1984

Cocklebur and velvetleaf interference in soybeans.

Jeffrey Leonard. Larson
University of Windsor

Recommended Citation

Larson, Jeffrey Leonard., "Cocklebur and velvetleaf interference in soybeans." (1984). *Electronic Theses and Dissertations.* Paper 1456.

0-315-24704-5

National Library of Canada
Bibliothèque nationale du Canada

CANADIAN [illegible] ON MICROFICHE
SUR MICROFICHE

NAME OF AUTHOR/*NOM DE L'AUTEUR* Jeffrey Leonard Larson

TITLE OF THESIS/*TITRE DE LA THÈSE* Cocklebur and velvetleaf interference in soybeans.

UNIVERSITY/*UNIVERSITÉ* University of Windsor, Windsor, Ont.

DEGREE FOR WHICH THESIS WAS PRESENTED/ *GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE* M.Sc.

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE GRADE* Fall, 1984

NAME OF SUPERVISOR/*NOM DU DIRECTEUR DE THÈSE* Dr. M. Weis

Permission is hereby granted to the NATIONAL LIBRARY OF CANADA to microfilm this thesis and to lend or sell copies of the film.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

L'autorisation est, par la présente, accordée à la BIBLIOT QUE NATIONALE DU CANADA de microfilmer cette thès de prêter ou de vendre des exemplaires du film.

L'auteur se réserve les autres droits de publication; n thèse ni de longs extraits de celle-ci ne doivent être impri ou autrement reproduits sans l'autorisation écrite de l'aute

DATED/*DATÉ* Aug 7 . 84 SIGNED/*SIGNÉ* Jeff Larson

PERMANENT ADDRESS/*RÉSIDENCE FIXE*
685 Maple Ave
Windsor, Ont
N9J 1P8

NL-91 (3-74)

COCKLEBUR AND VELVETLEAF INTERFERENCE IN SOYBEANS

by

Jeffrey Leonard Larson

A Thesis
submitted to the
Faculty of Graduate Studies and Research
through the Department of
Biology in Partial Fulfillment
of the requirments for the Degree
Master of Science at
the University of Windsor
Windsor, Ontario, Canada
1984

ABSTRACT

COCKLEBUR AND VELVETLEAF INTERFERENCE IN SOYBEANS

by

Jeffrey ~~Leonard~~ Larson

Potential density effects upon various components of soybean (*Glycine max* L.) growth were investigated using two weed species; cocklebur (*Xanthium strumarium* L.), and velvetleaf (*Abutilon theophrasti* Medic.), and their combination. Multiple and linear regression was used to establish both the "critical times" at which significant crop-weed interaction is first detected, and the "critical weed densities" at which significant density effects are detected through alterations in crop growth.

Temporal growth models for each weed density were developed for soybean vegetative biomass, total biomass, reproductive biomass, pod number, leaf number and height. Cocklebur density stress elicited significant reductions in soybean growth at six weeks after emergence; about two weeks prior to detection in velvetleaf treatments. The temporal trends in the combination treatment paralleled those using cocklebur. Significant reductions were observed in all the aforementioned soybean growth variables in response to increasing weed density except in height, where an increase was detected.

Soybean seed yield models were developed to explain the effects of season-long competition between the weed treatments and soybeans. The order of competitiveness, as evidenced by soybean seed yield reductions are as follows: cocklebur > combination > velvetleaf. The competitive effects of cocklebur and velvetleaf do appear to be additive in the combination treatments. The predicted "critical weed densities" were identical for all three weed treatments. Two weeds/m of soybean row, regardless of weed species, caused significant reductions in soybean seed yield. Thus cocklebur, velvetleaf, and their combination do pose a real threat to soybean crop production.

ACKNOWLEDGEMENTS

I would like to express my appreciation to my supervisor Mike Weis for his support throughout the duration of my studies at the University of Windsor. I would also like to thank the other members of my committee, Paul Hebert, Ihor Stebelsky, and Susan Weaver for their helpful reviews of my thesis. I would especially like to extend my appreciation to Susan Weaver for her invaluable advice and assistance. Her friendship will never be forgotten. I am particularly indebted to Jan Wilson for her friendship and excellent assistance in the field. Luise Hermanutz also receives special thanks for her many hours of field support.

I am also grateful for the extensive help and facilities offered by the Agriculture Canada Research Station at Harrow. Thanks also go to Ron Sutherland, Gerry Waldron, and Karen Miinch for their unselfish assistance in the field. Finally, I would like to thank Mike Petras for the use of his computer facilities.

TABLE OF CONTENTS

INTRODUCTION

SECTION

1. WEED RESPONSES

2. SOYBEAN RESPONSES

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

INTRODUCTION

I. GENERAL

Weeds have long posed a serious threat to crop production. Annual crop losses due to weed competition total 11.5% of the world's total food production (Chancellor, 1981). Prior to 1945, weeds were primarilly controlled through a large assortment of cultural practices. Mechanical removal of weeds can be accomplished by hand-weeding, hoeing, and tillage (Fryer, 1981). These labour intensive approaches towards weed control are often economically unfeasible and may produce undesirable complications such as soil erosion (McWhorter and Shaw, 1982). Fire has also proved beneficial in the removal of unwanted vegetation. Another strategy involves the rotation of crops to avoid or suppress weed problems (Fryer, 1981).

Herbicides have contributed to agricultural weed control largely since World War II. Earlier in this century, non-selective herbicides such as sodium chlorate were first used (Chancellor, 1981). Being non-selective, both weeds and crops were detrimentally affected. Persistence in the soil often reduced all plant growth for a matter of years. The discovery of plant hormones in the 1920's and the 1930's essentially led to the development of selective herbicides such as

2,4-D, an auxin-type analogue. Acceptance of 2,4-d-type herbicides was quite rapid, and they were widely used across North America by the mid 1950's. Control of broad-leaved weeds was very efficient, requiring only 10% of the capital output necessary for traditional weed control practices (Gressel, 1978). Agriculture became less labour intensive, allowing expansion of total world production acreage.

The shift towards herbicide use was not without deleterious consequences. Persistent herbicide use is often a strong selective force which can quickly eliminate susceptable weed biotypes (Gressel, 1978). The remaining resistant weeds may possess the ability to survive even the highest rates of application of specific herbicides. In the early 1970's this type of phenomenon was observed in Ontario, where lambsquarters and redroot pigweed were observed to have developed resistence to the herbicide atrazine (Gressel, 1978). Recent herbicide price increases have also led many to question the economic feasibility of herbicide use. In addition, there is also a growing concern among environmentalists about possible toxic side-effects.

Fryer (1981) suggested that a number of variables be taken into account in the development of a sound approach towards weed management. Foremost is a necessary understanding of the ecology of both weeds and crop plants. Several researchers have contributed to the definition of a realistic approach towards weed control, termed as "Integrated Weed Management" (IWM) (McWhorter and Shaw, 1982; Schreiber, 1982; Walker and Buchanan, 1982). Walker and Buchanan (1982) have defined IWM as "the application of many kinds of technologies in a mutually supportive manner. It involves the deliberate selection, integration, and implementation of effective weed control measures with due consideration of economic, ecological, and sociological consequences". Within this framework is a need to combine weed population models and overall crop production models (McWhorter and Shaw, 1982). Each crop-weed situation presents a unique set of circumstances which must be addressed individually before any general conclusions can be made.

Dew (1972) was one of the first to initiate the usage of mathematical modeling in the development of crop-weed interaction models. Studying the effects of wild oats on yields of barley, wheat, and flax, he developed a simple regression equation of the following type:

$Y = a + bX$ where Y = crop yield

X = weed density

a = Y-intercept

b = regression coefficient.

His model assumes that crops and weeds emerge simultaneously. This type of model is workable and has been used by many researchers in a variety of crop-weed situations where a single weed species predominates (Bloomberg et al., 1982; Kirkpatrick et al., 1983; Schweizer, 1979, 1983; Schwweizer and Bridge, 1983; Smith, 1983; Snipes et al., 1982; Thurlow and Buchanan, 1972).

Coble and Ritter (1978) realized that the 95% confidence intervals of regression equations could be used to establish weed threshold densities at which crop yield is significantly reduced. Theoretically, this could provide one of the criteria necessary to decide intelligently whether herbicide use is actually required. However, the establishment of threshold weed densities must also take into account a variety of varibles such as economic feasibility. For example, Marra and Carlson (1983), in determining economic threshold weed densities with soybeans, incorporated herbicide cost, cost of herbicide application, herbicide efficacy, and crop price into a single model. They also realize that there may be extreme yearly variation which may necessitate the inclusion of environmental data. Schreiber (1982) shares a similar viewpoint when he states that the inclusion of environmental data is necessary to expand upon the predictive capabilities of crop-weed interaction models. Most of the existing crop-weed interaction models deal solely with single weed species and thus may have limited applicability in multiple weed species situations.

Within this thesis, I am investigating the ecology of two weed species: cocklebur (*Xanthium strumarium* L.) and velvetleaf (*Abutilon theophrasti* Medic), grown singly and in combination with soybeans (*Glycine max* L.). Moreover, I investigated crop-weed interaction with respect to the time and magnitude of potential reductions in soybean growth due to weed competition. The development of crop-weed interaction models may provide a framework necessary for an intelligent descision of when and/or whether it becomes necessary to utilize post-emergent herbicides as a plausable approach towards weed control.

II. The Basis of Competition Modeling

The mechanisms for the procurement of the basic requirements of plant growth and development form the basis of plant competition theory. Any basic reqirement, i.e., light, nutrients, or water can become a limiting factor determining plant growth when plants are grown in close proximity. Evidence of resource limitation is often manifested through modifications in plant growth and development. When this occurs a plant is said to have been subjected to "density stress", to which the plant responds through "morphological compensations" also known as "density effects" (Harper, 1977). Interspecific competition theory depends upon the differences among plant species in response to density stress. There are several strategies that are generally used when one of the essentials of plant growth become limiting. When light is at a premium, a plant may respond by increasing its height in an attempt to overtop its competitors. Another solution to the same problem is the expansion of the canopy by increasing leaf number and/or leaf area. Water limitation often results in a reduction in total plant biomass. Some plants may respond by expanding their root network through increases in branching and total root size. Competition theory dictates that a plant grown under density stress is presented with a defined energy budget. Efficiency in resource utilization is maximized by the disproportionate allocation of energy into the growth of specific plant parts. Density stress serves as one of the determining factors defining this critical balance.

Harper (1977) refers to the temporal aspect of competition when he implies that plants grown under high density stress are more likely to reveal density effects before plants grown under conditions of lower density stress. A thorough description of plant competition must address not only magnitude of density effects, but also when evidence of such is revealed through detectable modifications in plant growth and development.

III. PLANT GROWTH ANALYSIS

In this study I wish to investigate the effects of weed density stress produced by cocklebur, velvetleaf, and their combination upon soybean growth and development. Previous investigations of crop-weed interaction often involved infrequent large harvests of both crops and weeds (Hunt, 1982). This "traditional approach" to crop-weed interaction is useful in the study of season-long weed density stress upon crop yield. However, the infrequent sampling regime provides primary data of insufficient quantity to develop realistic temporal growth models. Hunt (1982) suggests that a "functional approach", utilizing frequent smaller harvests will yield a more accurate description of plant growth. Critical growth phases such as floral initiation and the beginning of senescence are more likely to be detected using such an approach. I am using both approaches; the "traditional approach" investigates the effects of season-long weed density stress upon the components of soybean yield, and the "functional approach" investigates temporal patterns in weed-soybean interaction.

Several variations of the "traditional approach" to crop-weed interaction have been employed. Significant differences between density treatments can be detected using multiple range tests such as those described by

Duncan and Tukey (Sokal and Rohlf, 1969). Hagood et al. (1980) used Duncan's multiple range test to detect significant differences in density effects of velvetleaf on soybeans over several harvest dates. Hagood et al. (1981) again employed the same methodology in the investigation of jimsonweed competition with soybeans. Linear regression gained popularity in the 1970's as a means of describing density effects. Thurlow and Buchanan (1972) used this method to describe the effects of sickle-pod density upon soybean seed yield. The same researchers also utilized Duncan's multiple range test to detect significant density effects. Similar regimes were employed well into the 1980's by Snipes et al. (1982) and Bloomberg et al. (1982) studying the effects of cocklebur density on cotton and soybean yields respectively. A major advance in the development of crop yield models was the realization that the 95% confidence intervals of the regression equations could be used to predict the "critical weed density" at which crop yield is significantly reduced. Among the first to use this method were Coble and Ritter (1978) studying Pennsylvania smartweed in soybeans. Since that time many researchers have used linear regression to predict "critical weed densities" in a variety of crop-weed situations (Coble et al, 1981; Schweizer and Bridge, 1982; Schweizer, 1983). In this study I also used linear regressions and their 95% confidence intervals to predict "critical densities" of cocklebur, velvetleaf, and their combination required to significantly reduce soybean yield. In the development of temporal growth models, 95% confidence intervals were also utilized to predict the time at which density stress significantly reduced soybean growth. However, before potential crop-weed interaction can be properly addressed, the ecology of the weed species involved must be defined. Grown against a constant background density of soybeans, weed species may possibly interact among themselves. Such interaction may result in weeds of different sizes corresponding to specific densities. This leads to the query: "Will the weeds at each density elicit a similar density response in soybean growth on a per plant (weed) basis?". By employing similar methodologies for development of temporal growth models for both weeds and soybeans, a better understanding of weed-soybean systems can be obtained. The approach I am using is to investigate the weed species first, and then attempt to apply this information to the investigation of weed-soybean interaction.

IV. DESCRIPTION OF VELVETLEAF

Abutilon theophrasti Medic., also known as velvetleaf, is a member of the Malvaceae family. An annual herbaceous plant, it reaches a height of one to two meters (Alex and Switzer, 1974). It is characterized by soft hairy chordate leaves which are "velvety" to the touch.

Originally a native of southern Asia, velvetleaf is found throughout the continental United States. In several sections of the U.S. it poses a threat to cotton and soybean production (Eaton et al, 1976; Oliver, 1979). Within Canada it is confined to southern Ontario and Quebec where it is becoming an increasing problem in soybean crops (Alex and Switzer; 1974).

Velvetleaf has single or small clusters of bisexual flowers arising from leaf axils of the plant. Floral induction is photoperiodically controlled and can be considerably variable even within local populations. Within Ontario, velvetleaf flowers from late July until early September (Alex and Switzer, 1974). The fruit is a circular seed pod, (1.3-2.5 cm in diameter), with 12-15 carpels and 2-5 seeds per carpel. Total seed number depends upon plant size at the time of floral induction. Open grown plants have been known to produce as many as 17,000 seeds per plant (Chandler and Dale, 1974). In some studies, seed viability rapidly declines after two years, making it a temporary seed-bank member (Lueschen and Anderson, 1980).

V. DESCRIPTION OF COCKLEBUR

Xanthium strumarium L., commonly known as cocklebur, is a member of the Compositae family. An annual herbaceous plant , it grows to 20-150 cm in height (Weaver and Lechowicz, 1983). The species expresses considerable morphological variation especially with respect to the hard woody fruit or bur, which varies in size (1-3.5 cm), spine number, and spine length.

A major weed of cotton and soybeans in the United States (Barrentine, 1974), cocklebur is increasing in abundance in southwestern Ontario soybean crops (Weaver and Lechowicz, 1983). The major mode of seed dispersal is by water, accounting for its concentrated distribution around water courses. Its geographical range includes the entire continental U.S. and all of the Canadian provinces except Newfoundland (Weaver and Lechowicz, 1983). This distribution illustrates its ability to survive under a vast array of environmental conditions. Although it can grow upon a variety of substrata, optimal growth is observed in compact, sandy soils (Love and Dansereau, 1959).

Cocklebur is a self-compatible, wind-pollinated plant possessing small green inflorescences of both sexes (Love and Dansereau, 1959). Floral induction is photoperiodically controlled and occurs during the shortened days of late summer (McMillan, 1975). Although the photoperiodic requirement is variable throughout its range, northern populations flower synchronously. In southwestern Ontario, floral initiation occurs in mid-August followed by fruit-filling over the next two weeks (Weaver and Lechowicz, 1983). The fruit or bur number per plant varies considerably, but is largely dependent upon plant size at the time of floral initiation. Studies have found bur number per plant on open-grown plants to range from 500 in Illinois (Hicks, 1971) to 2300 in India (Kaul, 1965). The mature fruit (or bur) contains two achenes (seeds), usually of differing size. Both require a period of dormancy; the larger seed germinates in the spring following maturity while the smaller seed germinates later in the season or in the following year (Hicks, 1971). A study conducted in India indicates that seed viability declines rapidly after 18 months making it a temporary seed-bank member (Kaul, 1965). It is unknown whether this trend holds true in temperate soils.

MATERIALS AND METHODS

Field studies were conducted in 1982 and 1983 at the Agriculture Canada Research Station in Harrow, Ontario, Canada. The soil type was a combination of Granby and Brady sandy loam with an organic matter content of 2.5-2.6% and a pH of 5-5.2. Herbicides were used to control other weeds. In both years the herbicide Alachlor was applied pre-plant incorporated (PPI) at a rate of 2.5 kg/ha to control annual grasses. In 1982, the herbicide Lineron was applied preemergence at a rate of 0.5 kg/ha (half the recommended rate), in an attempt to control other broad-leaved weeds. Due to heavy rains, it unfortunately was lethal to one of the weed species studied (velvetleaf). Hence it was not used in 1983. Fertilizer (8-32-16 NPK) was applied at a rate of 300 kg/ha a few days prior to planting.

'Harcor' soybeans were planted in rows spaced 60 cm apart at the rate of four seeds/10 cm of soybean row on May 17, 1982, and on May 30, 1983. Cocklebur and velvetleaf were planted within 10 cm of the adjacent soybean row on the following day on both years. A completely randomized block design with four replicates was used. Within each replicate, each density treatment was represented by two 16 m rows isolated by a weed-free guard row. In 1982, the density treatments used were as follows; weed-free, 2,4,8, and 16 cocklebur plants/m of soybean row. Weeds were overplanted and thinned to the prescribed densities three weeks after emergence. Volunteer weeds were removed weekly by hoeing. In 1983, velvetleaf was planted at 2,4,8, and 16 plants/m of soybean row. In addition, combination treatments comprised of equal densities of cocklebur and velvetleaf were also used. The total weed densities were 2,4,8, and 16 plants/m of soybean row. A single cocklebur treatment of 16 plants/m was also used in an attempt to assess variation in yearly growth response.

In both years in each treatment, a single soybean plant located equidistant between two adjacent weeds was randomly sampled starting five weeks after emergence until maturity. Sampling was conducted weekly in 1982 and biweekly in 1983. In the control treatments (weed-free), two soybean plants, randomly located along the rows, were harvested at each sampling date. Measurements were taken of height, stem diameter, leaf number, pod number, reproductive biomass (dry), vegetative biomass (dry), and total biomass (reproductive biomass + vegetative biomass). At maturity, four meters of soybeans in each density treatment in each replicate were harvested in an attempt to study the effects of full-season weed density stress upon soybean seed yield. A portable threshing machine was utilized to isolate soybean seed.

In 1982, a single weed in each treatment and replication was randomly sampled each week starting five weeks after emergence until maturity. Measurements were taken of height, stem diameter, leaf number, and above ground vegetative biomass. In 1983, sampling was conducted on a biweekly basis. Leaf area was also measured for velvetleaf through the use of a portable leaf-area meter. In the combination treatments, both weed species were harvested at each sampling date.

In 1982, both soybean and weed germination appeared to be temporally variable. In an attempt to reduce this variability in 1983, weeds of similar size, in areas of consistent density, were flagged three weeks after emergence. Soybean plants were randomly sampled at the flagged locations throughout the summer. Flagged weeds were randomly sampled on the same dates. Hence density effects can only be considered after the time of flagging.

Linear and multiple regression techniques were used to develop temporal growth models for the aforementioned growth variables of soybeans with each weed species, singly and in combination. Where density effects were detected, 95% confidence limits of the regression equations were employed to determine the time at which they reached significance. The point of divergence of the lower 95% confidence limits of the regression equation of the control treatment (weed-free) with the upper 95% confidence limits of the regression equation of the density treatments represents the time at which density effects are first detectable. In addition to developing a temporal growth model for each weed density, density itself was also incorporated into an overall model for each growth variable. All of the regression equations were significant at an alpha level of 0.05.

A multiple regression analysis of variance was conducted for each weed growth variable for each weed species grown singly and in combination in an attempt to detect density effects. Where density effects were detected, temporal growth models were developed for the growth variables at each density. The 95% confidence limits of the regression equations were used to determine the time at which the higher density treatments elicited growth responses significantly different from those obtained at the lowest density treatment (2 weeds/m). Where density effects were not detected, overall temporal growth models (without density) were developed to describe weed growth over time. Again, all of the regression equations were significant at an alpha level of 0.05.

Soybean seed yield models were developed using the single weed species and their combination. The 95% confidence intervals of the regression equations were used to determine the "critical weed density" necessary to elicit significant reductions in soybean seed yield.

SECTION I

WEED RESPONSES

1.1 RESULTS

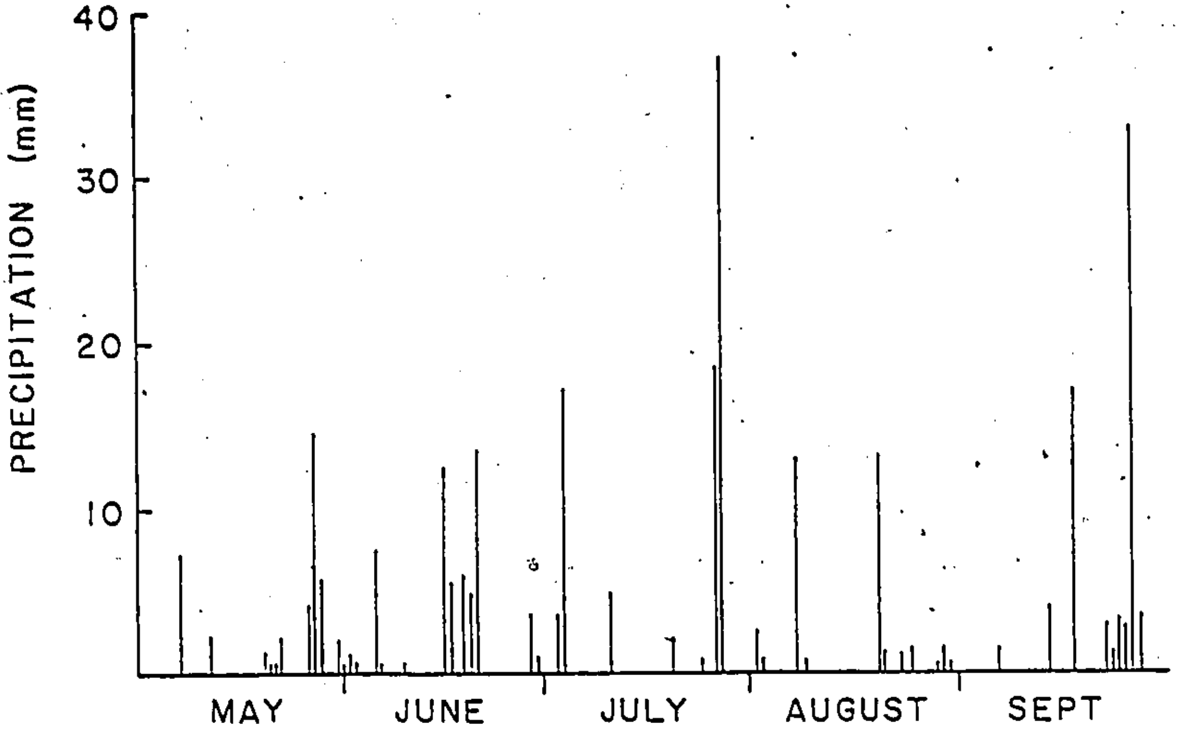
I. COCKLEBUR

Intraspecific responses to density were observed in a variety of growth parameters in cocklebur in 1982. Precipitation data revealed 83% and 101% of the longterm average in the respective years (51 year average). Yet in 1982, a drier year, cocklebur grew to a much larger size, with greater height, stem diameter, and total leaf number compared to 1983 (based on cocklebur at 16 plants/m in 1982 and 1983). One of the keys to the year-to-year variation in growth response lies not in total precipitation, but within its distribution throughout the growing season (Fig. 1.1). In 1982, the plants had emerged by June 1 and had sufficient rainfall during the initial stages of growth. In 1983, the plants had emerged by June 15 and were subjected to an immediate drought of 11 days. During this period plant growth was minimal.

