 weeks after the begining of rapid elongation of stems (CDE+L) and covering for two weeks (CDL) from the begining of rapid elongation of stems in 1987-1988.

Treatment	Seed Yield	Phytomass
	---------- kg ha^{-1} ----------	
Control	692	7153
CDE	1011	7997
CDL†	595	6896
CDE+L	1196	8032

† This treatment appeared to have the most extensive insect (*Scaptomyza*) damage in all of the 1987-1988 experiments.

Appendix I.10. Total above-ground dry matter (Phytomass) and harvest index at harvest for Mermaid meadowfoam as influenced by treatments in 1987-1988 and 1988-1989.

Treatment	Phytomass	Harvest Index
1987-1988	Mg ha^{-1}	
Control	6.84	0.080
Cover Early	7.09	0.101
Cover Early Plus Late	7.55	0.120
Shade	7.43	0.109
L.S.D. (0.05)	0.443	0.0252
1988-1989		
Control	5.45	0.109
Cover Early	5.68	0.119
Cover Early Plus Late	4.93†	0.128
Shade	5.54	0.137
L.S.D. (0.05)	0.778	0.023

† In 1988-1989, the standard deviation was two times larger for Cover Early Plus Late than any other treatment in both years.

Appendix Table I.11. Polynomial regression model coefficients describing the relationship of ln(phytomass) ln(leaf area index), ln(percent leaf tissue), (ln(percent stem tissue), and ln(percent bud+seed tissue) of Mermaid meadowfoam and Julian days (JD) for Control, Cover Early and Shade treatments in 1987-1988.

Independent Variable	Control	Cover Early	Shade
Phytomass			
Constant	1.583902536	1.553651275	1.826775634
JD	0.041765660	0.045571831	0.020665256
JD^2	0.000101601	0.000074198	0.000301957
JD^3	-0.000001012	-0.000000947	-0.000001486
Leaf Area Index			
Constant	-1.899283212	-2.455144185	-2.322769090
JD	-0.027463487	0.022322628	0.012303454
JD^2	0.001347320	0.000668240	0.000692652
JD^3	-0.000007257	-0.000004923	-0.000004484
Percent Leaf Tissue			
Constant	4.642099781	4.604224361	4.679911355
JD	-0.015936923	-0.011850492	-0.021170944
JD^2	0.000554729	0.000487430	0.000719248
JD^3	-0.000006068	-0.000005866	-0.000007666
JD^4	0.000000017	0.000000018	0.000000022
Percent Stem Tissue			
Constant	1.325029	1.680271	1.366969
JD	0.087039	0.040345	0.085204
JD^2	-0.003770	-0.002639	-0.004011
JD^3	0.000057212	0.000047692	0.000062271
JD^4	-0.000000334	-0.000000304	-0.000000367
JD^5	6.673674^{-10}	6.439447^{-10}	7.365945^{-10}
Percent Bud+Seed Tissue			
Constant	-193.6117404	-73.46506978	-146.8009909
JD	5.6449207	2.11424885	4.1447810
JD^2	-0.0601873	-0.02210906	-0.0427867
JD^3	0.0002812	0.00010261	0.0001945
JD^4	-0.0000005	-0.00000018	-0.0000003

Appendix Table I.12. Polynomial regression model coefficients describing the relationship of ln(phytomass), ln(leaf area index), ln(percent leaf tissue), (ln(percent stem tissue), and ln(percent bud+seed tissue) of Mermaid meadowfoam and Julian days (JD) for Control, Cover Early and Shade treatments in 1988-1989.

Independent Variable	Control	Cover Early	Shade
Phytomass			
Constant	3.521790904	3.134935039	3.185224874
JD	-0.061982567	-0.036219373	-0.038049864
JD^2	0.001258860	0.000938361	0.000937526
JD^3	-0.000004740	-0.000003657	-0.000003569
Leaf Area Index			
Constant	2.488786570	0.6363989042	-0.1915570246
JD	-0.236175909	-0.1295115036	-0.0805439403
JD^2	0.003903962	0.0025455692	0.0018339950
JD^3	-0.000016874	-0.0000121984	-0.0000090967
Percent Leaf Tissue			
Constant	5.308360108	5.749699766	5.524342754
JD	-0.056565213	-0.089149541	-0.073492294
JD^2	0.001363235	0.002117985	0.001782663
JD^3	-0.000012479	-0.000019221	-0.000016375
JD^4	0.000000035	0.000000054	0.000000046
Percent Stem Tissue			
Constant	2.029513792	2.040216520	2.705605396
JD	-0.065918173	-0.075026116	-0.106691675
JD^2	0.001150532	0.001323623	0.001646662
JD^3	-0.000004106	-0.000004831	-0.000005772
Percent Bud+Seed Tissue			
Constant	-3.934744638	-5.990958675	-5.964605578
JD	0.075868120	0.108568548	0.107500320
JD^2	-0.000192542	-0.000309457	-0.000304238