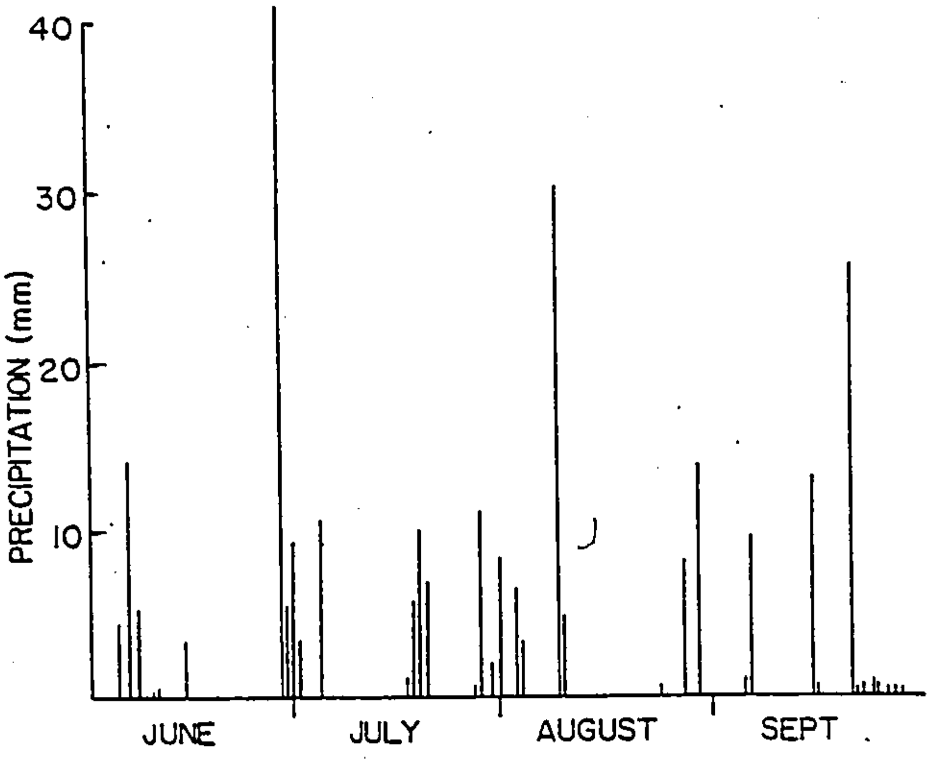
Multiple regression techniques were used to develop temporal growth models for both weed species. In 1982, density effects in cocklebur were reflected through modifications in height, leaf number, and vegetative biomass. Temporal models were developed for each growth variable at the entire range of plant densities (Tables 1.1,1.2,1.3,1.4). To ensure normality, some of the

Figure 1.1

Daily precipitation in mm, recorded at Agricultural Research Station, Harrow, Ontario in 1982 (upper graph) and 1983 (lower graph) field seasons.



40
30
20
10
PRECIPITATION (mm)
MAY
JUNE
JULY
AUGUST
SEPT



40
30
20
10
PRECIPITATION (mm)
JUNE
JULY
AUGUST
SEPT

Table 1.1. Regression equations for log vegetative biomass (g) vs. time (weeks after emergence) for each cocklebur density in 1982. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
2/m	-2.201	1.312	-0.064	0.907
	±0.337	±0.117	±0.009	
4/m	-2.130	1.338	-0.064	0.805
	±0.532	±0.185	±0.014	
8/m	-0.719	0.875	-0.036	0.891
	±0.298	±0.103	±0.008	
16/m	-1.986	1.211	-0.061	0.850
	±0.307	±0.124	±0.010	

Table 1.2. Regression equations for height (cm) vs. time (weeks after emergence) for each cocklebur density treatment in 1982. Standard errors are included for comparison.

TREATMENT	INTERCEPT	SLOPE	R^2
2/m	-21.313	14.495	0.892
	±5.414	±0.779	
4/m	-25.477	15.954	0.922
	±4.963	±0.714	
8/m	-21.980	17.081	0.911
	±5.740	±0.825	
16/m	-11.665	15.890	0.877
	±5.399	±0.842	

Table 1.3. Regression equations for log leaf number vs. time (weeks after emergence) for each cocklebur density in 1982. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
2/m	1.165	0.674	-0.032	0.861
	±0.223	±0.077	±0.006	
4/m	1.289	0.686	-0.033	0.725
	±0.344	±0.119	±0.009	
8/m	2.356	0.312	-0.010	0.694
	±0.242	±0.084	±0.006	
16/m	1.501	0.513	-0.026	0.665
	±0.214	±0.086	±0.007	

Table 1.4. Regression equations for stem diameter (mm) vs. time (weeks after emergence) for each cocklebur density in 1982. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
2/m	-2.269	3.136	-0.139	0.826
	±1.293	±0.449	±0.033	
4/m	-2.159	3.309	-0.142	0.708
	±1.986	±0.689	±0.051	
8/m	0.923	2.119	-0.069	0.794
	±1.296	±0.450	±0.033	
16/m	1.135	2.034	-0.087	0.797
	±0.725	±0.296	±0.024	

primary data were log-transformed as suggested by Hunt (1982), but only in cases where the temporal growth models were significantly improved by doing so. All log-transformations are natuarl log-transformations and are referred to throughout the text as log or ln. In addition, when applicable, density was also incorporated into an overall model for each variable (Table 1.5).

In 1982, increases in weed density resulted in increases in cocklebur height. By using the 95% confidence intervals of the regression equations for each density, the time at which the higher densities became significantly different from the lowest density (2 plants/m sobean row) were obtained. Cocklebur grown at a density stress of 8 and 16 plants/m row, were significantly taller than those at the lowest density at approximately 7 weeks after emergence (Fig. 1.2). At maturity, cocklebur grown at 16 plants/m were 19% taller than those grown at 2 plants/m. Reductions in vegetative biomass of high density cocklebur compared to the lowest density were detected 9 weeks after emergence (Fig. 1.3). At maturity, low density plants weighed 45% more than those of high density. Significantly smaller stem diameters were observed in the high density plants 10 weeks after emergence(Fig. 1.4). At season's end, stem diameter was 18% greater in low density plants. Leaf numbers were also significantly lower in plants grown at high density. Density effects appeared in leaf number at

Table 1.5. Multiple regression equations, incorporating density, for height (cm), log leaf number, log vegetative biomass, and stem diameter (mm) vs. time (weeks after emergence) for cocklebur in 1982. Standard errors are included for comparison.

		SLOPES			
VARIABLE	INTERCEPT	DENSITY	WEEK	WEEK^2	R^2
height	-29.788	1.245	15.897	---	0.894
	±3.498	±0.243	±0.407	---	
log leaf	1.882	-0.032	0.527	-0.024	0.729
number	±0.150	±0.007	±0.048	±0.004	
log veg.	-1.548	-0.027	1.181	-0.056	0.852
biomass	±0.212	±0.009	±0.068	±0.005	
stem	0.712	-0.079	2.434	-0.095	0.751
diameter	±0.744	±0.033	±0.239	±0.018	

Figure 1.2

Seasonal pattern of vegetative biomass accumulation (log transformed) in cocklebur grown at 2 and 16 plants/m soybean row. The vertical dashed line indicates the first significant difference from the low density treatment. Significant differences were not found in cocklebur grown at 4 and 8/m soybean row.

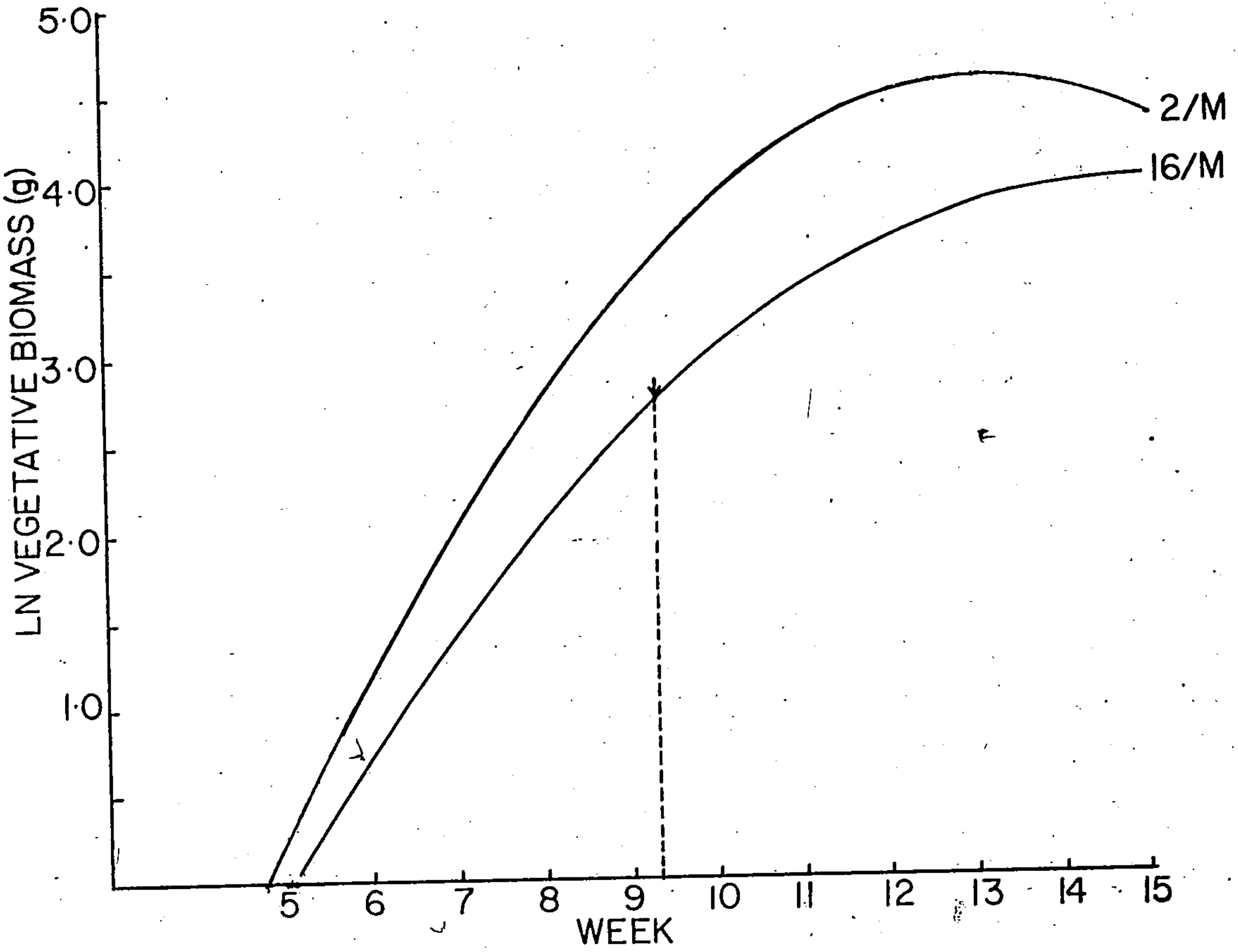

5·0
4·0
3·0
2·0
1·0
LN VEGETATIVE BIOMASS (g)
5
6
7
8
9
10
11
12
13
14
15
WEEK
2/M
16/M

Figure 1.3

Seasonal pattern of height increases in cocklebur grown at 2, 8, and 16 plants/m soybean row. The vertical dashed line indicates the first significant difference from the low density treatment. The regression predicting height at 8 plants/m was very similar to that at 16 plants/m row and for reasons of clarity was omitted from the graph (first significant difference was also the same as 16/m). A significant difference was not found in cocklebur grown at 4/m row.

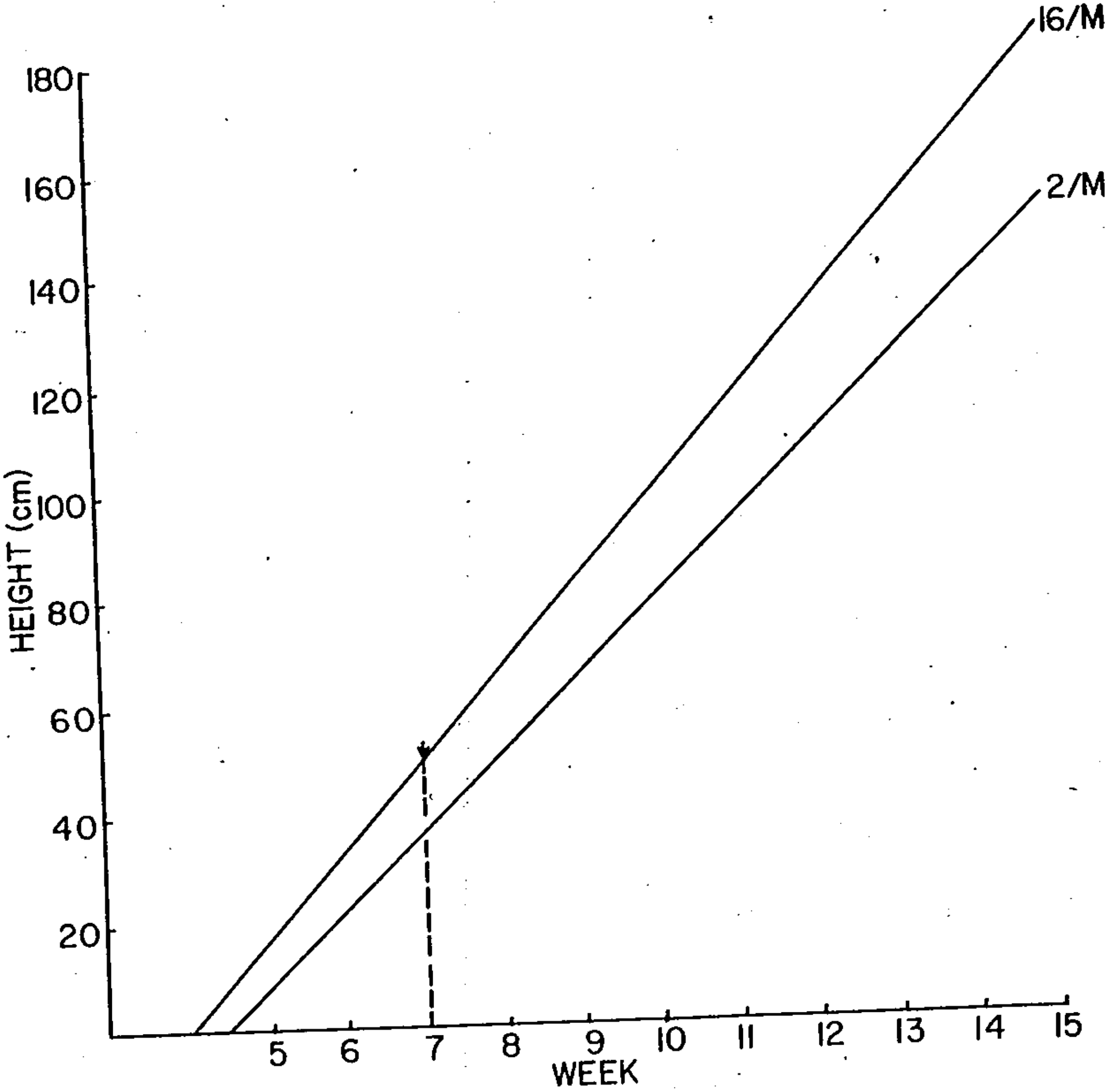
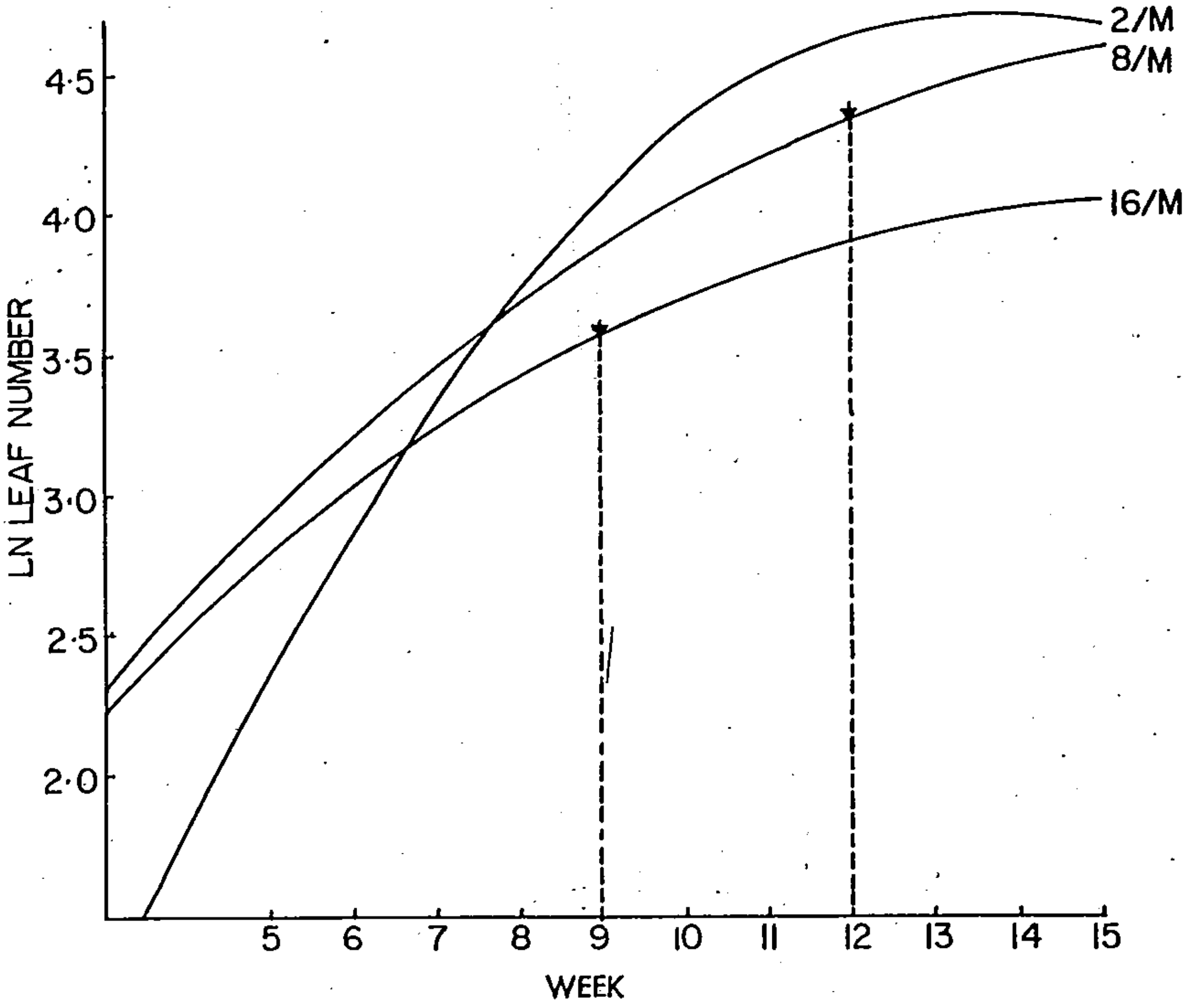

16/M
2/M
HEIGHT (cm)
180
160
140
120
100
80
60
40
20
5
6
7
8
9
10
11
12
13
14
15
WEEK

Figure 1.4

Seasonal pattern of leaf growth (log transformed leaf number) in cocklebur grown at 2, 8, and 16 plants/m soybean row. The dashed vertical lines indicate the first significant differences from the low density treatment. A significant difference was not found in cocklebur grown at 4/m row.



LN LEAF NUMBER
4·5
4·0
3·5
3·0
2·5
2·0
5
6
7
8
9
10
11
12
13
14
15
WEEK
2/M
8/M
16/M

12 and 9 weeks after emergence for plants grown at 8 and 16/m respectively (Fig. 1.5). At maturity, cocklebur grown at the lowest density had 107% more leaves than high density plants.

Cocklebur appears to exhibit a great deal of morphological plasticity in growth response to density stress. Generally, cocklebur grown under high density stress tend to increase in height, while showing reductions in vegetative biomass, stem diameter, and leaf number. Though it is unknown whether light became limiting under conditions of high density stress, the modifications in cocklebur canopy structure (ie. height and leaf number) suggest that this may be the case.

Cocklebur was studied in 1983 in two different ways; a single density of 16 plants/m soybean row was planted to access yearly variation, cocklebur was combined with velvetleaf to investigate interspecific density effects. Cocklebur grew considerably more in 1982 than in 1983 (based on the lone cocklebur density of 16 plants/m grown in 1983; Table 1.6). At maturity, cocklebur plants in 1982 were 25% taller, had 71% more leaves, and had a vegetative biomass 93% greater than plants of 1983. Stem diameter did not differ between years. Total weed density did not affect any of the growth variables studied in cocklebur in the 1983 combination treatments (Tables 1.7-1.10). I conclude that the reduced growth of 1983 may have been caused by both early season drought and the delay in planting date.

Figure 1.5

Seasonal pattern of stem growth (diameter) in cocklebur grown at 2 and 16 plants/m soybean row. The dashed vertical line indicates the first significant difference from the low density treatment. Significant differences were not found in plants grown at 4 and 8 plants/m row.

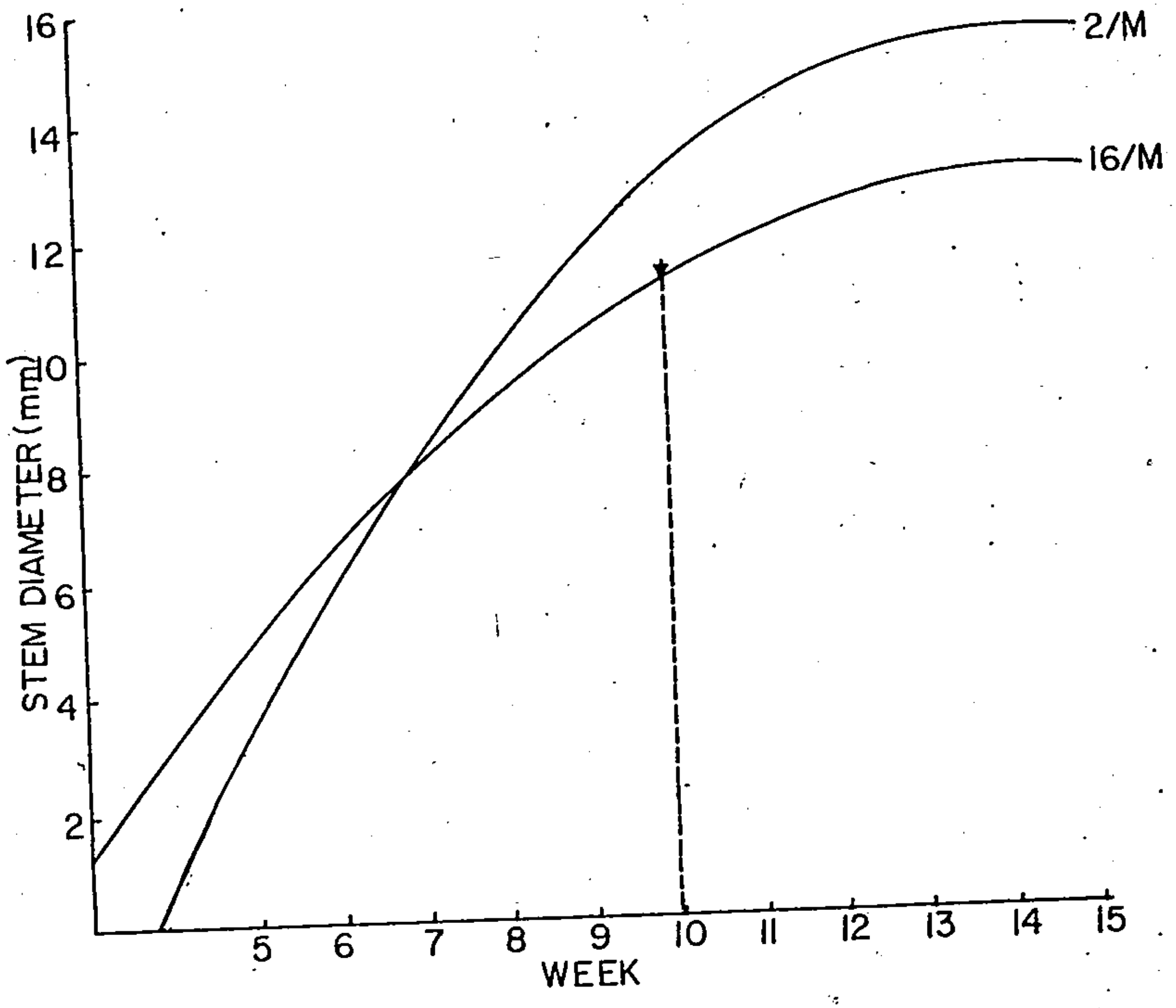

STEM DIAMETER (mm)
16
14
12
10
8
6
4
2
WEEK
5
6
7
8
9
10
11
12
13
14
15
2/M
16/M

Table 1.6. Multiple regression equations for height, log leaf number, log vegetative biomass, and stem diameter vs. time (weeks after emergence) for cocklebur grown at a density of 16 plants/m in 1983. Standard errors are included for comparison.

VARIABLE	INTERCEPT	SLOPES		R^2
		WEEK	$WEEK^2$	
height	-31.285	11.863	-----	0.775
	±13.232	±1.364		
log leaf number	2.422	0.083	-----	0.198
	±0.345	±0.036		
log veg. biomass	-3.386	1.061	-0.042	0.772
	±1.150	±0.266	±0.014	
stem diameter	2.797	0.656	-----	0.476
	±1.424	±0.147		

Table 1.7. Multiple regression analysis of variance for differences in cocklebur log vegetative biomass between densities over time in the combination treatments in 1983.

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
Density	1	0.0522	0.0522	0.10 ns
Week	1	116.8487	116.8487	224.48 ***
Week*Week	1	8.6766	8.6766	16.67 ***
Error	90	46.8472	0.5205	
Corrected Total	93	172.4246		

Table 1.8. Multiple regression analysis of variance for differences in cocklebur height between densities over time in the combination treatments in 1983.

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
Density	1	10.8250	10.8250	0.03 ns
Week	1	140245.2129	140245.2129	380.25 ***
Error	93	34300.4011	368.8215	
Corrected Total	95	174556.4391		

Table 1.9. Multiple regression analysis of variance for differences in cocklebur log leaf number between densities over time in the combination treatments in 1983.

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
Density	1	0.1301	0.1301	0.35 ns
Week	1	16.0395	16.0395	43.20 ***
Week*Week	1	1.3250	1.3250	3.57 ns
Error	90	33.4159	0.3713	
Corrected Total	93	50.9106		

Table 1.10. Multiple regression analysis of variance for differences in cocklebur stem diameter between densities over time in the combination treatments in 1983.

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
Density	1	1.1281	1.1281	0.18 ns
Week	1	577.2947	577.2947	92.98 ***
Week*Week	1	18.6057	18.6057	3.00 ns
Error	92	571.2165	6.2089	
Corrected Total	95	1168.2450		

II. VELVETLEAF

In 1983, velvetleaf revealed no responses to density stress when either planted alone or in combination with cocklebur (Tables 1.11-1.16). Hence temporal growth models were developed for each growth variable irrespective of density (Table 1.17). Floral initiation in velvetleaf began 10 weeks after emergence. Virtually all of the temporal growth models describe declines associated with senescence at this time (Figures 1.6-1.9).

The relative growth rate of velvetleaf was lower than that of cocklebur throughout the season (Fig. 1.10). Yet there was no evidence of interspecific density effects when grown in combination with cocklebur within the density range examined.

Table 1.11. Multiple regression analysis of variance for differences in velvetleaf log vegetative biomass between densities over time (1983).

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
Density	1	0.7628	0.7628	1.07 ns
Week	1	7.9186	7.9186	11.12 ***
Week*Week	1	23.9336	23.9336	33.62 ***
Error	92	65.5019	0.7120	
Corrected Total	95	98.1169		

Table 1.12. Multiple regression analysis of variance for differences in velvetleaf log height between densities over time (1983).

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
Density	1	0.0193	0.0193	0.16 ns
Week	1	21.7374	21.7374	184.14 ***
Week*Week	1	10.7724	10.7724	91.26 ***
Error	92	10.8603	0.1180	
Corrected Total	95	43.3894		

Table 1.13. Multiple regression analysis of variance for differences in velvetleaf log leaf number between densities over time (1983).

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
Density	1	0.1796	0.1796	1.64 ns
Week	1	2.3159	2.3159	21.08 ***
Week*Week	1	0.7570	0.7570	6.89 ***
Error	92	10.1051	0.1098	
Corrected Total	95	13.3576		

Table 1.14. Multiple regression analysis of variance for differences in velvetleaf log total leaf area between densities over time (1983).

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
Density	1	1.0656	1.0656	1.44 ns
Week	1	0.3163	0.3163	0.43 ns
Week*Week	1	57.2433	57.2433	77.45 ***
Error	92	68.0003	0.7391	
Corrected Total	95	126.6254		

Table 1.15. Multiple regression analysis of variance for differences in velvetleaf log stem diameter between densities over time (1983).

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
Density	1	0.1497	0.1497	1.64 ns
Week	1	2.4628	2.4628	26.98 ***
Week*Week	1	3.2358	3.2358	35.44 ***
Error	92	8.3992	0.0913	
Corrected Total	95	14.2475		

Table 1.16. Multiple regression analysis of variance for differences in velvetleaf log vegetative biomass between densities over time in the combination treatments in 1983.

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
Density	1	2.5846	2.5846	2.55 ns
Week	1	26.9949	26.9949	26.58 ***
Week*Week	1	12.5966	12.5966	12.40 ***
Error	92	93.4211	1.0154	
Corrected Total	95	135.5972		

Table 1.17. Multiple regression equations for log height, log leaf number, log leaf area, log vegetative biomass, and log stem diameter vs. time (weeks after emergence) for velvetleaf in 1983 (using pooled densities). Standard errors are included for comparison.

		SLOPES		
VARIABLE	INTERCEPT	WEEK	WEEK^2	R^2
log height	-1.048 ±0.287	0.848 ±0.066	-0.037 ±0.003	0.700
log leaf - number	1.042 ±0.244	0.168 ±0.056	-0.012 ±0.003	0.245
log leaf area	-3.779 ±0.623	1.809 ±0.144	-0.095 ±0.008	0.456
log veg. biomass	-6.303 ±0.697	1.145 ±0.161	-0.054 ±0.008	0.289
log stem diameter	-1.096 ±0.251	0.409 ±0.058	-0.019 ±0.003	0.313

Figure 1.6

Seasonal pattern of vegetative biomass accumulation (log transformed) in velvetleaf (pooled densities). Means are log transformed and include standard errors.

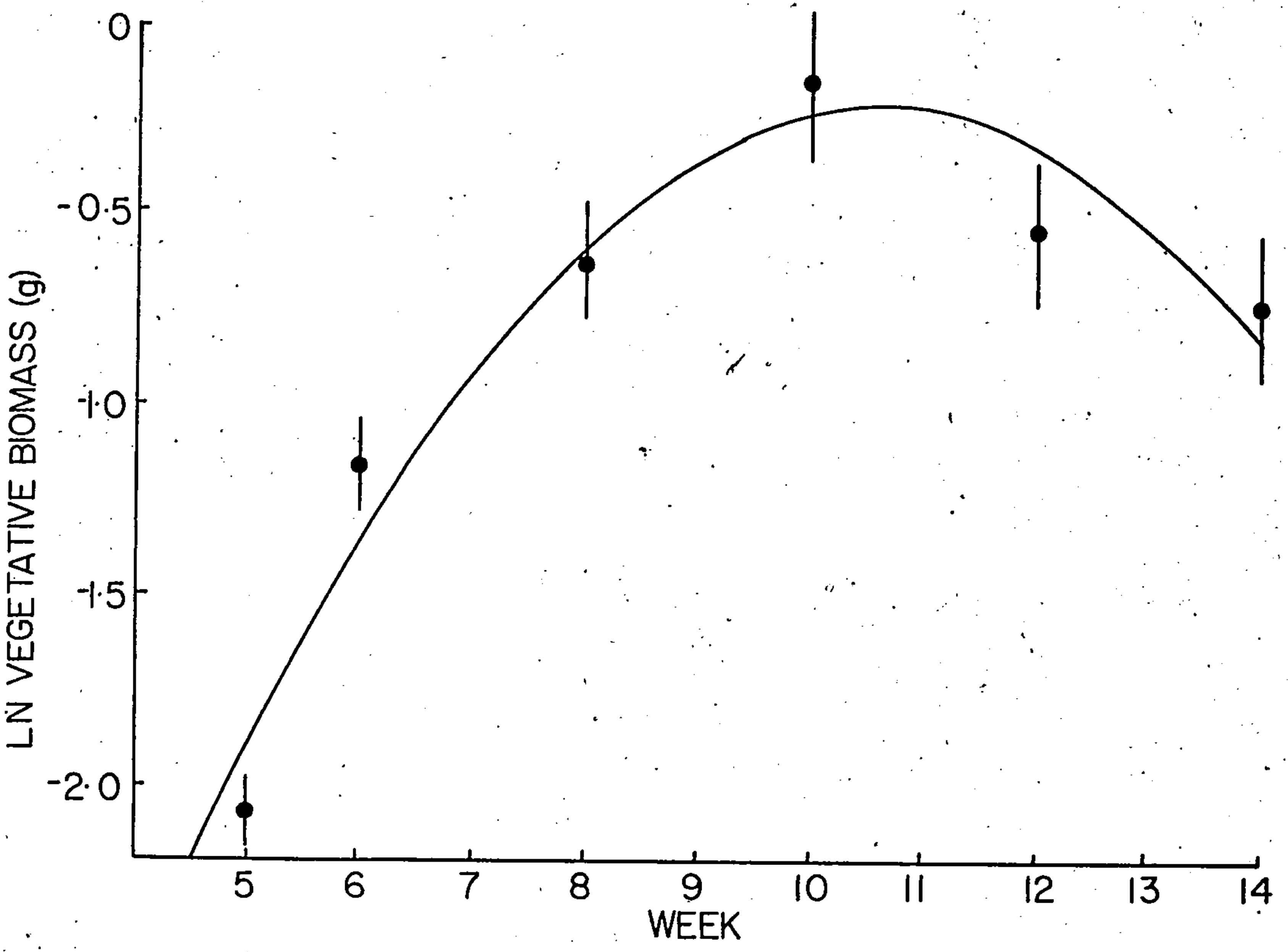

0
-0·5
-1·0
-1·5
-2·0
LN VEGETATIVE BIOMASS (g)
5
6
7
8
9
10
11
12
13
14
WEEK

Figure 1.7

Seasonal pattern of height increases (log transformed) in velvetleaf (pooled densities). Means are log transformed and include standard errors.

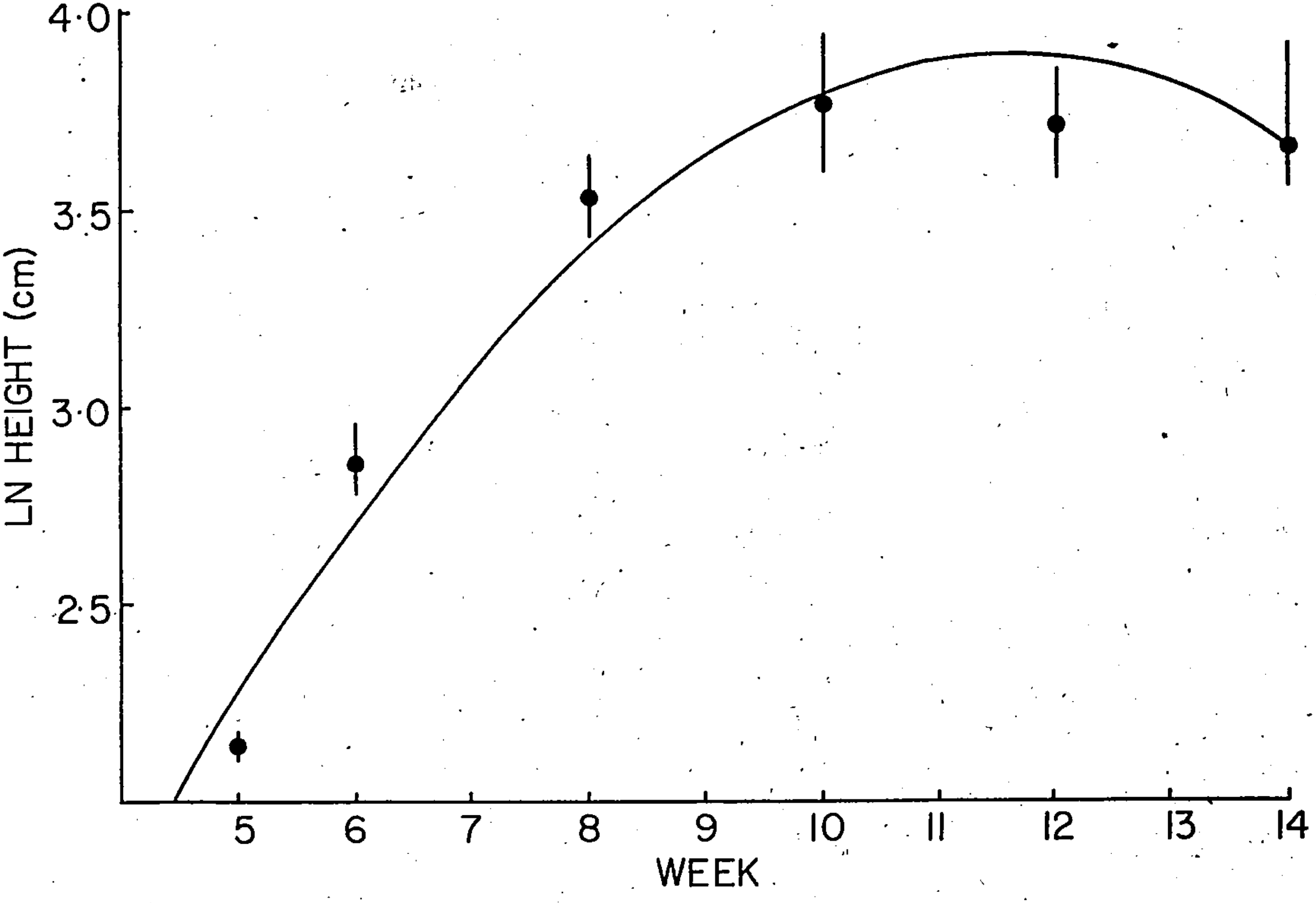

4·0
3·5
3·0
2·5
LN HEIGHT (cm)
5
6
7
8
9
10
11
12
13
14
WEEK

Figure 1.8

Seasonal pattern of leaf growth (log transformed leaf number) in velvetleaf (pooled densities). Means are log transformed and include standard errors.

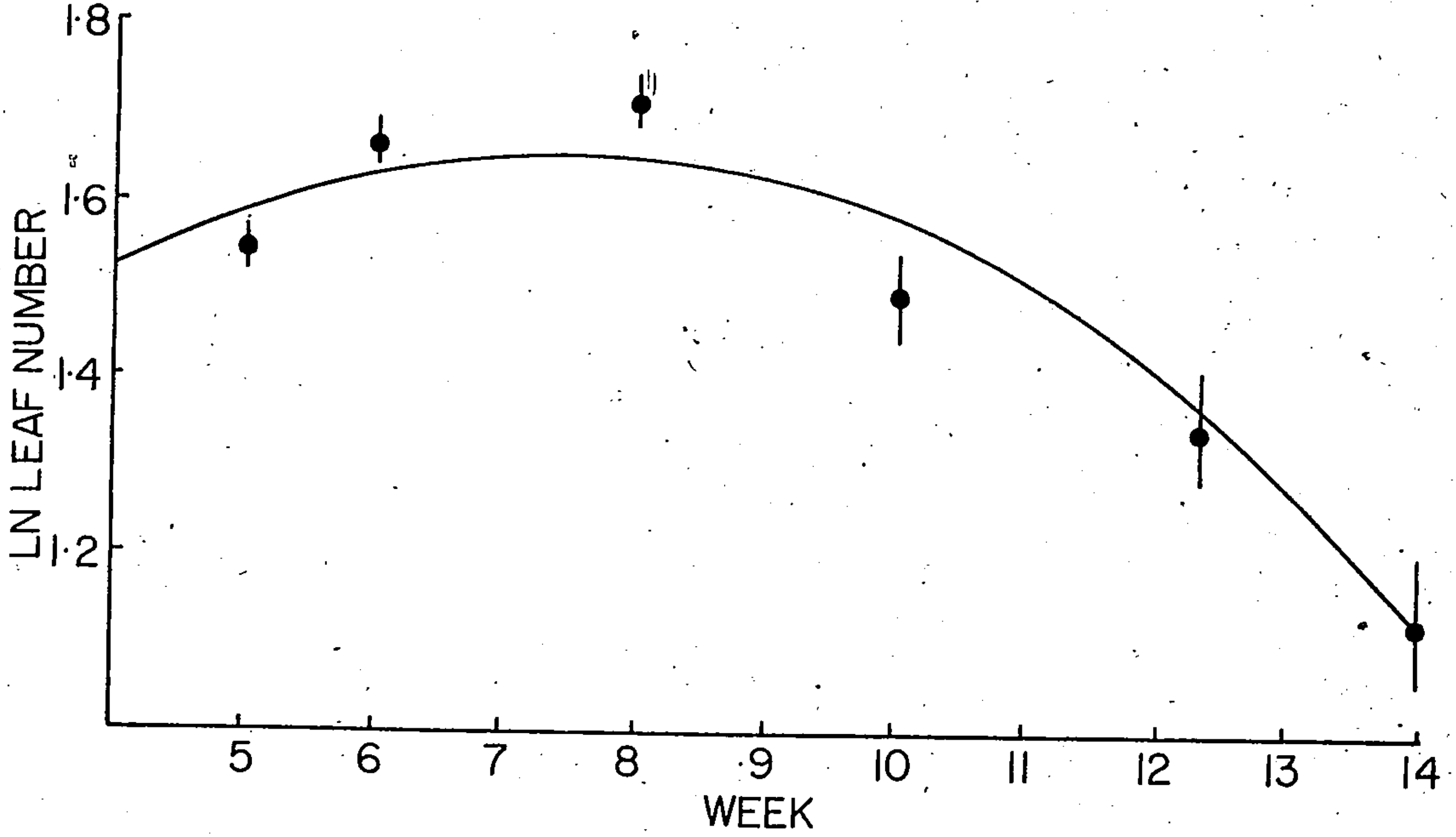

LN LEAF NUMBER
1·8
1·6
1·4
1·2
5
6
7
8
9
10
11
12
13
14
WEEK

Figure 1.9

Seasonal pattern of leaf growth (log transformed leaf area) in velvetleaf (pooled densities). Means are log transformed and include standard errors.

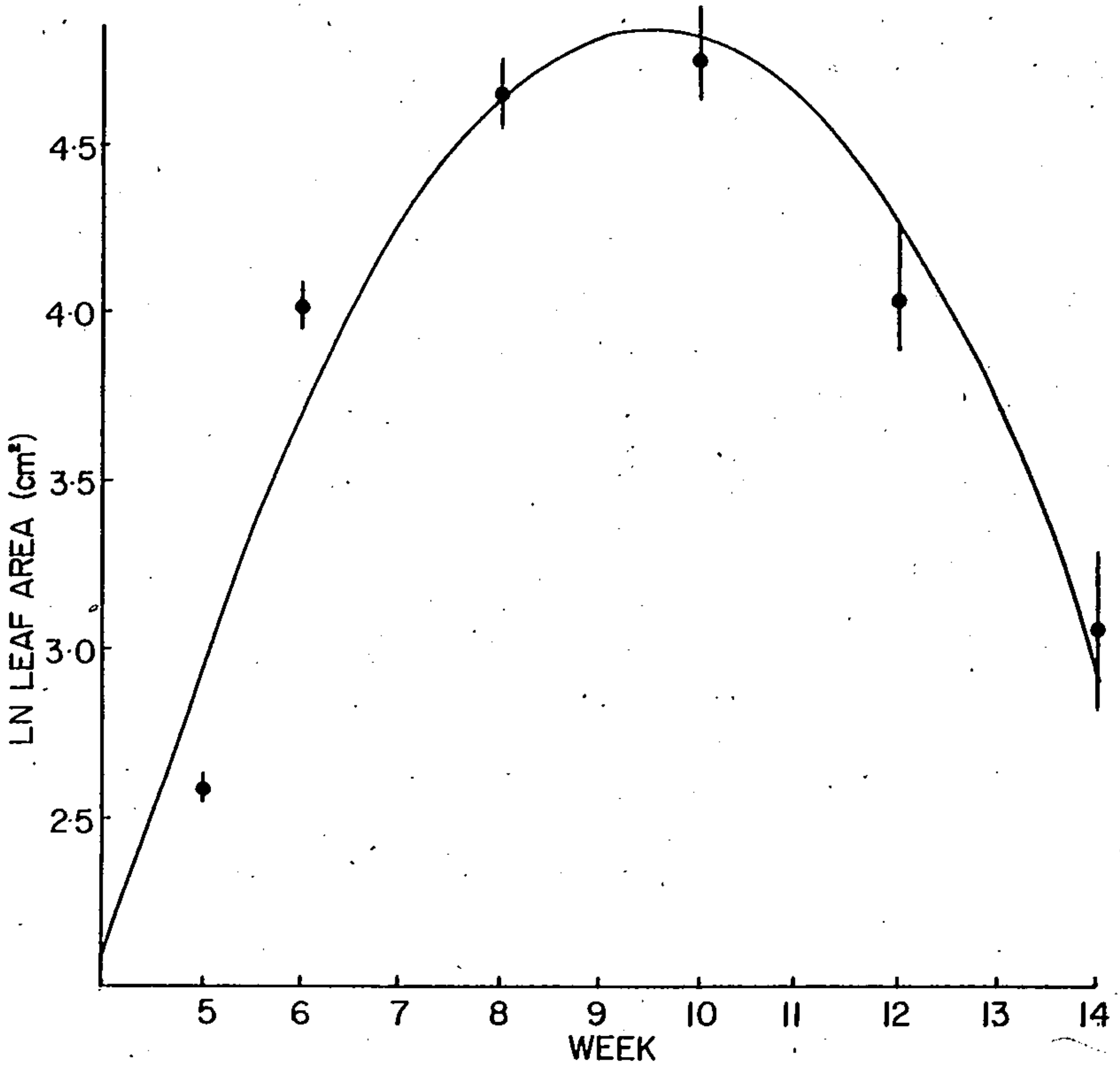
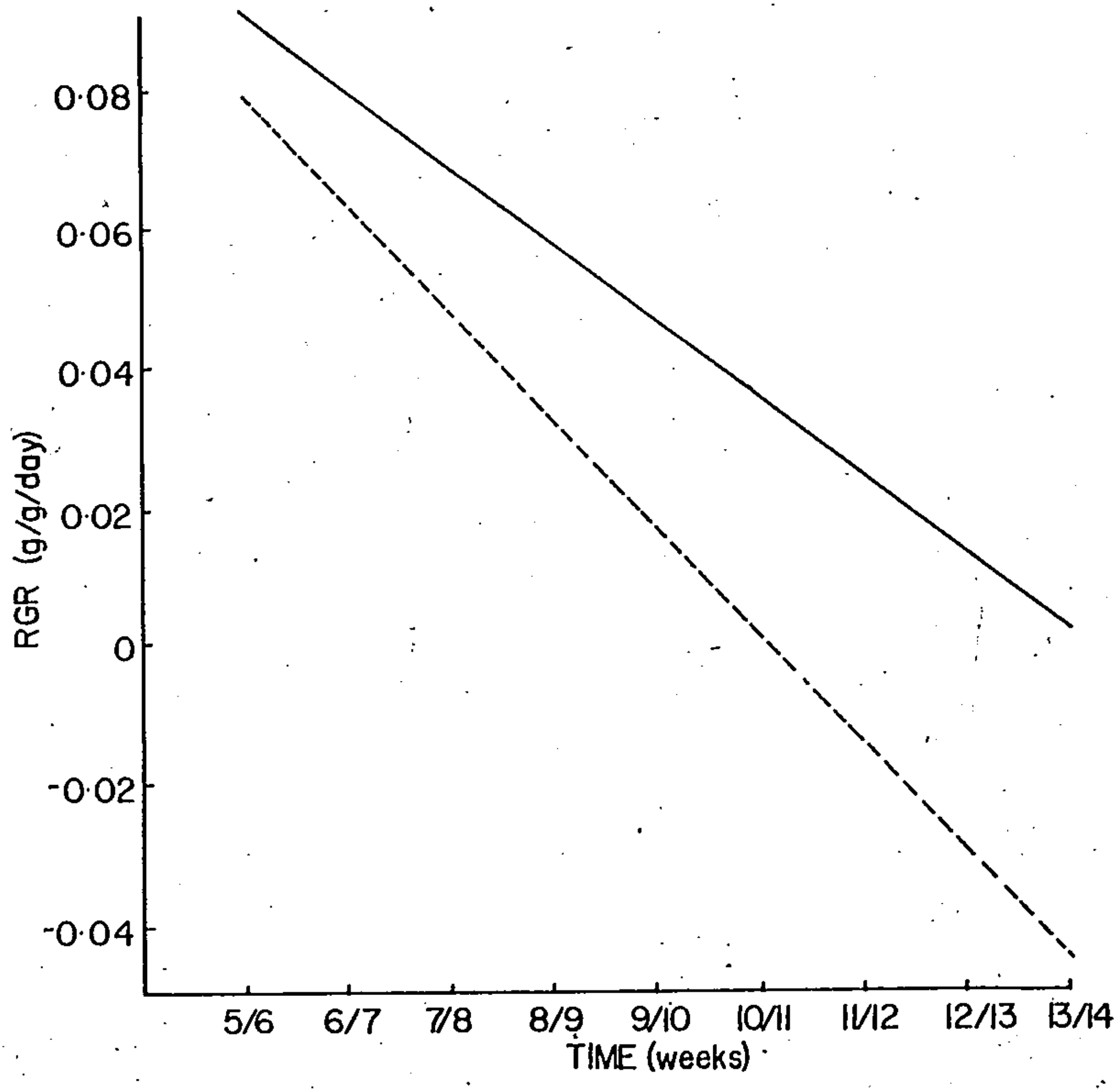

LN LEAF AREA (cm²)
4·5
4·0
3·5
3·0
2·5
5
6
7
8
9
10
11
12
13
14
WEEK

Figure 1.10

Seasonal patterns of relative growth rates (calculated from vegetative biomass) of cocklebur and velvetleaf grown at 16 plants/m soybean row. The solid line represents the relative growth rate of cocklebur and the dashed line that of velvetleaf.


RGR (g/g/day)
0·08
0·06
0·04
0·02
0
-0·02
-0·04
5/6
6/7
7/8
8/9
9/10
10/11
11/12
12/13
13/14
TIME (weeks)

1.2 DISCUSSION

In this section, I have indicated whether density effects can be detected in cocklebur and velvetleaf grown under field conditions with constant soybean density. In addition, when density effects were detected, I determined a time at which they became significant.

Environmental variability may influence the magnitude of density stress. The literature presents contradictory examples of specific densities of a single species required to elicit density effects. Kirkpatrick et al. (1983) found evidence of competitive interaction in jimsonweed planted at 1.6 plants/m soybean row. However, Hagood et al. (1981) found that jimsonweed vegetative biomass was reduced only at densities greater than 8 plants/sq. m. Short term studies are often of insufficient length to detect density effects because of year-to-year variation. Many researchers use very low weed densities and expect to observe reductions in crop-plant growth. This appears to be a consequence of experimental design; the common goal is to detect density effects in the associated crop plant while ignoring potential effects of weed interaction. I believe that a thorough investigation of crop-weed interaction should also include a description of weed growth within the crop-weed complex.

In 1982, cocklebur exhibited density effects in a variety of growth parameters. Cocklebur grown under high density stress were taller, had fewer leaves, smaller stem diameters, and reduced vegetative biomass when compared to plants grown at lower densities. This is in agreement with Bloomberg et al. (1980) who found similar reductions in vegetative biomass in cocklebur when grown with soybeans.

Multiple regressions were used to develop temporal growth models for each of the growth variables aforementioned. Modifying an approach of Coble and Ritter (1978), the divergence point of the 95% confidence intervals of the growth curves for each density were calculated to obtain the time at which density effects appeared. Generally, plants grown under high density stress will reveal density effects before those grown under conditions of lower density stress (Harper, 1977). I also agree with Harper that density stress differentially affects different growth variables. This is also true on a temporal basis; significant differences between high and low density cocklebur were detected in height, vegetative biomass, leaf number, and stem diameter at 7, 9, 9, and 10 weeks after emergence respectively.

In 1983, cocklebur was grown alone at 16 plants/m soybean row, and in combination with velvetleaf at total weed densities of 2,4,8, and 16 plants/m row. Total cocklebur growth was reduced in 1983, primarily because of the later planting date and the drought during the critical stages of early plant growth. No density effects were detected when cocklebur was grown in combination with velvetleaf. This is important when addressing the problem of potential additivity of competitive effects of cocklebur and velvetleaf upon soybean growth (see Section 2).

In 1983, velvetleaf did not respond to density stress either when grown alone or in combination with cocklebur. Chandler (1977) found evidence of interaction between velvetleaf at 5 plants/m of soybean row. The detection of density effects in velvetleaf may also depend upon environmental conditions. Hagood et al. (1980) found density responses during a dry year but not in a year of above average precipitation.This is common in studies where data is collected over different years and in different locales. The resulting lack of agreement in findings reiterates the necessity of the inclusion of environmental data in predictive modeling (Schreiber, 1982). It has been suggested that the major mode of competition in Abutilon involves mechanisms such as increases in height (Lee and Bazzaz, 1980). This implies that competition for light may be important. Although no specific density responses were detected, it appeared that floral initiation was delayed by approximately four to five days in the highest density treatment (16 total weeds/m row).

1.3 SUMMARY

Multiple regression techniques were used to develop temporal growth models for a variety of growth parameters in cocklebur and velvetleaf. With cocklebur, density effects were detected in 1982 enabling the inclusion of density in the temporal growth models. The predictive models were used to estimate the time at which density effects appeared for each variable. Density effects were first observed in cocklebur in height and leaf number, suggesting that competition for light may constitute the main mode of competition. Zimmerman (1983) measured light levels within the canopy structure of monocultures of high and low density cocklebur. He confirms that the main mode of competition in cocklebur grown under agricultural conditions is indeed that of competition for light. In 1983, cocklebur growth was reduced, but there was no evidence of density effects when grown in combination with velvetleaf. Measurements of velvetleaf revealed no evidence of competitive stress under similar conditions. It appears that environmental variability does play a large role in the development of temporal growth models and it should be incorporated if they are to be of more than limited applicability. This requires experimentation on a very large scale with density responses to be catalogued

under a wide array of environmental regimes.

SECTION II

SOYBEAN RESPONSES

2.1 RESULTS

I. COCKLEBUR

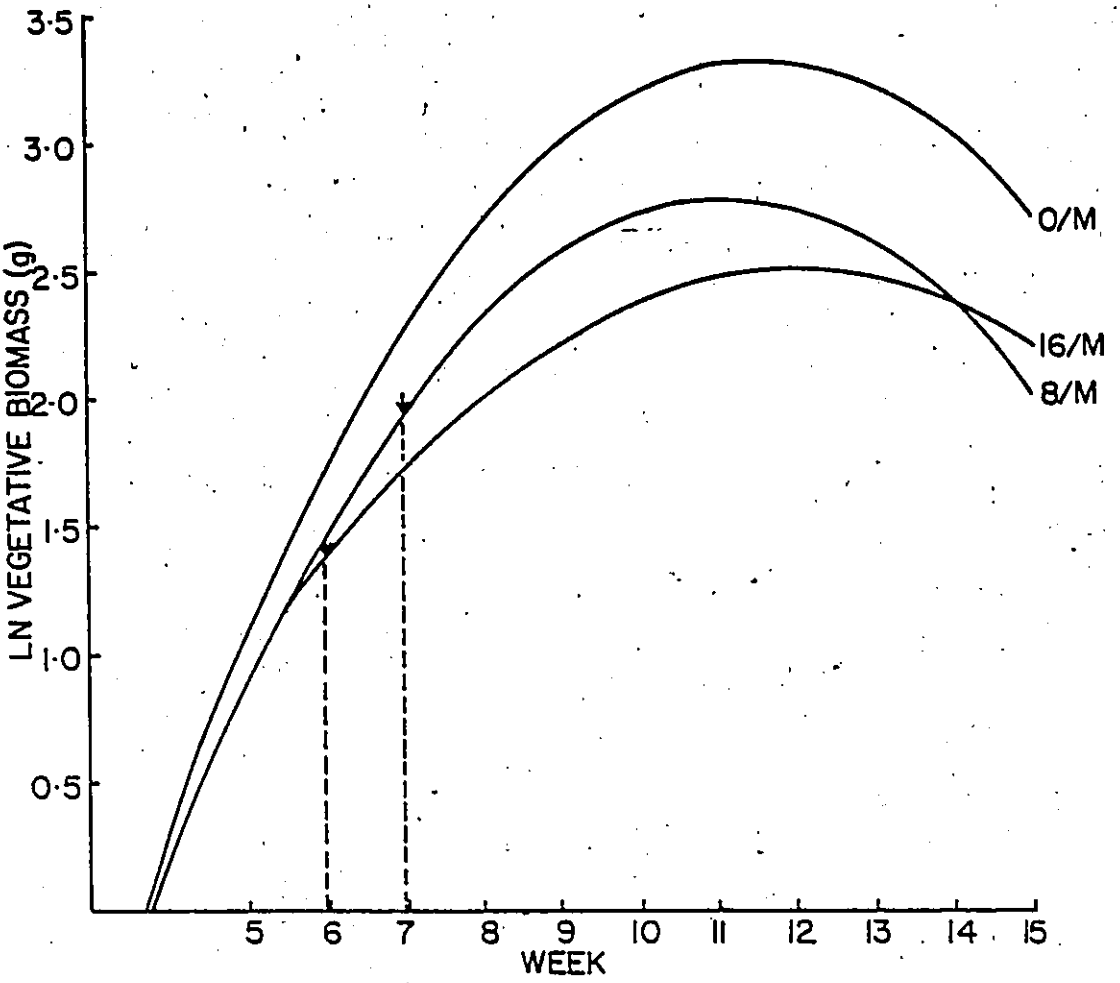
A. GROWTH ANALYSIS

Soybean growth was characteristically logistic in all density treatments (Fig. 2.1). The accumulation of vegetative biomass declined rapidly twelve weeks after emergence primarily due to the initiation of leaf senescence. Total biomass leveled off at maturity as consequence of the cessation of reproductive growth (Fig. 2.1). At maturity, soybeans grown under high cocklebur density stress (16 plants/m row) were significantly smaller than the control plants both in terms of vegetative and total biomass. These trends were consistent over both years of the study (Figures 2.1,2.2).

Multilinear regression of the natural logarithm of the vegetative biomass and the natural logarithm of the total biomass over time using linear and squared terms were calculated for each cocklebur density (Tables 2.1,2.2). In 1982, the individual equations provided good approximations to the data with R^2 values ranging from 0.62 to 0.77 for ln vegetative biomass, and 0.72 to 0.85 for ln total biomass. Density was also incorporated into an overall equation for each of the aforementioned growth variables (Table 2.3). R^2 values of 0.68 and 0.77 were obtained for the regressions of ln vegetative

Figure 2.1

Relationship between vegetative biomass (upper graph), total biomass (lower graph), and week in soybeans grown in cocklebur density treatments in 1982. The vertical dashed lines indicate the first significant differences from the control treatments (weed-free). Significant differences were not found in soybean plants grown at 2 and 4 cocklebur/m row.


LN VEGETATIVE BIOMASS (g)
3·5
3·0
2·5
2·0
1·5
1·0
0·5
5
6
7
8
9
10
11
12
13
14
15
WEEK
0/M
16/M
8/M

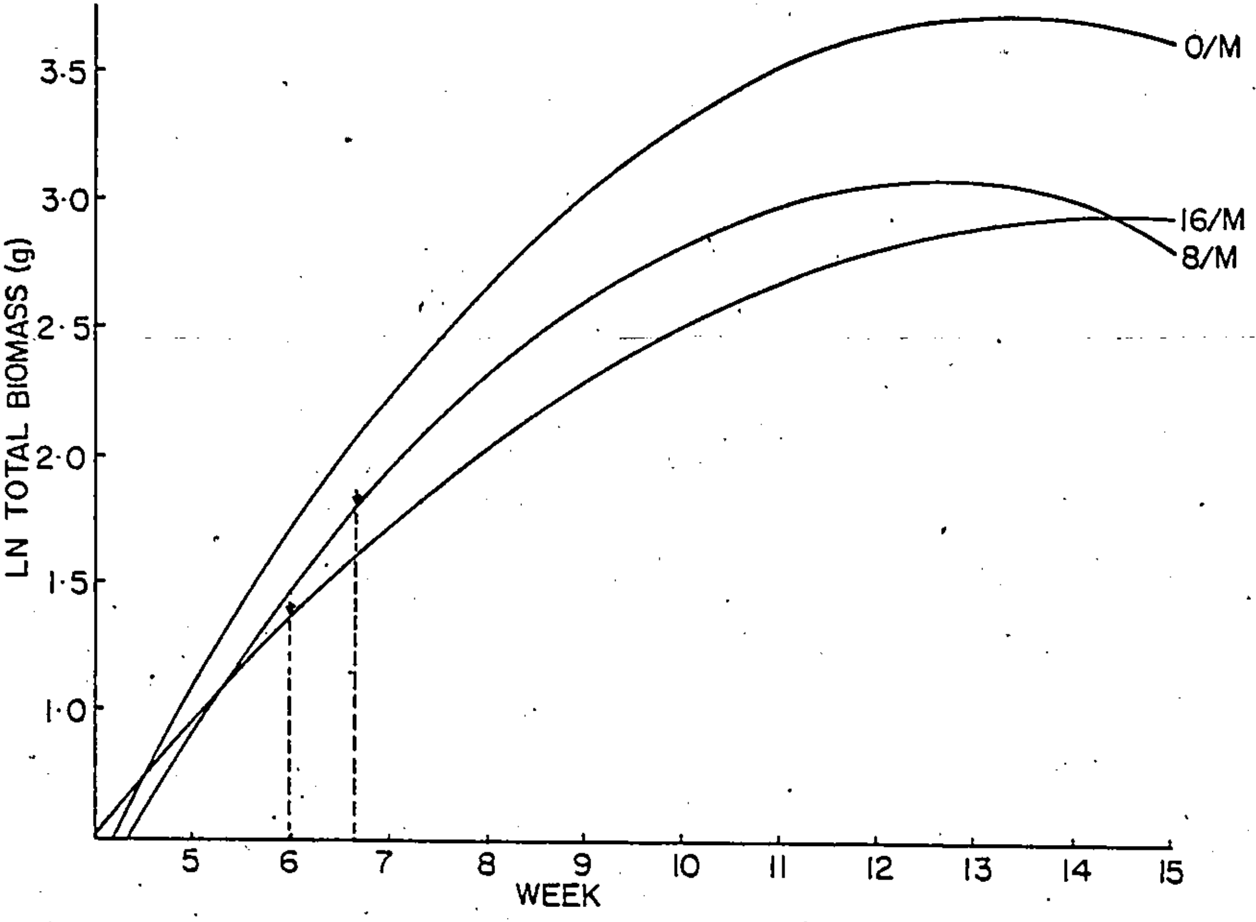
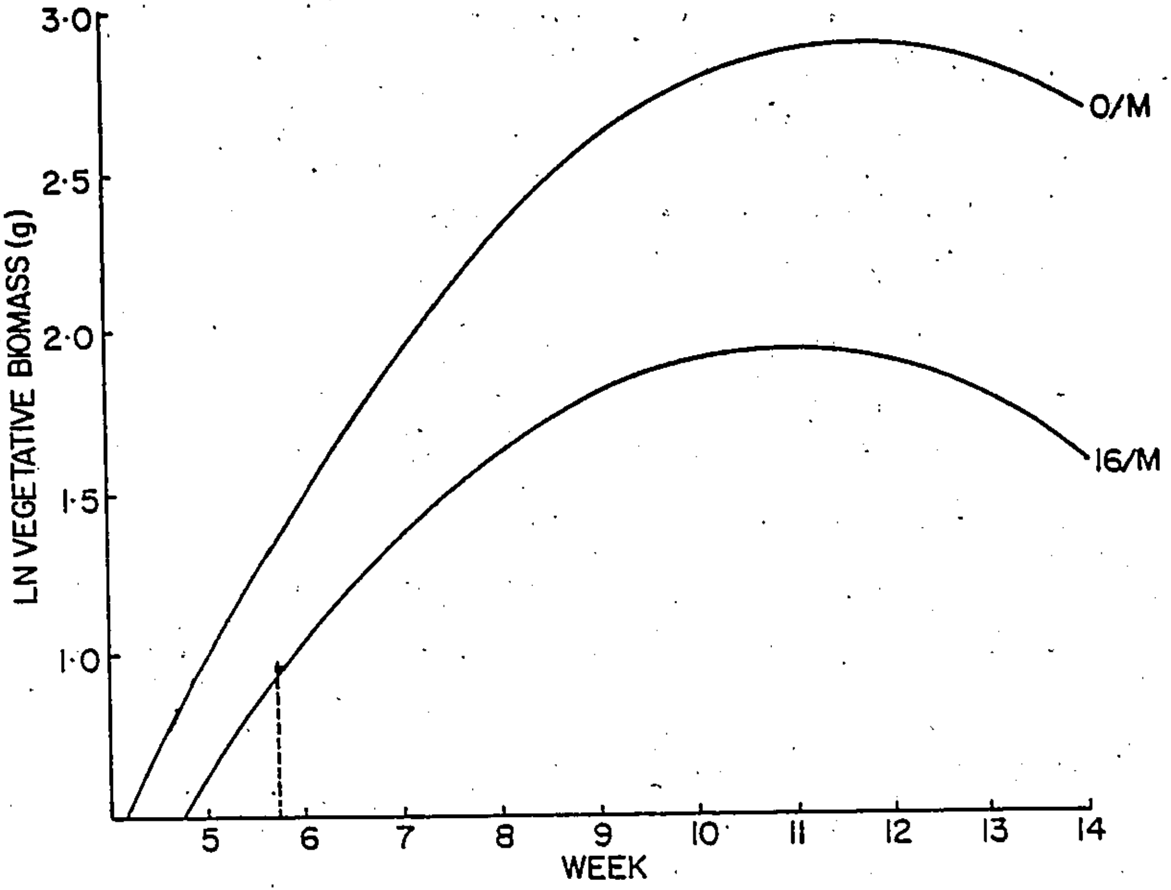
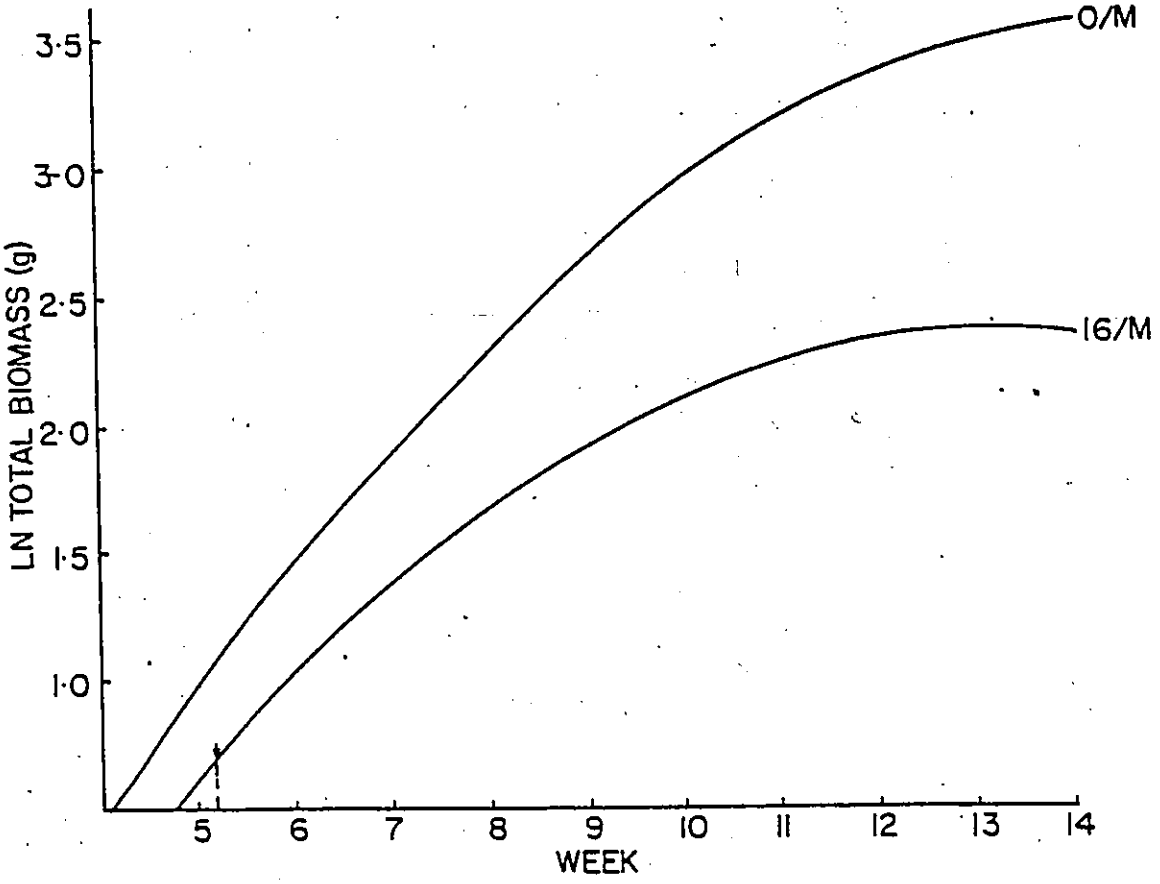

LN TOTAL BIOMASS (g)
3·5
3·0
2·5
2·0
1·5
1·0
5
6
7
8
9
10
11
12
13
14
15
WEEK
0/M
16/M
8/M

Figure 2.2

Relationship between vegetative biomass (upper graph), total biomass (lower graph), and week in soybeans grown in cocklebur density treatments in 1983. The vertical dashed lines indicate the first significant differences from the control treatments (weed-free).



LN VEGETATIVE BIOMASS (g)
3·0
2·5
2·0
1·5
1·0
5
6
7
8
9
10
11
12
13
14
WEEK
0/M
16/M



LN TOTAL BIOMASS (g)
3·5
3·0
2·5
2·0
1·5
1·0
5
6
7
8
9
10
11
12
13
14
WEEK
0/M
16/M

Table 2.1. Regression equations of soybean vegetative biomass (log transformed) vs. time for cocklebur density treatments in 1982. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
0/m	-3.850	1.245	-0.054	0.660
	±0.303	±0.065	±0.003	
2/m	-4.042	1.236	-0.054	0.771
	±0.637	±0.143	±0.007	
4/m	-3.883	1.234	-0.055	0.616
	±0.876	±0.196	±0.010	
8/m	-3.364	1.104	-0.050	0.677
	±0.668	±0.150	±0.008	
16/m	-2.103	0.770	-0.032	0.651
	±0.602	±0.135	±0.007	

Table 2.2. Regression equations of soybean total biomass (log transformed) vs. time for cocklebur density treatments in 1982. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
0/m	-3.205	1.049	-0.040	0.765
	±0.285	±0.061	±0.003	
2/m	-3.552	1.077	-0.042	0.849
	±0.589	±0.132	±0.007	
4/m	-3.425	1.085	-0.043	0.720
	±0.815	±0.183	±0.009	
8/m	-2.853	0.944	-0.038	0.748
	±0.662	±0.149	±0.008	
16/m	-1.695	0.639	-0.022	0.761
	±0.584	±0.131	±0.007	

Table 2.3. Regression equations, including density, for soybean vegetative biomass, total biomass, reproductive biomass, pod number, leaf number, and height (all log transformed) vs. time for cocklebur density treatments in 1982. Standard errors are included for comparison.

		SLOPES			
VARIABLE	INTERCEPT	DENSITY	WEEK	WEEK^2	R^2
Vegetative	-3.531	-0.037	1.181	-0.052	0.667
Biomass	±0.234	±0.005	±0.051	±0.003	
Total	-2.939	-0.040	1.000	-0.038	0.770
Biomass	±0.222	±0.005	±0.048	±0.002	
Reproductive	-22.677	-0.051	3.607	-0.126	0.919
Biomass	±0.651	±0.007	±0.123	±0.006	
Pod	-17.603	-0.049	3.413	-0.131	0.826
Number	±0.711	±0.008	±0.135	±0.006	
Leaf	-1.398	-0.035	0.988	-0.050	0.416
Number	±0.306	±0.006	±0.064	±0.003	
Height	1.792	0.003	0.590	-0.030	0.845
	±0.061	±0.002	±0.019	±0.001	

biomass and ln total biomass respectively. In 1983, when only high density cocklebur (16 plants/m row) were planted to assess yearly variation, R^2 values of 0.48 and 0.76 were obtained for the regressions of ln vegetative biomass and ln total biomass (Table 2.4).

Sample sizes were too small at any particular harvest to reveal significant differences between density treatments by using a multiple range test. In both years, 95% confidence intervals of the regression equations were utilized to define the time at which density stress elicited effects which differed significantly from the control treatment (weed-free). Soybeans grown under the highest density stress (16 weeds/m row) should exhibit density effects before soybeans grown under lower density stress. In this respect, the responses of both vegetative and total biomass are similar; plants grown under high density stress (16 cocklebur/m row) showing reductions six weeks after emergence. The trends were consistent over both years of the study (Figures 2.1,2.2).

In 1982, there were density effects detected in cocklebur vegetative biomass (see section 1). The inclusion of a weighted density variable (cocklebur vegetative biomass * cocklebur density) in the temporal growth model for soybean vegetative biomass did not result in a significant improvement in the model (Table 2.4a). Apparently each cocklebur plant elicits an effect

Table 2.4. Regression equations for soybean vegetative biomass, total biomass, reproductive biomass, pod number, and leaf number (all log transformed) vs. time for the cocklebur density treatment of 16 plants/m in 1983. Standard errors are included for comparison.

		SLOPES		
VARIABLE	INTERCEPT	WEEK	WEEK^2	R^2
Vegetative	-2.566	0.825	-0.038	0.481
Biomass	±1.098	±0.254	±0.013	
Total	-2.137	0.679	-0.026	0.761
Biomass	±0.827	±0.191	±0.010	
Reproductive	-19.042	3.049	-0.113	0.927
Biomass	±3.072	±0.576	±0.026	
Pod	-14.778	3.020	-0.127	0.826
Number	±3.245	±0.608	±0.028	
Leaf	-0.609	0.643	-0.036	0.416
Number	±0.817	±0.189	±0.010	

Table 2.4a. Multiple regression analysis of variance for differences in soybean log vegetative biomass between densities over time in cocklebur density treatments in 1982.

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
Den*Cocklebur Veg. Biomass	1	0.9768	0.9768	3.34 ns
Week	1	163.0243	163.0243	557.30 ***
Week*Week	1	113.1826	113.1826	386.91 ***
Error	492	143.9229	0.2925	
Corrected Total	495	421.1067		

upon soybean growth based upon density rather than plant size.

In summary, soybean growth (vegetative and total biomass) is reduced under conditions of high cocklebur density stress. Growth in soybean plants grown under high cocklebur density stress is reduced sooner and in greater magnitude than those grown under low density stress.

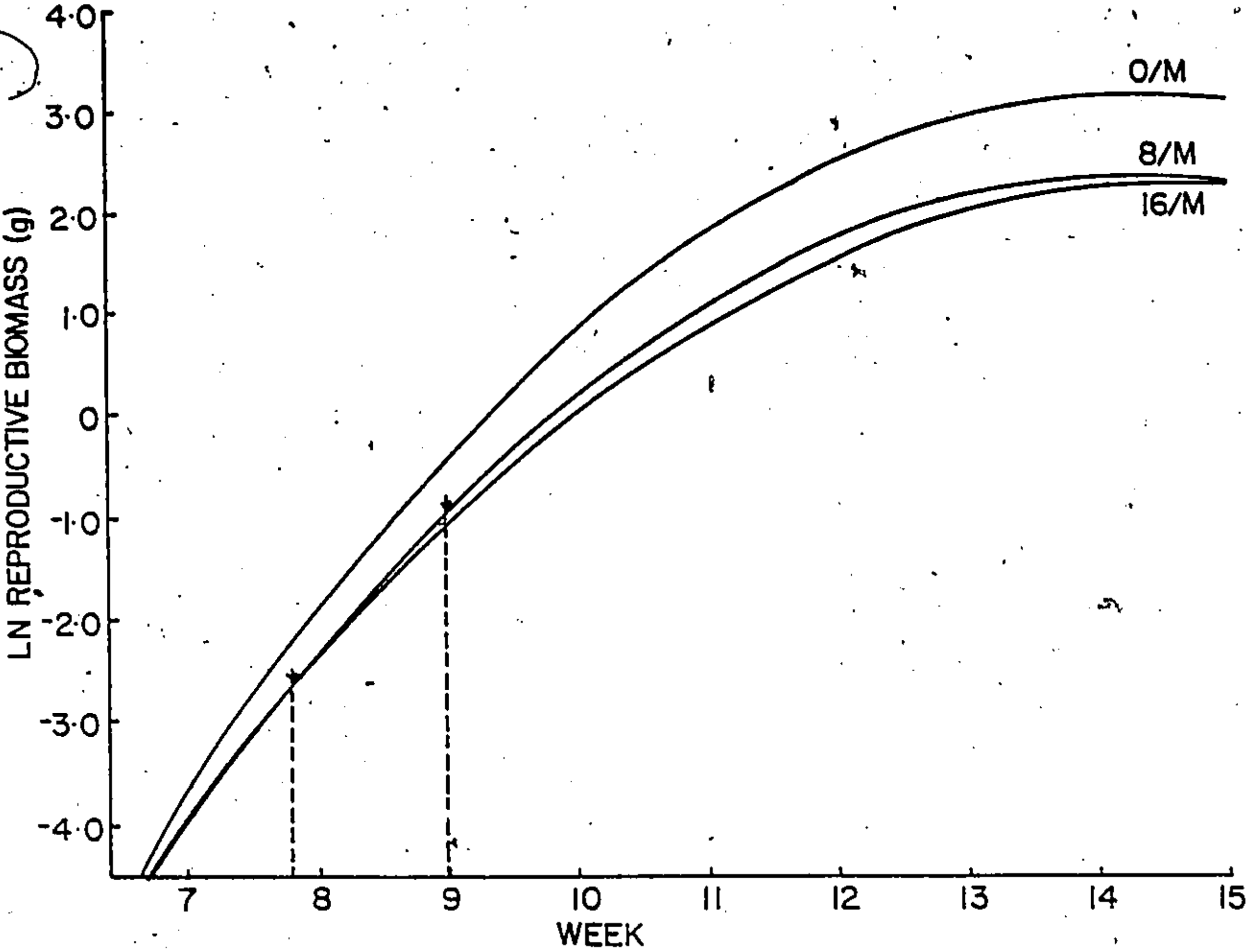
B. FRUIT PRODUCTION

The accumulation of reproductive biomass was generally logistic throughout the growing season (Fig. 2.3). Floral initiation occurred by the seventh week after emergence in all density treatments. The majority of pod-filling occured between the ninth and twelveth weeks after emergence. Soybeans grown with high density cocklebur had significantly lower reproductive biomass and pod numbers than the control plants. These reductions were consistent over both years (Figures 2.3,2.4).

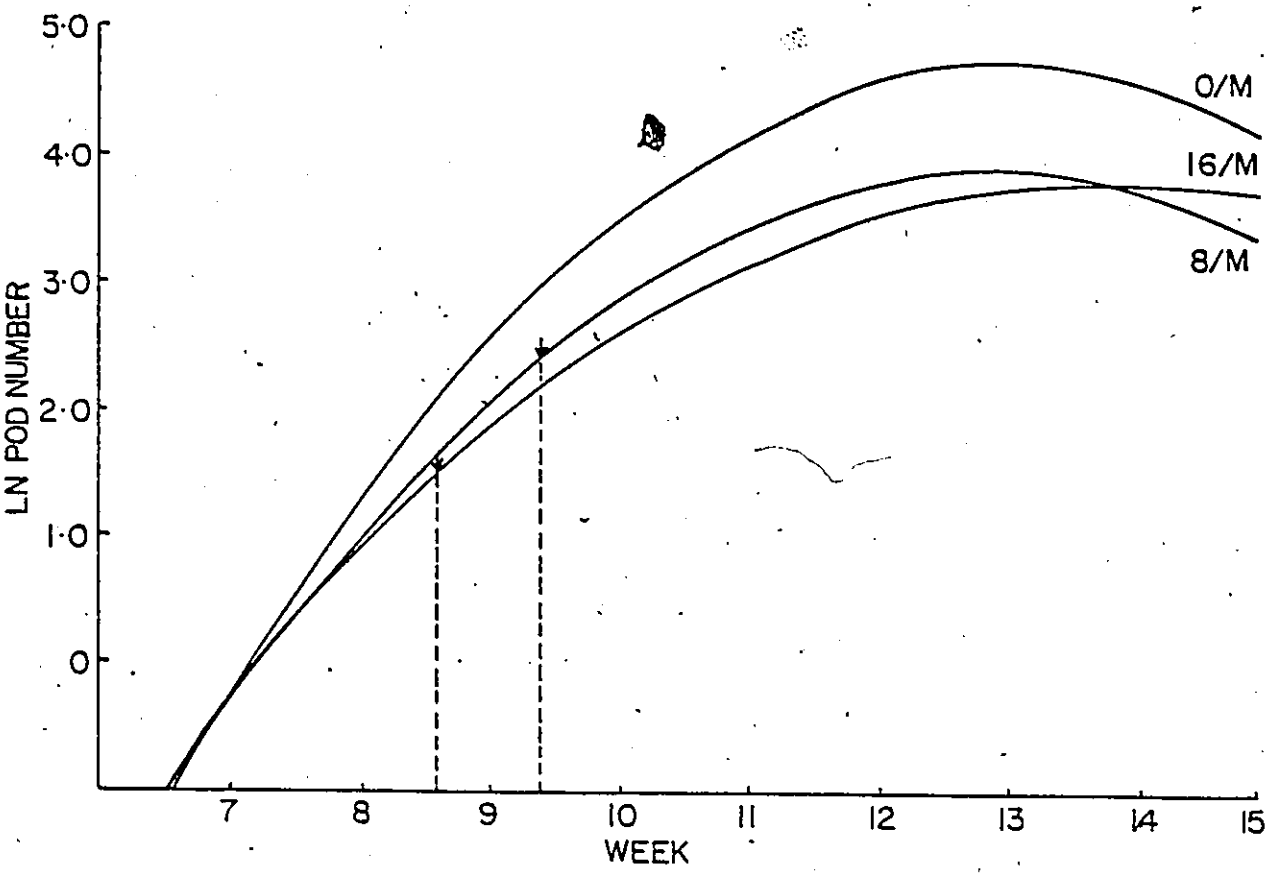
Multiple regression was used to develop temporal growth models for both natural logarithm reproductive biomass and natural logarithm pod number (Tables 2.5,2.6). The regression equations for ln reproductive biomass described the data quite well with R values ranging from 0.91 to 0.92. The R^2 values for the

Figure 2.3

Relationship between reproductive biomass (upper graph), pod number (lower graph), and week in soybeans grown in cocklebur density treatments in 1982. The vertical dashed lines indicate the first significant differences from the control treatments (weed-free). Significant differences were not found in soybean plants grown at 2 and 4 cocklebur/m row.



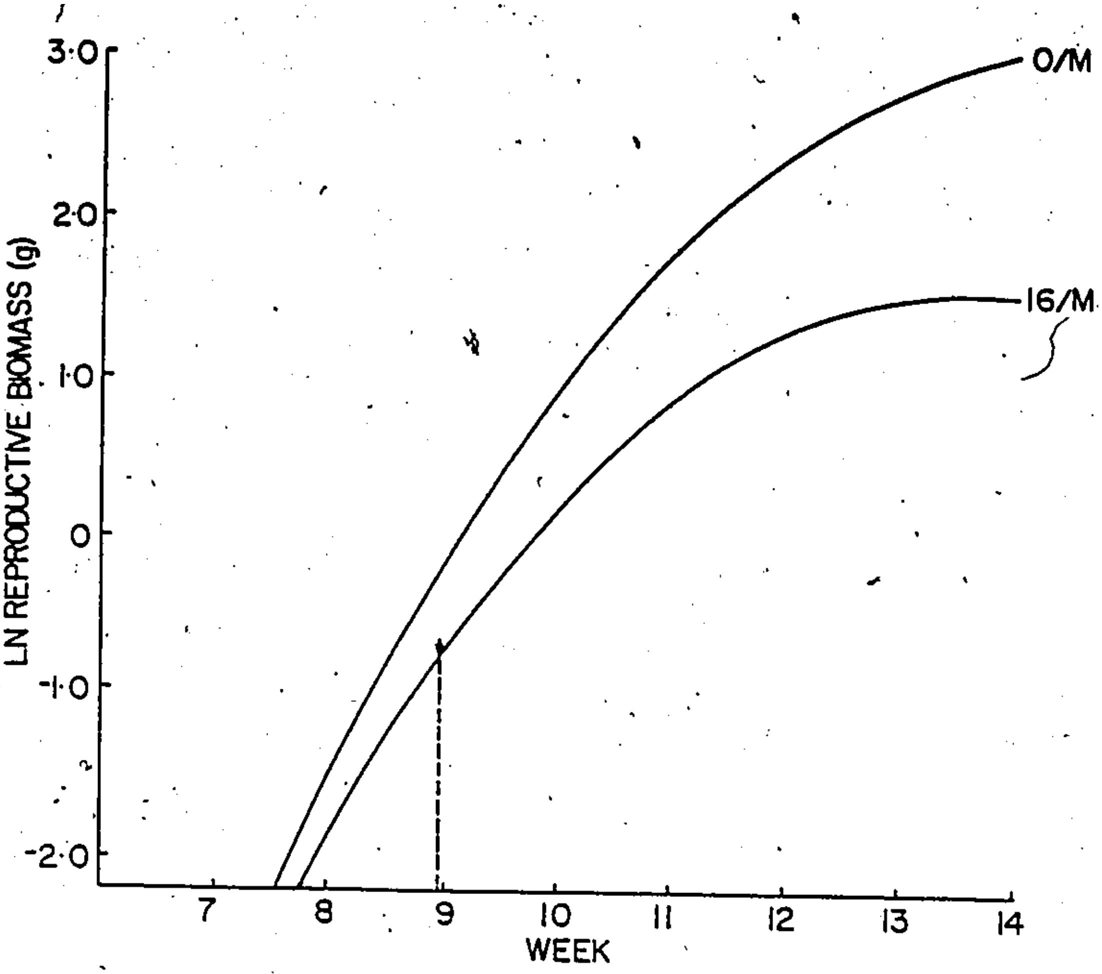
LN REPRODUCTIVE BIOMASS (g)
4·0
3·0
2·0
1·0
0
-1·0
-2·0
-3·0
-4·0
7
8
9
10
11
12
13
14
15
WEEK
0/M
8/M
16/M



LN POD NUMBER
5·0
4·0
3·0
2·0
1·0
0
7
8
9
10
11
12
13
14
15
WEEK
0/M
16/M
8/M

Figure 2.4

Relationship between reproductive biomass (upper graph), pod number (lower graph), and week in soybeans grown in cocklebur density treatments in 1983. The vertical dashed lines indicate the first significant differences from the control treatments (weed-free).


3·0
2·0
1·0
0
-1·0
-2·0
LN REPRODUCTIVE BIOMASS (g)
O/M
16/M
7
8
9
10
11
12
13
14
WEEK

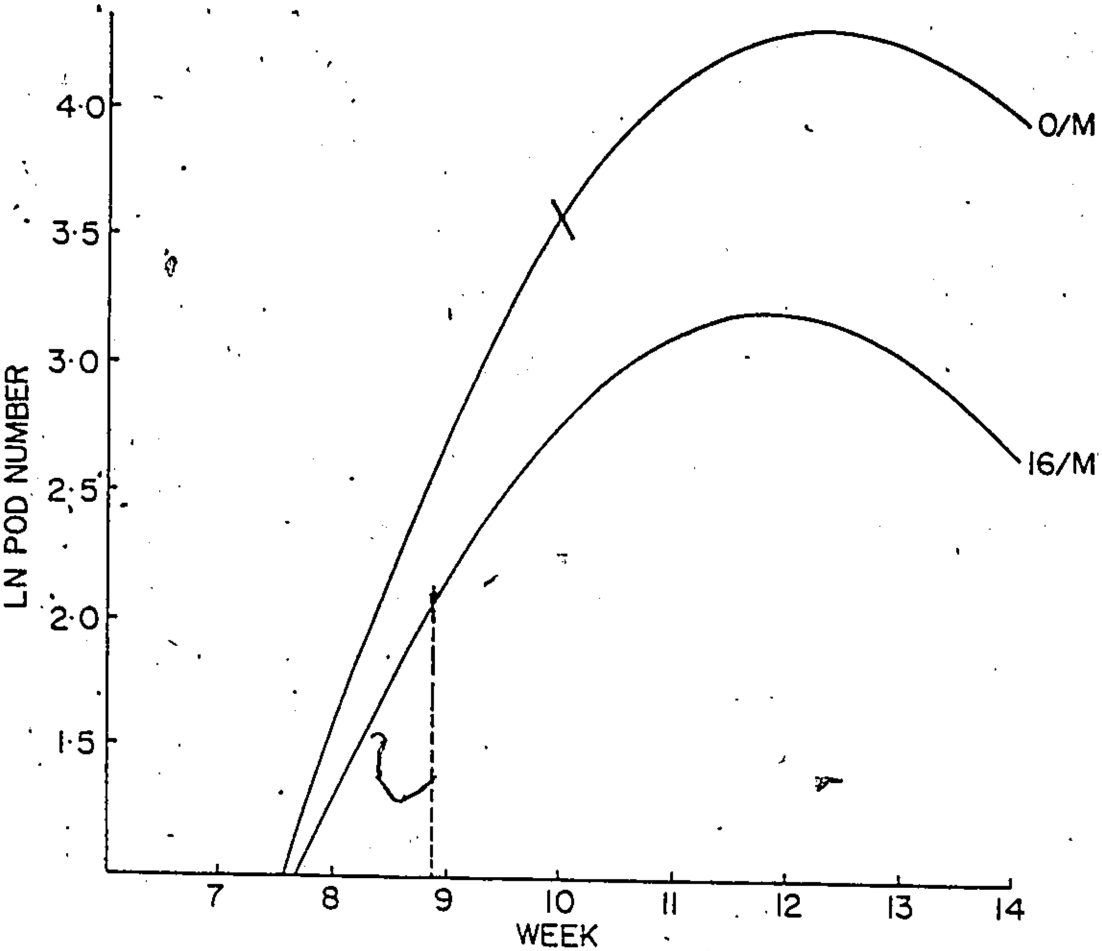

4·0
3·5
3·0
2·5
2·0
1·5
LN POD NUMBER
O/M
16/M
7
8
9
10
11
12
13
14
WEEK

Table 2.5. Regression equations of soybean reproductive biomass (log transformed) vs. time for cocklebur density treatments in 1982. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
0/m	-23.248	3.697	-0.130	0.923
	$\pm$0.789	$\pm$0.149	$\pm$0.007	
2/m	-22.300	3.518	-0.123	0.910
	$\pm$2.422	$\pm$0.459	$\pm$0.021	
4/m	-22.657	3.619	-0.129	0.921
	$\pm$2.198	$\pm$0.416	$\pm$0.019	
8/m	-22.215	3.470	-0.123	0.907
	$\pm$2.369	$\pm$0.449	$\pm$0.020	
16/m	-20.508	3.095	-0.105	0.918
	$\pm$2.209	$\pm$0.418	$\pm$0.019	

Table 2.6. Regression equations of soybean pod number (log transformed) vs. time for cocklebur density treatments in 1982. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	$WEEK^2$	R^2
0/m	-18.453	3.562	-0.137	0.840
	±0.853	±0.161	±0.007	
2/m	-16.313	3.139	-0.120	0.817
	±2.481	±0.470	±0.021	
4/m	-19.018	3.639	-0.142	0.801
	±2.815	±0.533	±0.024	
8/m	-16.357	3.131	-0.121	0.805
	±2.438	±0.462	±0.021	
16/m	-13.401	2.553	-0.096	0.787
	±2.384	±0.451	±0.021	

individual regression equations for ln pod number were more variable; ranging from 0.79 to 0.84. The overall models, incorporating density, provided excellent fits to the data with R^2 values of 0.92 for ln reproductive biomass and 0.83 for ln pod number (Table 2.3).

Utilizing the 95% confidence intervals of the regression equations, the time at which density effects became significant were obtained. In 1982, soybeans grown under high density stress (16 cocklebur/m row) exhibited significant reductions in both reproductive biomass and pod number at eight and nine weeks after emergence respectively (Fig. 2.3). At 8 cocklebur/m, reductions in the aforementioned variables occurred one week later than in the highest density treatment. Similar temporal trends were detected in 1983 (Fig. 2.4). The overall temporal equations predict similar reductions at maturity for both reproductive biomass and pod number. The two aforementioned criteria may suggest that density stress may elicit its effect at the time of floral initiation or shortly thereafter. Evidence of the manisfestation of density effects is present before pod-filling begins. This trend is consistent over both years.

In summary, the temporal growth models predict significant reductions in reproductive biomass and pod number in both of the high density cocklebur treatments (8,16 cocklebur/m row) when compared to the control.

These effects are present very early, certainly before pod-filling begins.

C. CANOPY DEVELOPMENT

Canopy development in soybeans is largely dependent upon increases in plant height and leaf number (and/or leaf area). In 1982, when subjected to cocklebur density stress, soybean height was significantly affected (Table 2.3). Significant increases in soybean height were detected in the cocklebur density treatments. Soybean leaf number increased along a quadratic trajectory until nine to ten weeks after emergence at which time leaf senescence began (Fig. 2.5). At that time, soybean plants grown under conditions of high density stress (8,16 cocklebur/m row) had significantly fewer leaves than the control plants. The rates of leaf senescence from this point on appeared to be similar across all densities.

Temporal growth models were developed for each density of natural logarithm leaf number using multiple regression techniques (Table 2.7). The temporal growth models provided a fair approximation of the actual data with R^2 values ranging from 0.33 to 0.42 (Table 2.7). The overall model incorporating density had an R^2 value of 0.42 (Table 2.3). Although temporal growth models were developed for natural logarithm height at each

Figure 2.5

Relationship between leaf number and week in soybeans grown in cocklebur density treatments in 1982. The vertical dashed lines indicate the first significant differences from the control treatment (weed-free). Significant differences were not found in soybean plants grown at 2 and 4 cocklebur/m row.

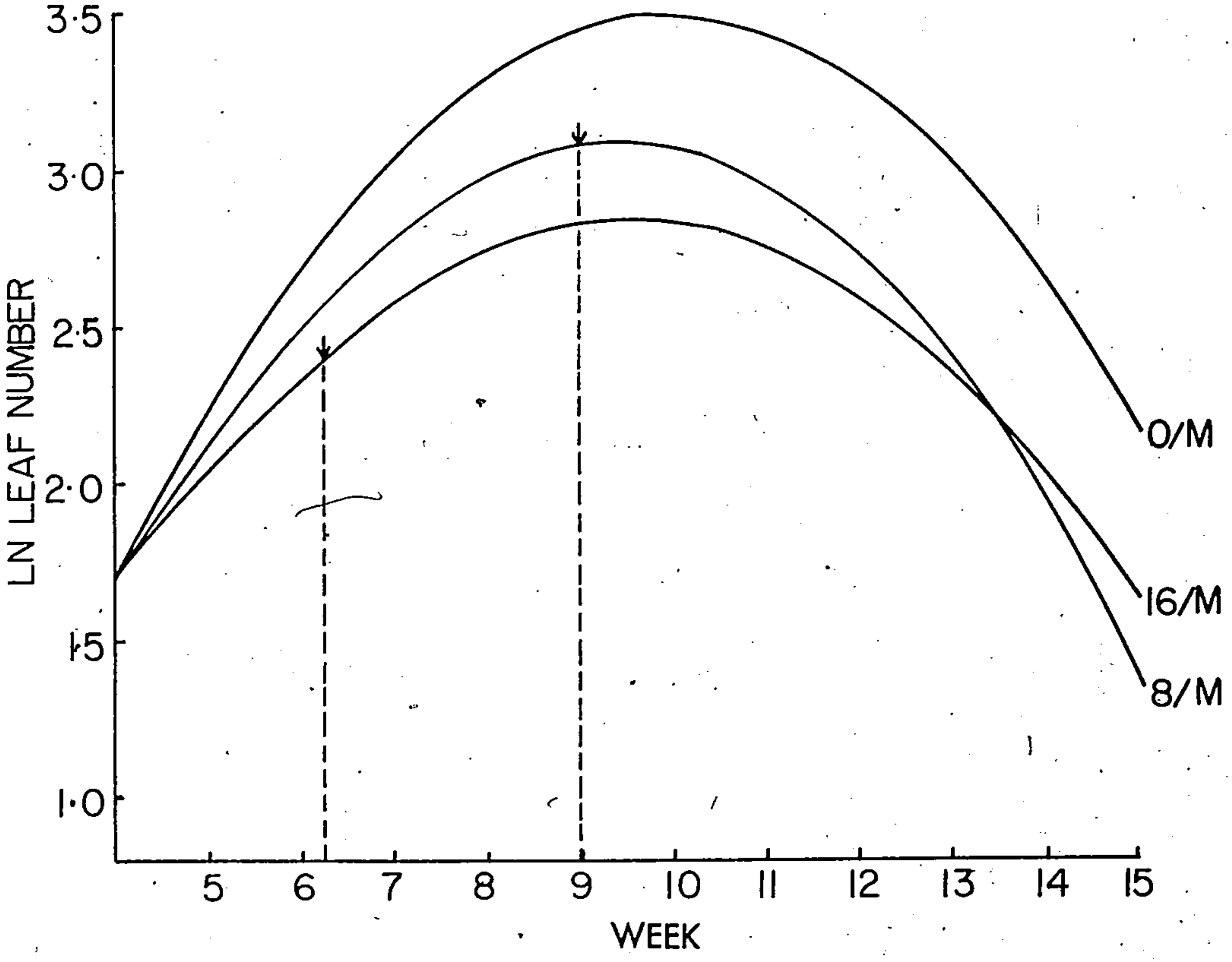

3·5
3·0
2·5
2·0
1·5
1·0
LN LEAF NUMBER
5
6
7
8
9
10
11
12
13
14
15
WEEK
0/M
16/M
8/M

Figure 2.6

Relationship between leaf number and week in soybeans grown in cocklebur density treatments in 1983. The vertical dashed lines indicate the first significant difference from the control treatment (weed-free).

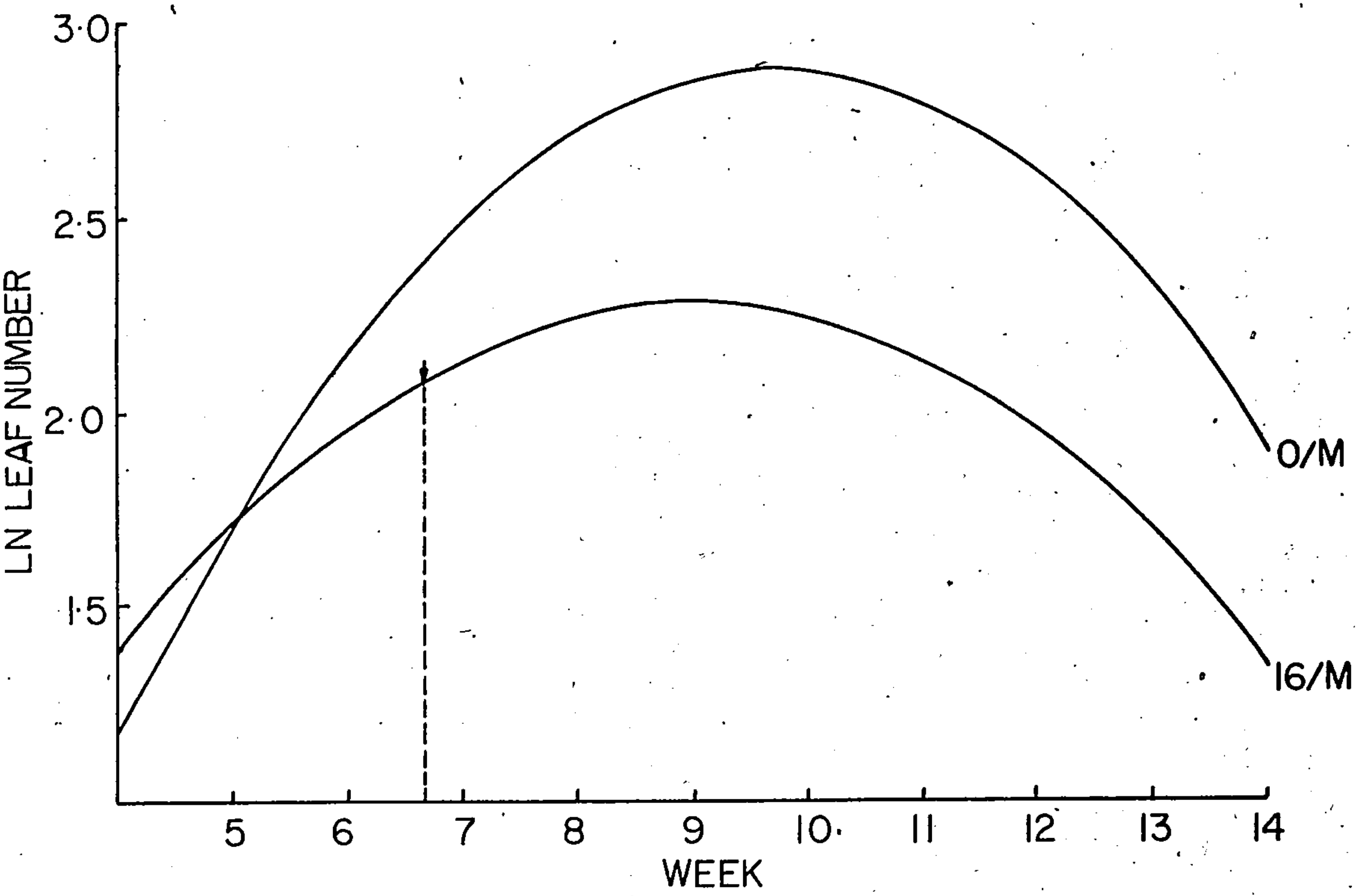

3·0
2·5
2·0
1·5
LN LEAF NUMBER
5
6
7
8
9
10
11
12
13
14
WEEK
0/M
16/M

Table 2.7. Regression equations of soybean leaf number (log transformed) vs. time for cocklebur density treatments in 1982. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	$WEEK^2$	R^2
0/m	-1.734 ±0.461	1.048 ±0.093	-0.053 ±0.004	0.354
2/m	-1.653 ±0.855	1.001 ±0.192	-0.052 ±0.010	0.402
4/m	-1.978 ±0.962	1.095 ±0.216	-0.056 ±0.011	0.386
8/m	-1.461 ±0.849	0.975 ±0.190	-0.053 ±0.010	0.422
16/m	-0.819 ±0.773	0.769 ±0.173	-0.040 ±0.009	0.334

density, significant differences were not detectable between densities due to variability which resulted in overlapping 95% confidence intervals. However, when density was incorporated into an overall model for ln height, it was significant (Table 2.3). The overall model for ln height had an R^2 value of 0.85.

The 95% confidnce intervals of the regression equations were utilized to determine the time at which density effects became significant. In both years of the study, the highest density cocklebur treatment (16/m row) exhibited significant density effects between six and seven weeks after emergence (Figures 2.5,2.6). In 1982, cocklebur grown at a density of 8/m revealed density effects nine weeks after emergence. Density effects were not significant at lower cocklebur densities.

In summary, soybean canopy development was altered by high cocklebur density stress. Canopy development wass affected by changes in plant height, and by different rates of leaf development. Compensations in soybean leaf number in response to cocklebur density stress may imply that one of the modes of interaction involves mechanisms of competition for light. This has significant implications in soybean development. The initiation of leaf senescence appears to be accompanied by pod-filling indicting a shift in resource allocation within the plant.

II. VELVETLEAF

A. GROWTH ANALYSIS

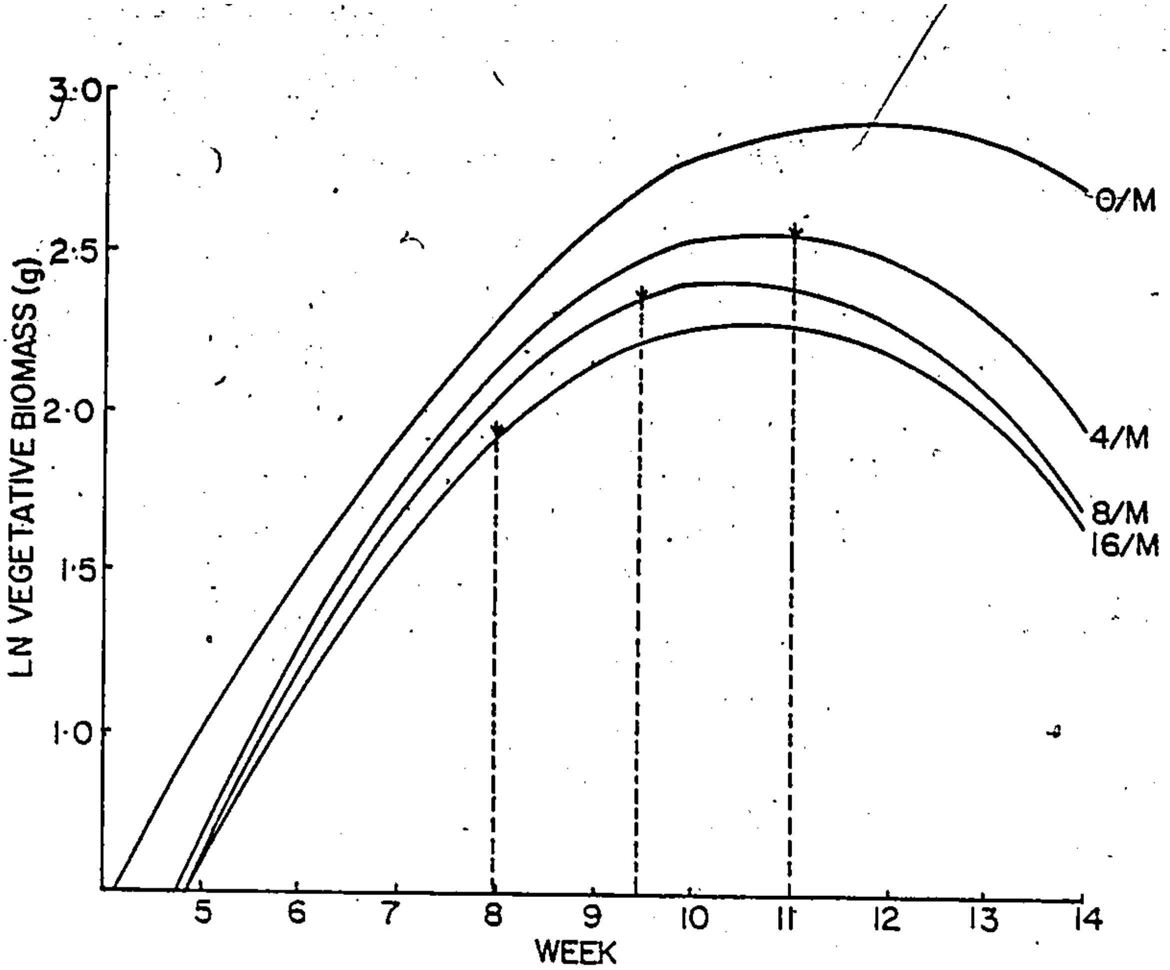
The accumulation of vegetative biomass when soybeans are grown with velvetleaf declined twelve weeks after emergence primarily due to leaf senescence (Fig. 2.7). Total biomass increased until season's end when it leveled off as a consequence of the cessation of reproductive growth (Fig. 2.7). At maturity, soybeans grown under the entire range of velvetleaf densities were significantly smaller than the control plants in terms of vegetative and total biomass (Fig. 2.7).

Multiple regression techniques were used to develop temporal growth models for natural logarithm vegetative biomass and natural logarithm total biomass. The models explained the data very well (Tables 2.8,2.9). R^2 values for the regression equations of the individual density treatments ranged from 0.64 to 0.80 for ln vegetative biomass, and from 0.79 to 0.89 for ln total biomass. The incorporation of density into an overall model yielded R^2 values of 0.76 for ln vegetative biomass, and 0.86 for ln total biomass (Table 2.10).

The 95% confidence intervals of the regression equations were utilized to define the time at which density effects became significant. Soybeans grown with high velvetleaf densities show evidence of density

Figure 2.7

Relationship between vegetative biomass (upper graph), total biomass (lower graph), and week in soybeans grown in velvetleaf density treatments in 1983. The dashed vertical lines indicate the first significant differences from the control treatments (weed-free). Plants grown at 2 velvetleaf/m were significantly different from the control treatments at 11 weeks after emergence for both variables.


LN VEGETATIVE BIOMASS (g)
3·0
2·5
2·0
1·5
1·0
WEEK
5
6
7
8
9
10
11
12
13
14
0/M
4/M
8/M
16/M

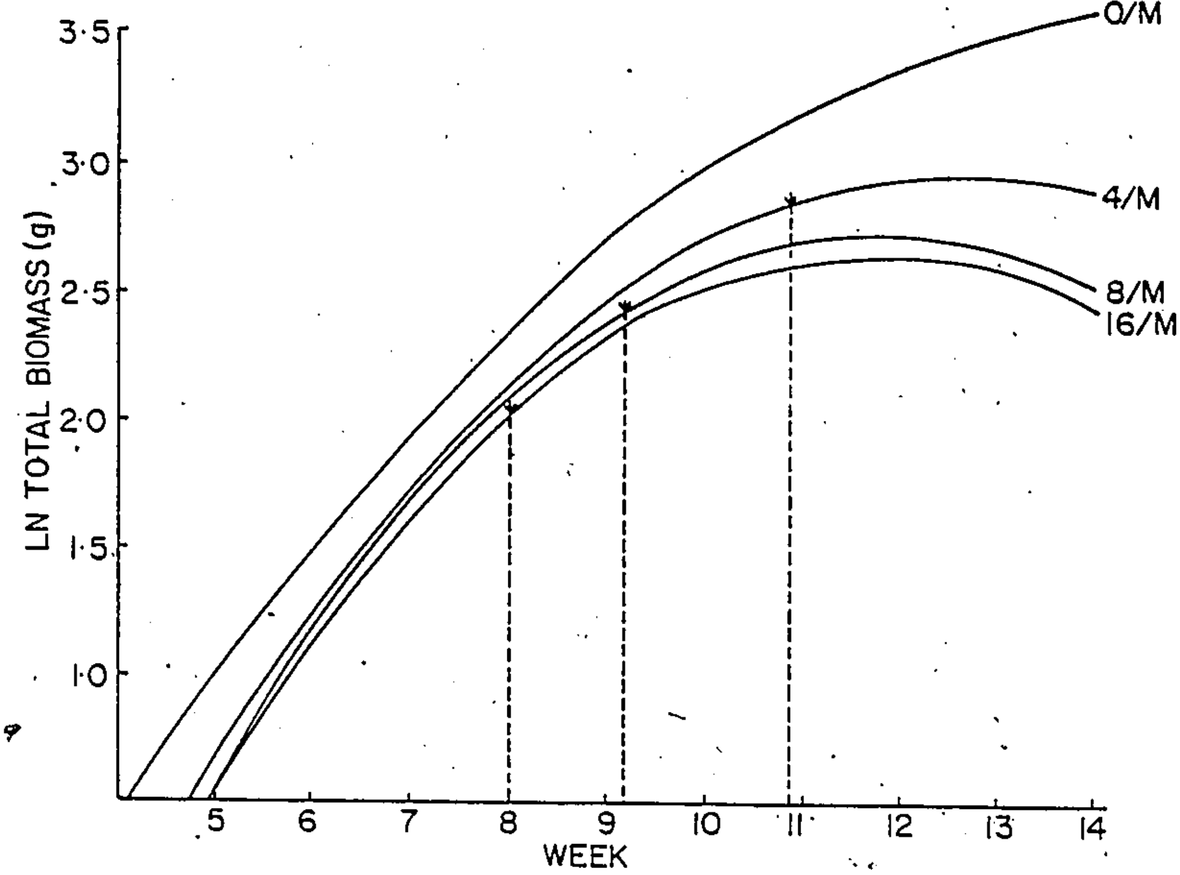

LN TOTAL BIOMASS (g)
3·5
3·0
2·5
2·0
1·5
1·0
WEEK
5
6
7
8
9
10
11
12
13
14
0/M
4/M
8/M
16/M

Table 2.8. Regression equations of soybean vegetative biomass (log transformed) vs. time for velvetleaf density treatments in 1983. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
0/m	-3.036	1.012	-0.043	0.799
	±0.272	±0.063	±0.003	
2/m	-3.333	1.073	-0.049	0.718
	±0.888	±0.205	±0.011	
4/m	-4.226	1.269	-0.059	0.752
	±0.882	±0.204	±0.011	
8/m	-4.371	1.298	-0.062	0.765
	±0.805	±0.186	±0.010	
16/m	-3.947	1.175	-0.055	0.641
	±1.029	±0.238	±0.013	

Table 2.9. Regression equations of soybean total biomass (log transformed) vs. time for velvetleaf density treatments in 1983. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	$WEEK^2$	R^2
0/m	-2.348	0.795	-0.027	0.894
	±0.247	±0.057	±0.003	
2/m	-2.646	0.857	-0.032	0.828
	±0.850	±0.197	±0.010	
4/m	-3.335	1.000	-0.040	0.835
	±0.859	±0.199	±0.010	
8/m	-3.804	1.115	-0.048	0.827
	±0.808	±0.187	±0.010	
16/m	-3.610	1.052	-0.044	0.792
	±0.892	±0.206	±0.011	

Table 2.10. Regression equations, including density, of soybean vegetative biomass, total biomass, reproductive biomass, pod number, leaf number, and height (all log transformed) vs. time for velvetleaf treatments in 1983. Standard errors are included for comparison.

			SLOPES		
VARIABLE	INTERCEPT	DENSITY	WEEK	$WEEK^2$	R^2
Vegetative	-3.247	-0.040	1.076	-0.048	0.763
Biomass	±0.244	±0.005	±0.056	±0.003	
Total	-2.578	-0.041	0.866	-0.031	0.859
Biomass	±0.230	±0.005	±0.053	±0.003	
Reprod.	-19.163	-0.048	3.068	-0.107	0.929
Biomass	±0.994	±0.007	±0.186	±0.008	
Pod	-17.036	-0.049	3.467	-0.141	0.755
Number	±1.238	±0.009	±0.232	±0.011	
Leaf	-2.093	-0.028	1.032	-0.054	0.420
Number	±0.327	±0.007	±0.075	±0.004	
Height	-0.265	-0.005	0.859	-0.036	0.914
	±0.121	±0.002	±0.028	±0.001	

effects sooner than plants subjected to lower densities. Both vegetative and total biomass follow similar patterns with respect to the temporal aspect of interaction (Fig. 2.7). Evidence of density stress appeared eight weeks after emergence in the highest velvetleaf density treatment (16 plants/m row) and about eleven weeks after emergence in the lowest density treatment (2 plants/m row).

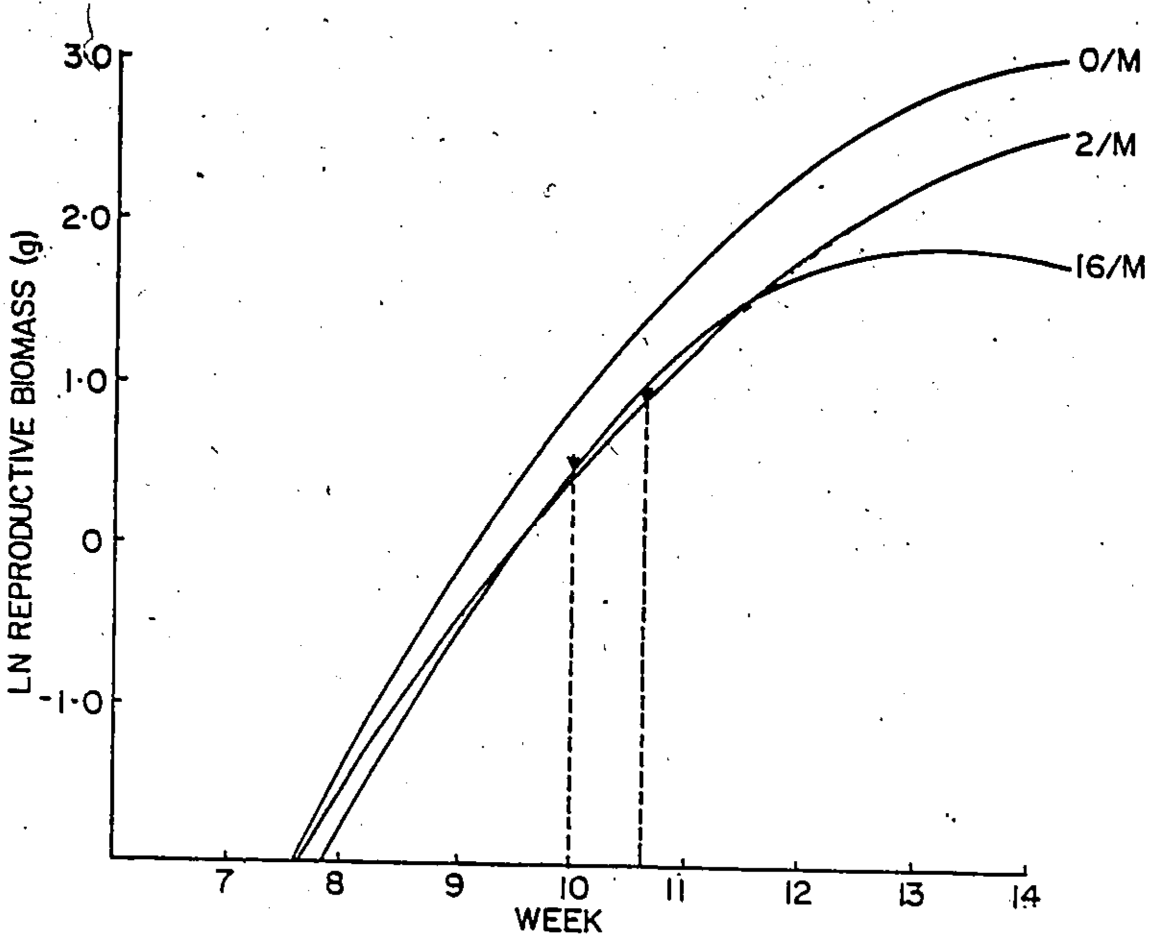
In summary, soybean growth (vegetative and total biomass) was significantly reduced by the entire range of velvetleaf densities tested. Reductions in vegetative and total biomass were comparable. Higher velvetleaf density elicited density effects in soybeans sooner and in greater magnitude than did lower velvetleaf density.

B. FRUIT PRODUCTION

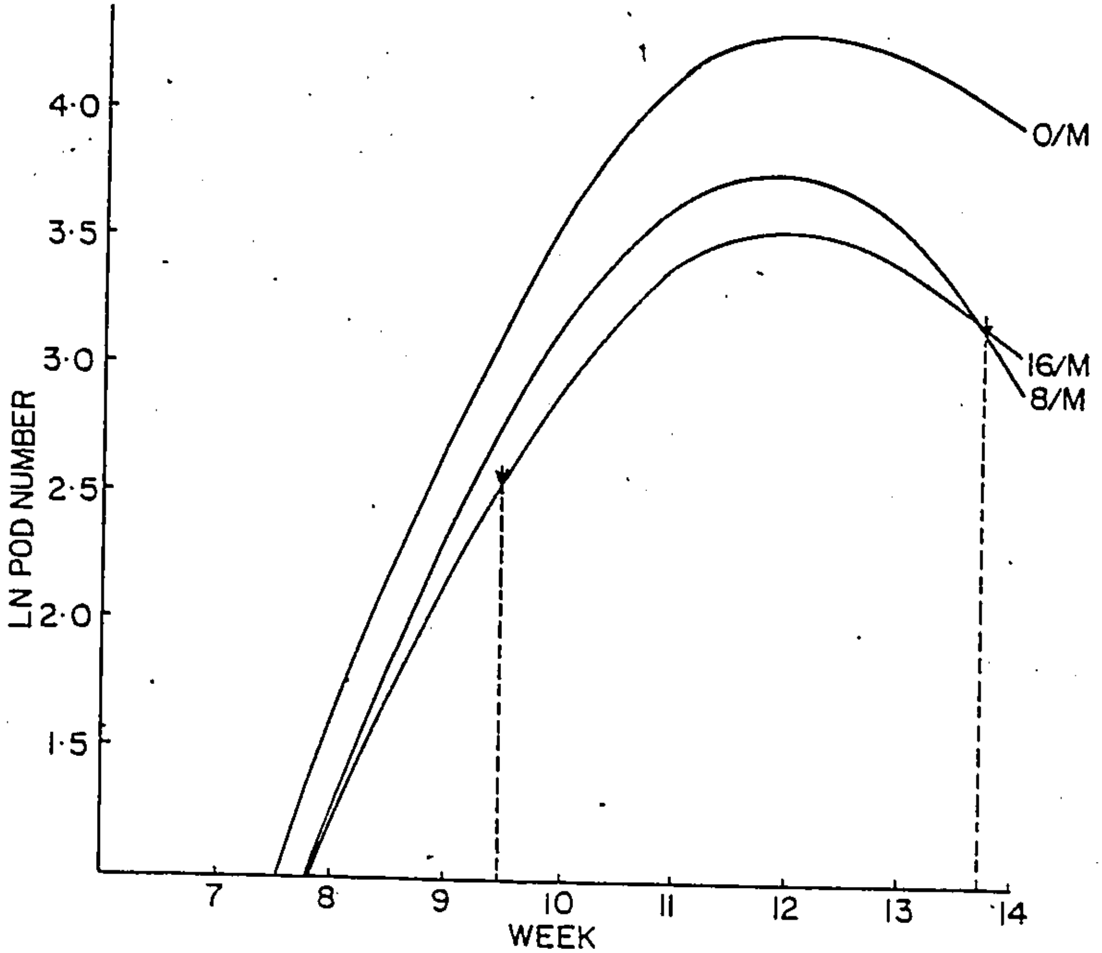
Reproductive growth in these soybeans was logistic throughout the growing season for all velvetleaf density treatments (Fig 2.8). Floral initiation occurred synchronously across all treatments approximately seven weeks after emergence. Most pod-filling took place between nine and twelve weeks after emergence. Reproductive biomass was significantly reduced under all conditions of velvetleaf density stress when compared to the control treatments (Fig. 2.8). Pod number was reduced only in response to the higher velvetleaf

Figure 2.8

Relationship between reproductive biomass (upper graph), pod number (lower graph), and week in soybeans grown in velvetleaf density treatments in 1983. The dashed vertical lines indicate the first significant differences from the control treatments (weed-free). Not indicated on the upper graph for reasons of clarity, are plants grown at 4 and 8 velvetleaf/m row, which were significantly different from the control treatments at 10 and 11 weeks after emergence respectively. Significant differences were not found in pod number in plants grown at velvetleaf densities of 2 and 4/m row.



LN REPRODUCTIVE BIOMASS (g)
3.0
2.0
1.0
0
-1.0
7
8
9
10
11
12
13
14
WEEK
0/M
2/M
16/M



LN POD NUMBER
4.0
3.5
3.0
2.5
2.0
1.5
7
8
9
10
11
12
13
14
WEEK
0/M
16/M
8/M

Table 2.11. Regression equations of soybean reproductive biomass (log transformed) vs. time for velvetleaf density treatments in 1983. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
0/m	-19.276	3.058	-0.105	0.952
	±1.032	±0.193	±0.009	
2/m	-15.858	2.396	-0.077	0.935
	±3.445	±0.646	±0.029	
4/m	-14.425	2.169	-0.069	0.925
	±3.456	±0.648	±0.029	
8/m	-23.766	3.929	-0.150	0.876
	±4.651	±0.872	±0.040	
16/m	-23.145	3.859	-0.149	0.925
	±3.321	±0.623	±0.028	

Table 2.12. Regression equations of soybean pod number (log transformed) vs. time for velvetleaf density treatments in 1983. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
0/m	-18.056	3.628	-0.147	0.783
	±1.476	±0.277	±0.013	
2/m	-9.242	2.067	-0.082	0.777
	±2.935	±0.550	±0.025	
4/m	-14.703	3.010	-0.123	0.702
	±4.537	±0.851	±0.039	
8/m	-20.907	4.182	-0.177	0.638
	±5.836	±1.094	±0.050	
16/m	-16.596	3.318	-0.137	0.797
	±3.631	±0.681	±0.031	

density treatments (8,16 plants/m)(Fig. 2.8).

Temporal growth models for natural logarithm reproductive biomass and natural logarithm pod number were developed through multiple regression. Despite the limited number of sampling dates (4), the temporal models provided very good approximations to the data (Tables 2.11,2.12). R^2 values for the individual regression equations for each density range from 0.88 to 0.95 for ln reproductive biomass, and from 0.64 to 0.80 for ln pod number. When density was included as a variable in the regression equations, R^2 values of 0.93 and 0.76 were obtained for ln reproductive biomass and ln pod number respectively (Table 2.10).

The 95% confidence intervals of the regression equations were employed to determine the time at which density effects became significant. Again, soybeans grown under higher density stress exhibited density effects before plants grown under lower density pressure. Reductions in reproductive biomass and pod number were first detected as significant in the tenth and ninth weeks after emergence in the highest density treatments (16 plants/m row) (Fig. 2.8). In the lowest density treatment (2 plants/m row), density effects on reproductive biomass and pod number were significant at eleven and fourteen weeks after emergence respectively.

In summary, soybean reproductive biomass was significantly reduced by all of the velvetleaf densities tested. Pod number was reduced only at the higher velvetleaf densities (8,16 plants/m row). Reductions in both reproductive biomass and pod number were similar at these densities. This might suggest that density stress may elict an effect at the time of floral initiation or shortly thereafter, rather than during the period of pod-filling.

C. CANOPY DEVELOPMENT

Soybean canopy development is dependent upon increases in plant height and leaf number (and/or leaf area). Soybean height increased in response to increases in velvetleaf density (Table 2.10). Soybean leaf number increased along a quadratic trajectory until nine to ten weeks after emergence when leaf senescence began (Fig. 2.9). At that time, soybean plants grown with high weed densities had significantly fewer leaves than the control plants. The rate of senescence from this point on appeared to be slightly less in plants grown under high density stress (Fig. 2.9).

Temporal growth models were developed for each velvetleaf density for the natural logarithm of leaf number using multiple regression techniques. The regression equations provided a fair approximation to the data with R^2 values ranging from 0.33 to 0.58 (Table 2.13). When density was included in an overall model, an

Figure 2.9

Relationship between leaf number and week in soybeans grown in velvetleaf density treatments in 1983. The dashed vertical lines indicate the first significant differences from the control treatments (weed-free). Significant differences were not found in plants grown at 2 velvetleaf/m row.

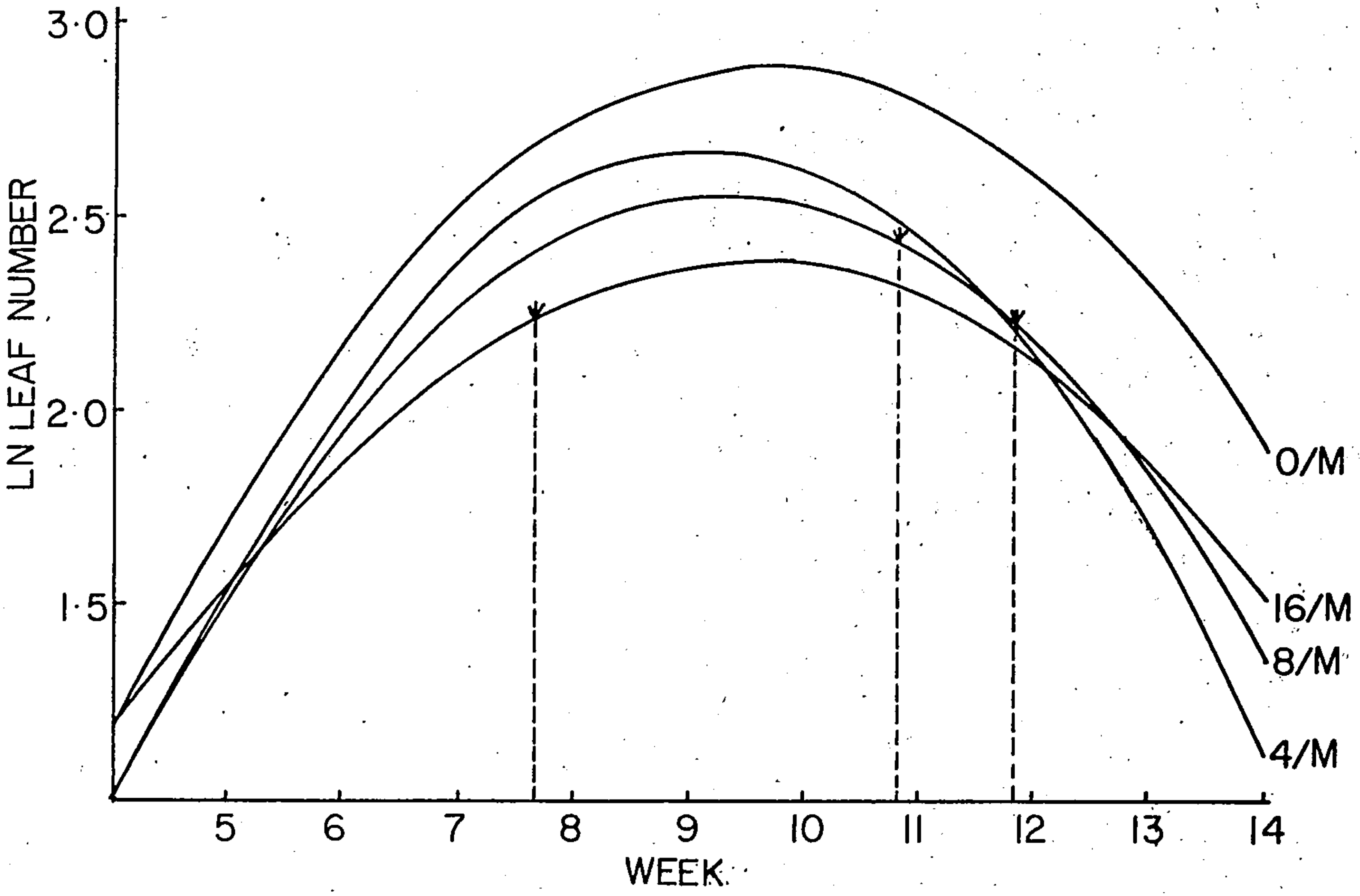

3·0
2·5
2·0
1·5
LN LEAF NUMBER
5
6
7
8
9
10
11
12
13
14
WEEK
0/M
16/M
8/M
4/M

Table 2.13. Regression equations of soybean leaf number (log transformed) vs. time for velvetleaf density treatments in 1983. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
0/m	-2.235	1.058	-0.055	0.396
	±0.414	±0.096	±0.005	
2/m	-1.483	0.858	-0.045	0.405
	±0.984	±0.227	±0.012	
4/m	-2.862	1.213	-0.066	0.531
	±1.146	±0.265	±0.014	
8/m	-2.374	1.061	-0.057	0.579
	±0.873	±0.202	±0.011	
16/m	-1.376	0.792	-0.042	0.329
	±1.072	±0.248	±0.013	

R^2 value of 0.42 was obtained (Table 2.10). Temporal growth models were also developed for each velvetleaf density for natural logarithm height using multiple regression. Significant differences between densities were not detectable due to variability as evidenced by overlapping 95% confidence intervals. When density was incorporated into an overall model for ln height, it was significant and had an R^2 value of 0.91 (Table 2.10).

- The 95% confidence intervals were utilized to determine the time at which density effects became significant. Some interesting trends were detected when the temporal effects of density stress were separated (Fig. 2.9). Leaf number was significantly reduced in the growth phase of leaf development (up to nine to ten weeks) when soybeans were subjected to the highest velvetleaf density stress (16 plants/m row). Conversely, leaf number was significantly reduced in the senescence phase (after nine to ten weeks) when soybeans were subjected to intermediate velvetleaf densities (4,8 plants/m row).

In summary, soybean height was affected by the regime of velvetleaf densities tested. Soybean leaf number is reduced during the growth phase of leaf development under conditions of high velvetleaf density stress, and during the time of leaf senescence under intermediate velvetleaf density pressure.

III. COMBINATIONS

A. GROWTH ANALYSIS

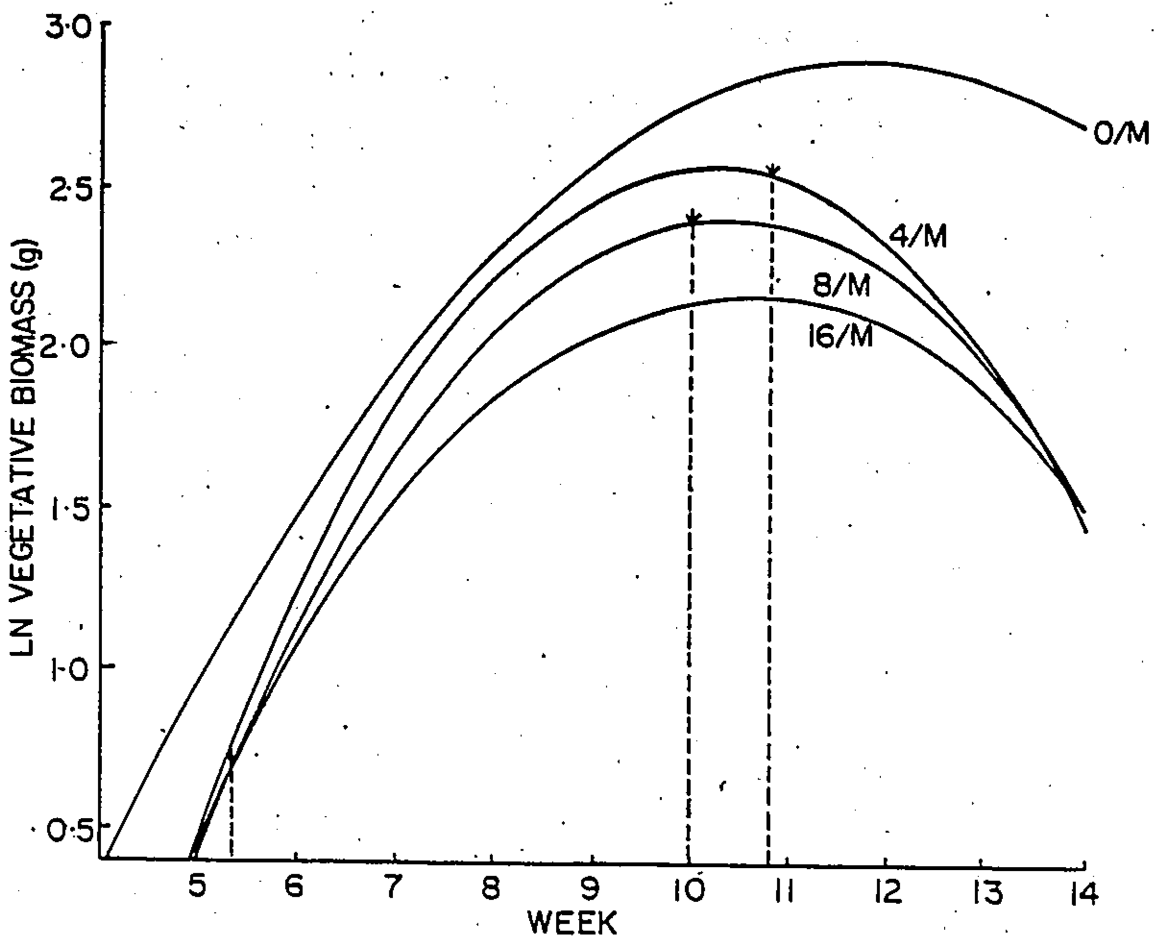
Soybean growth was characteristically logistic in all density treatments (Fig. 2.10). The accumulation of vegetative biomass declined rapidly twelve weeks after emergence due to leaf senescence. Total biomass tended to level off at maturity as a consequence of the cessation of reproductive growth (Fig. 2.10). At maturity, soybeans grown under all weed densities (cocklebur + velvetleaf) were significantly smaller than the control plants in terms of vegetative and total biomass (Fig. 2.10).

Multiple regression techniques were used to develop temporal growth models for natural logarithm vegetative biomass and natural logarithm total biomass at each weed density (Tables 2.14,2.15). The models provided good approximations to the data with R^2 values ranging from 0.68 to 0.80 for ln vegetative biomass, and from 0.78 to 0.89 for ln total biomass. Incorporating density into overall temporal models yielded R^2 values of 0.75 for ln vegetative biomass and 0.84 for ln total biomass (Table 2.16).

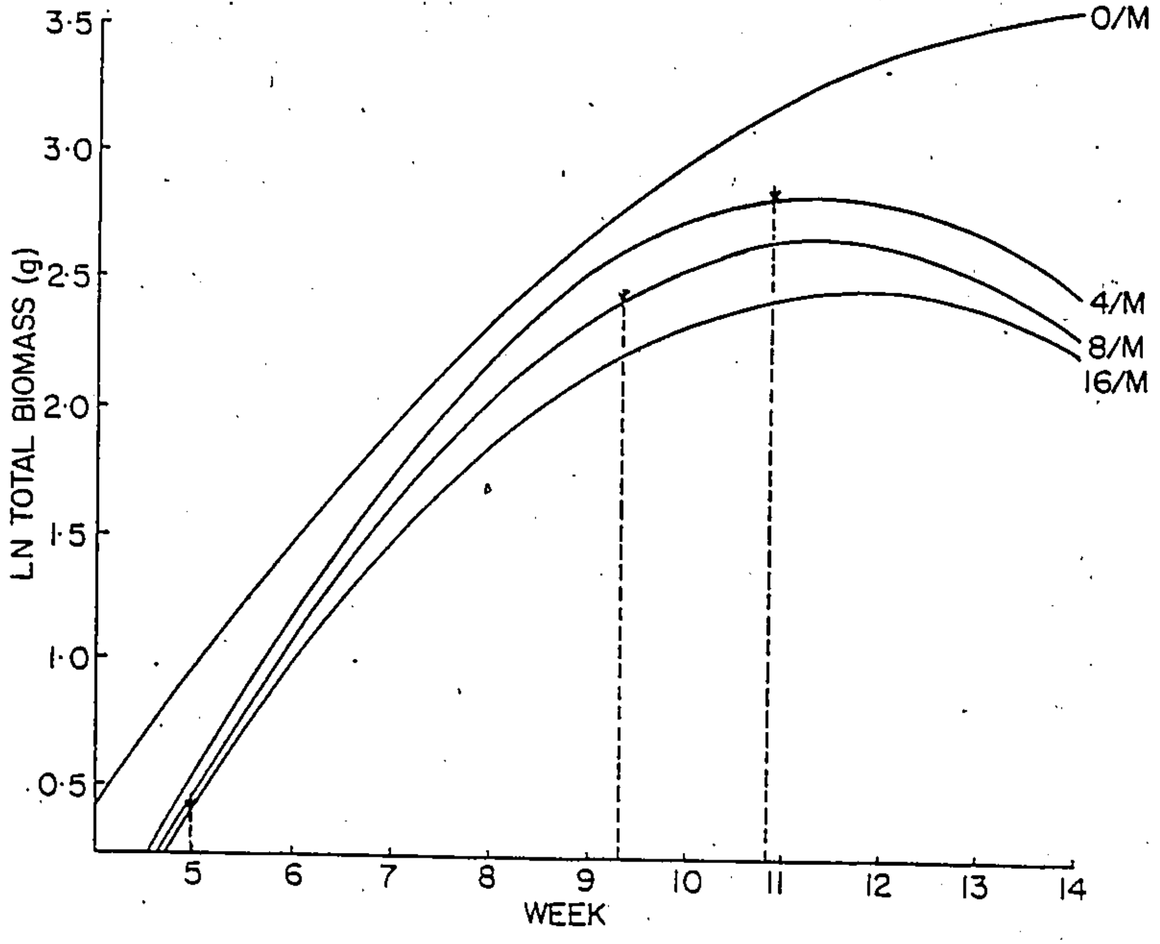
The 95% confidence intervals of the regression equations were utilized to define the time at which density stress elicited effects significantly differing

Figure 2.10

Relationship between vegetative biomass (upper graph), total biomass (lower graph), and week in soybeans grown in combination weed density treatments in 1983. The dashed vertical lines indicate the first significant differences from the control treatments (weed-free). Significant differences were found 11 weeks after emergence in plants grown at a density of 2 weeds/m for both varibles.



3·0
2·5
2·0
1·5
1·0
0·5
LN VEGETATIVE BIOMASS (g)
0/M
4/M
8/M
16/M
5
6
7
8
9
10
11
12
13
14
WEEK



3·5
3·0
2·5
2·0
1·5
1·0
0·5
LN TOTAL BIOMASS (g)
0/M
4/M
8/M
16/M
5
6
7
8
9
10
11
12
13
14
WEEK

Table 2.14. Regression equations of soybean vegetative biomass (log transformed) vs. time for combination weed density treatments in 1983. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
0/m	-3.036	1.012	-0.043	0.799
	±0.272	±0.063	±0.003	
2/m	-3.502	1.057	-0.047	0.681
	±1.020	±0.236	±0.012	
4/m	-5.590	1.607	-0.079	0.796
	±0.835	±0.193	±0.010	
8/m	-4.988	1.429	-0.069	0.728
	±0.943	±0.218	±0.011	
16/m	-3.995	1.171	-0.056	0.721
	±0.823	±0.190	±0.010	

Table 2.15. Regression equations of soybean total biomass (log transformed) vs. time for combination weed density treatments in 1983. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
0/m	-2.348	0.795	-0.027	0.894
	±0.247	±0.057	±0.003	
2/m	-3.156	0.927	-0.035	0.817
	±0.934	±0.216	±0.011	
4/m	-4.614	1.313	-0.058	0.836
	±0.842	±0.195	±0.010	
8/m	-4.318	1.221	-0.054	0.789
	±0.931	±0.215	±0.011	
16/m	-3.733	1.068	-0.046	0.785
	±0.865	±0.200	±0.011	

Table 2.16. Regression equations, including density, of soybean vegetative biomass, total biomass, reproductive biomass, pod number, leaf number, and height (all log transformed) vs. time for combination weed treatments in 1983. Standard errors are included for comparison.

		SLOPES			
VARIABLE	INTERCEPT	DENSITY	WEEK	WEEK^2	R^2
Vegetative	-3.410	-0.049	1.114	-0.050	0.750
Biomass	±0.258	±0.005	±0.059	±0.003	
Total	-2.759	-0.050	0.908	-0.034	0.844
Biomass	±0.246	±0.005	±0.057	±0.003	
Reprod.	-19.005	-0.062	3.045	-0.106	0.912
Biomass	±1.106	±0.008	±0.207	±0.009	
Pod	-17.830	-0.065	3.612	-0.148	0.767
Number	±1.242	±0.009	±0.233	±0.011	
Leaf	-2.258	-0.030	1.072	-0.056	0.444
Number	±0.324	±0.007	±0.075	±0.004	
Height	-0.261	-0.011	0.858	-0.036	0.907
	±0.127	±0.003	±0.029	±0.002	

from controls (weed-free). Based upon this approach, density effects were significant in all of the density treatments for both vegetative and total biomass (Fig. 2.10). Soybeans subjected to the highest density (16 weeds/m row) exhibited density effects at the time of the first harvest (5 weeks after emergence) in both vegetative and total biomass (Fig. 2.10). Whether density stress was sufficient to reduce growth before this time is unknown. Soybeans grown at lower density pressures display density effects later in the season (Fig. 2.10).

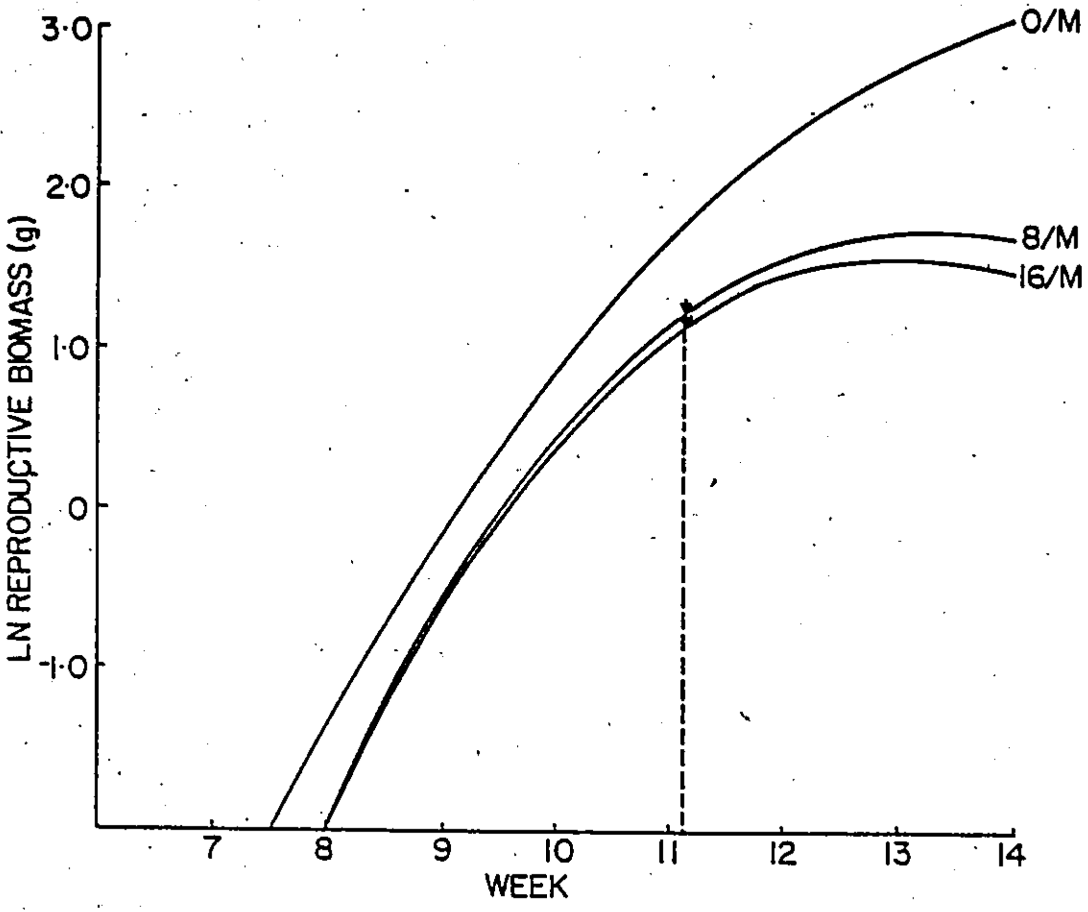
In summary, soybean vegetative and total biomass were significantly reduced by the entire range of weed densities tested. Density effects were observed very early after emergence (5 weeks) under conditions of high weed density stress.

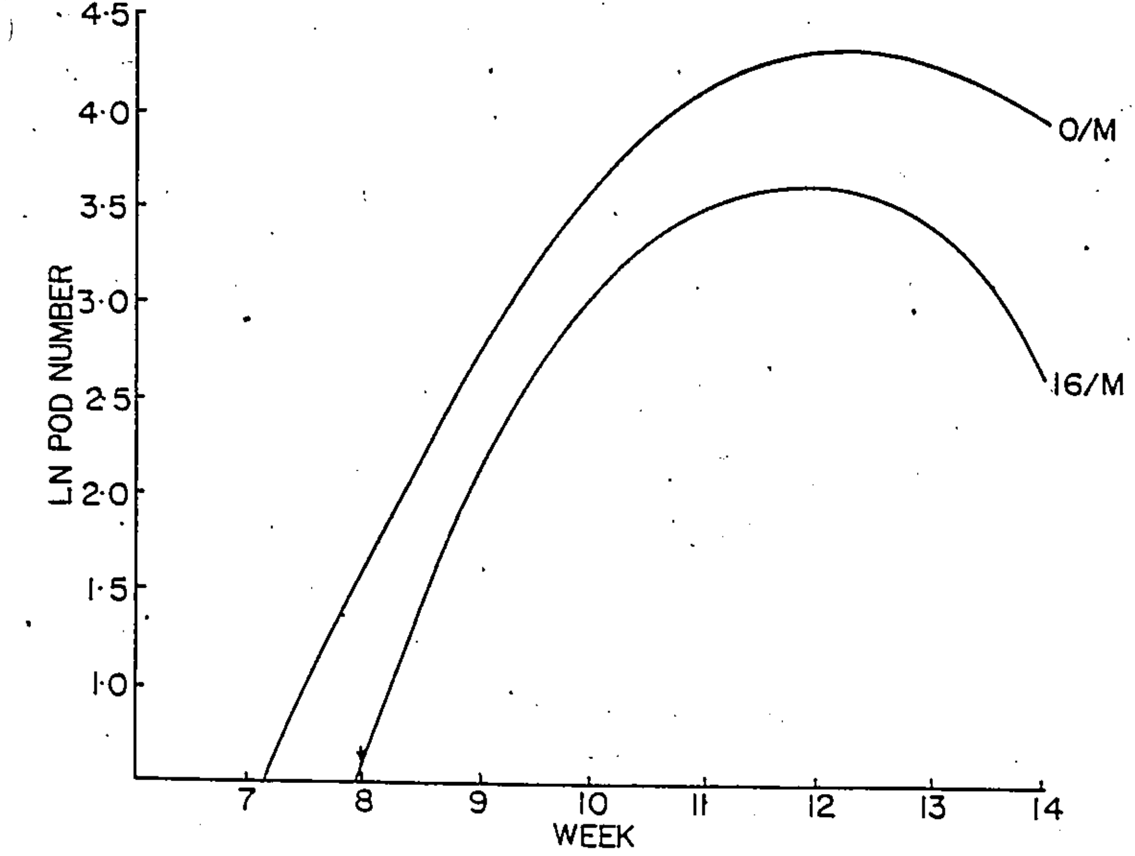
B. FRUIT PRODUCTION

Reproductive growth in the soybean was logistic throughout the growing season in all the weed density treatments (Fig. 2.11). Floral initiation occured synchronously across all treatments approximately seven weeks after emergence. Pod-filling took place between nine and twelve weeks after emergence. Reproductive biomass was significantly reduced under all but the lowest weed density treatment (Fig. 2.11). Pod number

Figure 2.11

Relationship between reproductive biomass (upper graph), pod number (lower graph), and week in soybeans grown in combination weed density treatments in 1983. The dashed vertical lines indicate the first significant differences from the control treatments (weed-free). Significant differences were not found in reproductive biomass in plants grown at weed densities of 2 and 4/m row. Significant differences were not found in pod number in plants grown at a weed density of 2/m row. Not indicated on the lower graph, for reasons of clarity, are plants grown at weed densities of 4 and 8/m row which were significantly different from the control treatment at 10 weeks after emergence.


LN REPRODUCTIVE BIOMASS (g)
3·0
2·0
1·0
0
-1·0
7
8
9
10
11
12
13
14
WEEK
0/M
8/M
16/M


LN POD NUMBER
4·5
4·0
3·5
3·0
2·5
2·0
1·5
1·0
7
8
9
10
11
12
13
14
WEEK
0/M
16/M

was significantly reduced under the same densities (Fig. 2.11). At maturity reductions in both reproductive biomass and pod number were similar.

Temporal growth models were developed for natural logarithm reproductive biomass and natural logarithm pod number for each weed density using multiple regression (Tables 2.17,2.18). The models provided good approximations to the data with R^2 values ranging from 0.85 to 0.95 for ln reproductive biomass, and from 0.55 to 0.89 for ln pod number. The incorporation of density into overall models for each yielded R^2 values of 0.91 for ln reproductive biomass, and 0.77 for ln pod number (Table 2.16).

The 95% confidence intervals of the regression equations were used to separate the temporal aspects of density effects. Significant reductions in soybean reproductive biomass occurred eleven weeks after emergence in all but the lowest density treatment (Fig. 2.11). Differences in pod number were detected as early as eight weeks after emergence in the highest density treatment (Fig. 2.11)

In summary, high weed densities can reduce soybean reproductive biomass and pod number. Density effects were detected very soon after floral initiation.

C. CANOPY DEVELOPMENT

Soybean height was affected by total weed density stress (Table 2.16). Increases in total weed density resulted in increases in soybean height. Soybean leaf number increased in a quadratic manner until nine to ten weeks after emergence at which time leaf senscence begins (Fig. 2.12). At that time, soybeans grown under the highest weed density had significantly fewer leaves than the control plants (Fig. 2.12).

Temporal growth models were developed for natural logarithm leaf number using multiple regression (Table 2.19). The regression equations for each density provide a fair fit to the data with R^2 values ranging from 0.40 to 0.68. When density was incorporated into an overall model, an R^2 value of 0.44 was obtained (Table 2.16). Although temporal growth models were developed for natural logarithm height for each density, variability prevented the detection of differences between densities using 95% confidence intervals of each individual regression. When density was incorporated into an overall model for ln height, it was significant and had an R^2 value of 0.91 (Table 2.16).

The 95% confidence intervals of the regression equations determined the time at which density effects became significant. Soybeans grown under the highest

Table 2.17. Regression equations of soybean reproductive biomass (log transformed) vs. time for combination weed treatments in 1983. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
0/m	-19.276	3.058	-0.105	0.952
	±1.032	±0.193	±0.009	
2/m	-18.305	2.810	-0.095	0.879
	±4.994	±0.936	±0.042	
4/m	-13.135	2.017	-0.066	0.848
	±4.381	±0.821	±0.037	
8/m	-21.709	3.531	-0.133	0.899
	±3.984	±0.747	±0.034	
16/m	-22.575	3.724	-0.144	0.846
	±4.834	±0.906	±0.041	

Table 2.18. Regression equations of soybean pod number (log transformed) vs. time for combination weed treatments in 1983. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	WEEK^2	R^2
0/m	-18.056 ±1.476	3.628 ±0.277	-0.147 ±0.013	0.783
2/m	-13.134 ±3.602	2.692 ±0.675	-0.107 ±0.031	0.788
4/m	-11.259 ±4.645	2.447 ±0.871	-0.101 ±0.039	0.554
8/m	-20.368 ±4.897	4.031 ±0.918	-0.169 ±0.042	0.720
16/m	-26.698 ±3.333	5.151 ±0.625	-0.219 ±0.028	0.889

weed density treatment (16 plants/m row) exhibited evidence of density stress sooner than those grown at lower densities (Fig. 2.12). Leaf number was reduced in the development stage of leaf /growth under high weed density pressure (16 plants/m), and in the senescence stage under intermediate weed density pressure (4,8 plants/m row) as was observed in the velvetleaf tneatments.

In summary, soybean leaf number was significantly reduced when subjected to the density stress presented by the combination of cocklebur and velvetleaf. Soybean height showed increases in response to increasing weed density stress.

Figure 2.12

Relationship between leaf number and week in soybeans grown in combination weed treatments in 1983. The dashed vertical lines indicate the first significant differences from the control treatments (weed-free). Significant differences were not found in plants grown at a weed density of 2/m row.

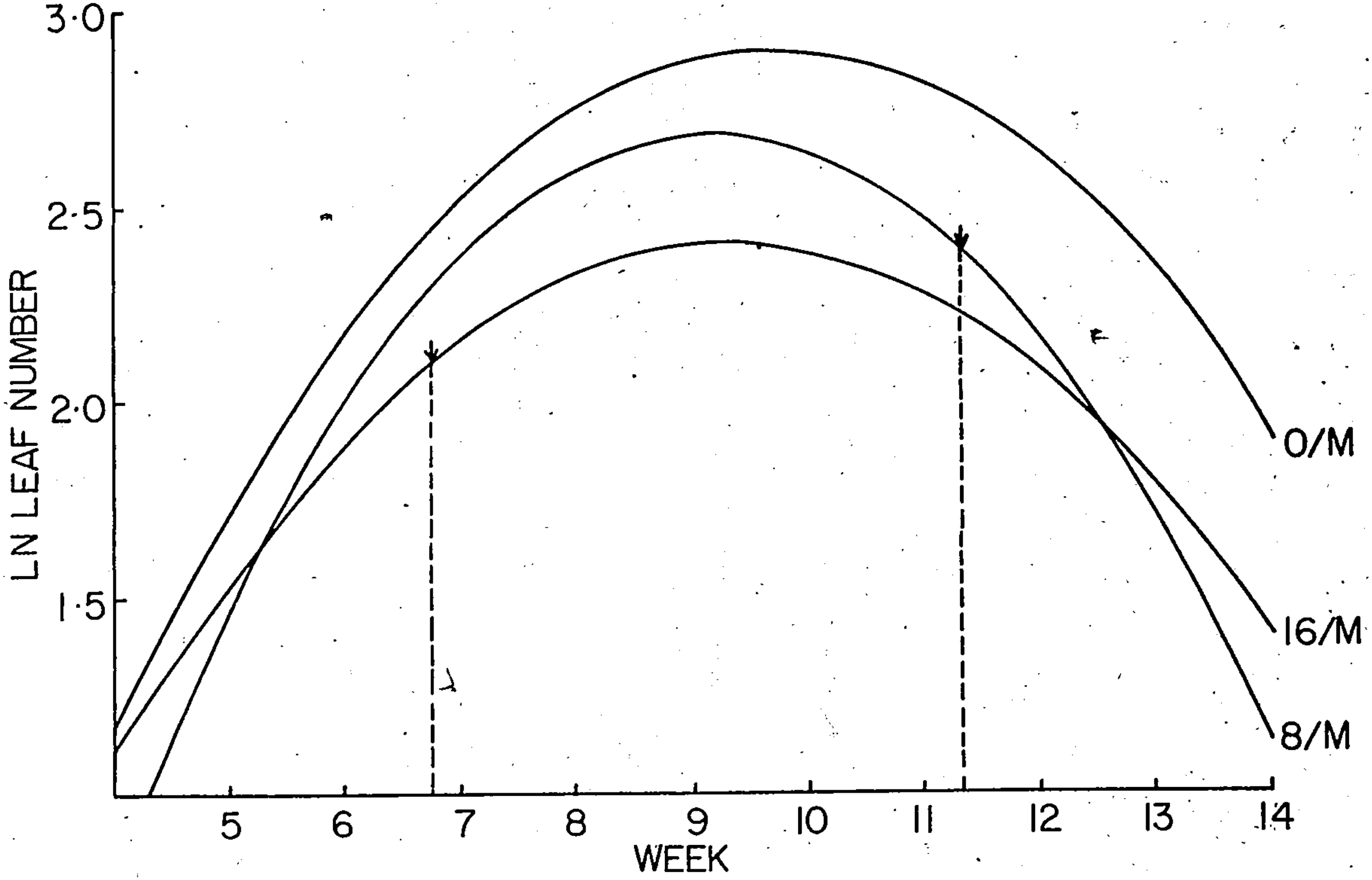

3·0
2·5
2·0
1·5
LN LEAF NUMBER
5
6
7
8
9
10
11
12
13
14
WEEK
0/M
16/M
8/M

Table 2.19. Regression equations of soybean leaf number (log transformed) vs. time for combination weed treatments in 1983. Standard errors are included for comparison.

		SLOPES		
TREATMENT	INTERCEPT	WEEK	$WEEK^2$	R^2
0/m	-2.235 ±0.414	1.058 ±0.096	-0.055 ±0.005	0.396
2/m	-2.086 ±1.077	0.980 ±0.249	-0.051 ±0.013	0.425
4/m	-3.190 ±1.041	1.286 ±0.241	-0.071 ±0.013	0.611
8/m	-3.180 ±0.850	1.269 ±0.196	-0.069 ±0.010	0.683
16/m	-1.666 ±0.853	0.868 ±0.197	-0.046 ±0.010	0.489

2.2 YIELD ANALYSIS

I.- COCKLEBUR

To analyze the effects of season-long cocklebur competition on soybean seed yield, four meters of soybeans were harvested from each treatment in each block at maturity. Care was taken to harvest plants only in areas of consistent cocklebur density. The sample sizes were sufficiently large enough to allow analysis of density effects upon yield by Tukey's multiple range test as well as linear regression.

Tukey's multiple range test indicated that all of the cocklebur densities except 2/m caused significant reductions in soybean seed yield (Table 2.20). In 1982, soybean seed yield was reduced 67% when subjected to a density stress of sixteen cocklebur/m soybean row (Table 2.20).

Linear regression was used to develop a model to predict natural logarithm bean weight from cocklebur density (Fig. 2.13). The equation described the data very well as evidenced by the R^2 value of 0.77. At sixteen cocklebur/m soybean row the model predicts a 67% reduction in soybean seed yield. The "critical weed density" required to significantly reduce soybean seed yield, was predicted by using the 95% confidence interval of the regression equation. The "critical

Table 2.20. Effect of cocklebur densities on soybean seed yield in 1982.

Cocklebur Density (plants/m row)	Soybean Seed Biomass/m row	Percent Reduction
0	178.6a	-
2	127.4ab	29
4	116.9b	35
8	103.5b	42
16	58.4c	67

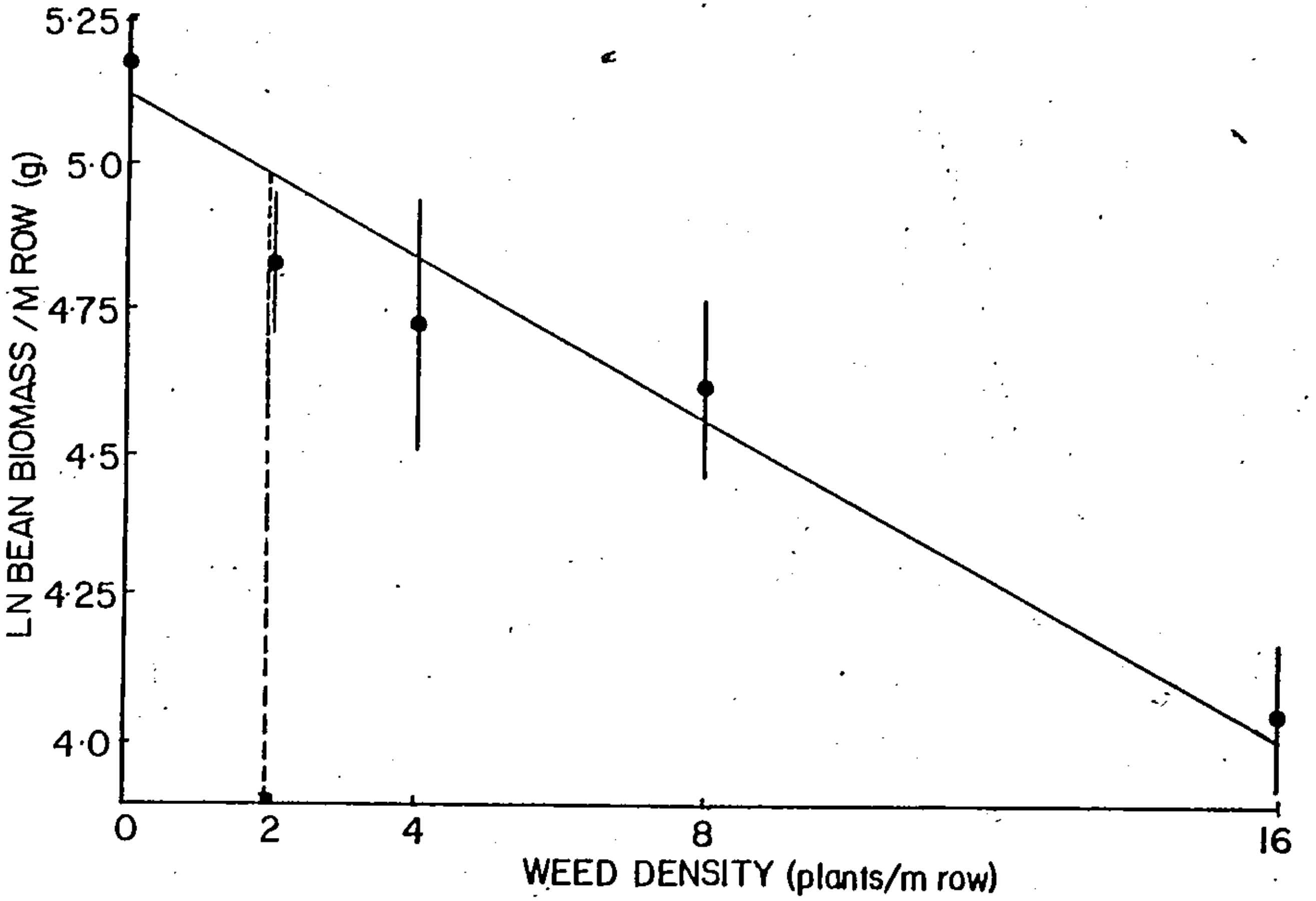
Means followed by the same letter are not sigificantly different at the 5% level as determined by Tukey's multiple range test.

Figure 2.13

Effect of cocklebur density on soybean seed yield in 1982. The dashed vertical line indicates the predicted minimum cocklebur density required to decrease yield significantly. The regression equation obtained for seed yield was

$$\log(\text{seed biomass}) = 5.815 - 0.069(\text{density})$$

with an R^2 value of 0.774.


LN BEAN BIOMASS /M ROW (g)
5·25
5·0
4·75
4·5
4·25
4·0
0
2
4
8
16
WEED DENSITY (plants/m row)

density" of cocklebur required to significantly reduce soybean seed yield was two plants/m of soybean row (Fig. 2.13), thus differing slightly from a posteriori analysis using Tukey's test.

In 1983, a complete range of cocklebur density treatments were not grown. Cocklebur at sixteen plants/m row, were grown to assess yearly variation in soybean density response. Soybean yield reductions were slightly less in 1983 when compared to 1982, possibly because of adequete precipitation in 1983. The yields in 1983, were reduced by 53% at 16 cocklebur/m row. Soybean density responses were similar over both years of the study. In 1983, the 95% confidence interval of the regression equation also indicated a "critical density" of two cocklebur/m row was required to significantly reduce soybean seed yield (Fig. 2.14).

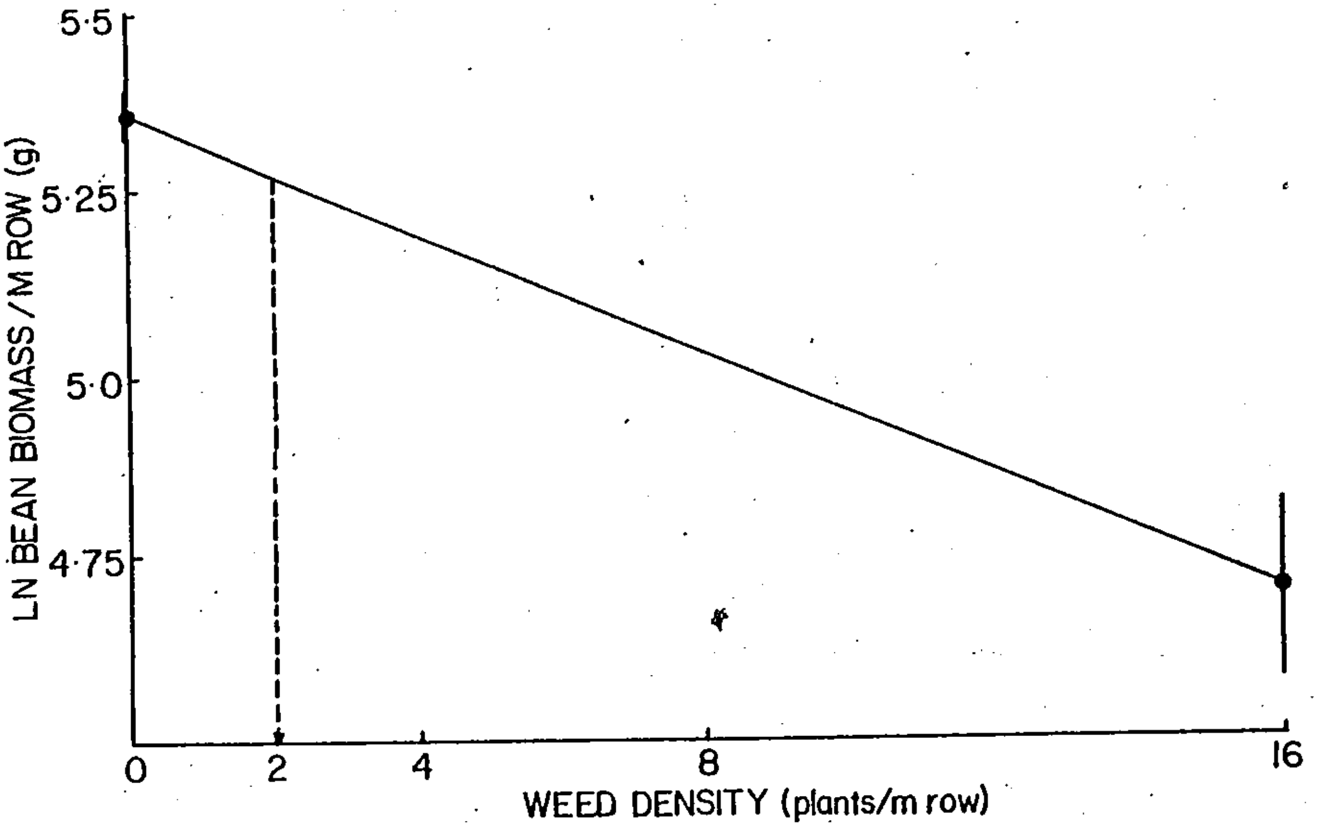
In summary, cocklebur density stress can cause significant reductions in soybean seed yield. There are two valid approaches to determining the "critical density" of cocklebur required to significantly reduce soybean seed yield. Tukey's multiple range test suggests that four cocklebur/m row will cause significant yield reductions, while linear regression predicts a "critical density" of two cocklebur/m. Though both approaches are entirely valid, Tukey's multiple range test requires a larger sample size in order to detect density effects.

Figure 2.14

Effect of cocklebur density on soybean seed yield in 1983. The dashed vertical line indicates the predicted minimum cocklebur density required to decrease yield significantly. The regression equation obtained for seed yield was

$$\log(\text{seed biomass}) = 5.362 - 0.048(\text{density})$$

with an R^2 value of 0.665.


5·5
5·25
5·0
4·75
LN BEAN BIOMASS / M ROW (g)
0
2
4
8
16
WEED DENSITY (plants/m row)

II. VELVETLEAF

The approach towards soybean yield analysis with velvetleaf was similar to that previously described for cocklebur. Sampling methods and harvest sizes were identical.

Tukey's multiple range test was utilized to determine if the observed reductions in soybean seed yield were significant (Table 2.21). Soybean seed yield was reduced 36% under a density stress of 16 velvetleaf/m soybean row. Tukey's multiple range test indicated that a density of four velvetleaf/m row was required to elicit significant soybean seed yield reductions (Table 2.21).

Linear regression was used to develop a yield model to predict natural logarithm bean weight from velvetleaf density. The model provided only a fair approximation to the data as evidenced by an R^2 value of 0.44 (Fig. 2.15). At 16 velvetleaf/m row, the model predicts a 38% reduction in soybean seed yield. The 95% confidence interval of the regression model was used to predict the "critical density" of velvetleaf required to cause significant reductions in soybean seed yield (Fig. 2.15). It was predicted that two velvetleaf/m row provided density stress sufficient to significantly reduce soybean seed yield.

In summary, velvetleaf density stress can reduce soybean seed yield. Tukey's multiple range test

Table 2.21. Effect of velvetleaf densities on soybean seed yield in 1983.

Velvetleaf Density (plants/m row)	Soybean Seed Biomass/m row	Percent Reduction
0	216.6a	-
2	197.8ab	9
4	168.2bc	22
8	154.0bc	29
16	138.0c	36

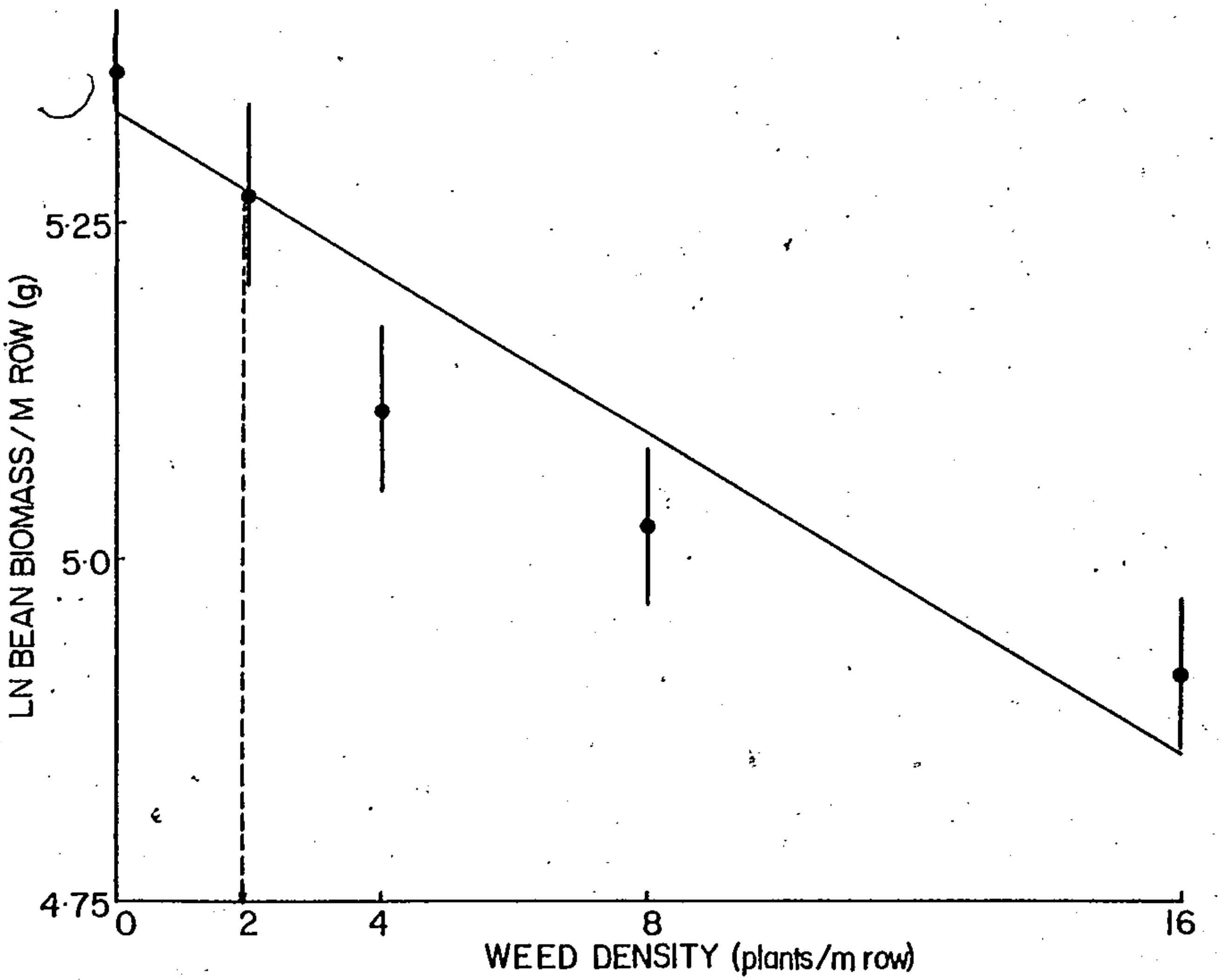
Means followed by the same letter are not significantly different at the 5% level as determined by Tukey's multiple range test.

Figure 2.15

Effect of velvetleaf density on soybean seed yield in 1983. The dashed vertical line indicates the predicted minimum velvetleaf density required to decrease yield significantly. The regression equation obtained for seed yield was

$$\log(\text{seed biomass}) = 5.333 - 0.030(\text{density})$$

with an R^2 value of 0.439.


LN BEAN BIOMASS / M ROW (g)
5·25
5·0
4·75
0
2
4
8
16
WEED DENSITY (plants/m row)

indicated that four velvetleaf/m row will cause significant yield reductions. Linear regression predicted that two velvetleaf/m soybean row is the "critical density" which will cause significant reductions in soybean seed yield.

III: COMBINATIONS

The approach used to density effects in soybean yield in the combination treatments was identical to that aforementioned in the single weed species treatments.

Soybean seed yield was reduced 39% by a total weed density of sixteen plants/m row (Table 2.22). Tukey's multiple range test indicated that four weeds/m row are required to significantly reduce soybean seed yield.

A model predicting natural logarithm bean weight from weed density was developed through linear regression (Fig. 2.16). It provided a fair approximation to the data, as evidenced by the R^2 value of 0.47. At 16 weeds/m the model predicts a soybean yield reduction of 41%. The 95% confidence interval of the regression equation predicted a "critical density" of two weeds/m soybean row (Fig. 2.16).

In summary, the combination treatments containing both cocklebur and velvetleaf, significantly reduced soybean seed yield. "Critical weed densities" necessary to significantly reduce soybean yield are four weeds/m using the Tukey approach, and two weeds/m using linear regression.

Table 2.22. Effect of combination weed treatment densities on soybean seed yield in 1983.

Weed Density (plants/m row)	Soybean Seed Biomass/m row	Percent Reduction
0	216.6a	-
2	184.0ab	15
4	171.6bc	21
8	151.3bc	30
16	131.5c	39

Means followed by the same letter are not significantly different at the 5% level as determined by Tukey's multiple range test.

Figure 2.16

Effect of weed density (cocklebur + velvetleaf) on soybean seed yield in 1983. The dashed vertical line indicates the predicted minimum weed density required to decrease yield significantly. The regression equation obtained for seed yield was

$$\log(\text{seed biomass}) = 5.328 - 0.033(\text{density})$$

with an R^2 value of 0.471.

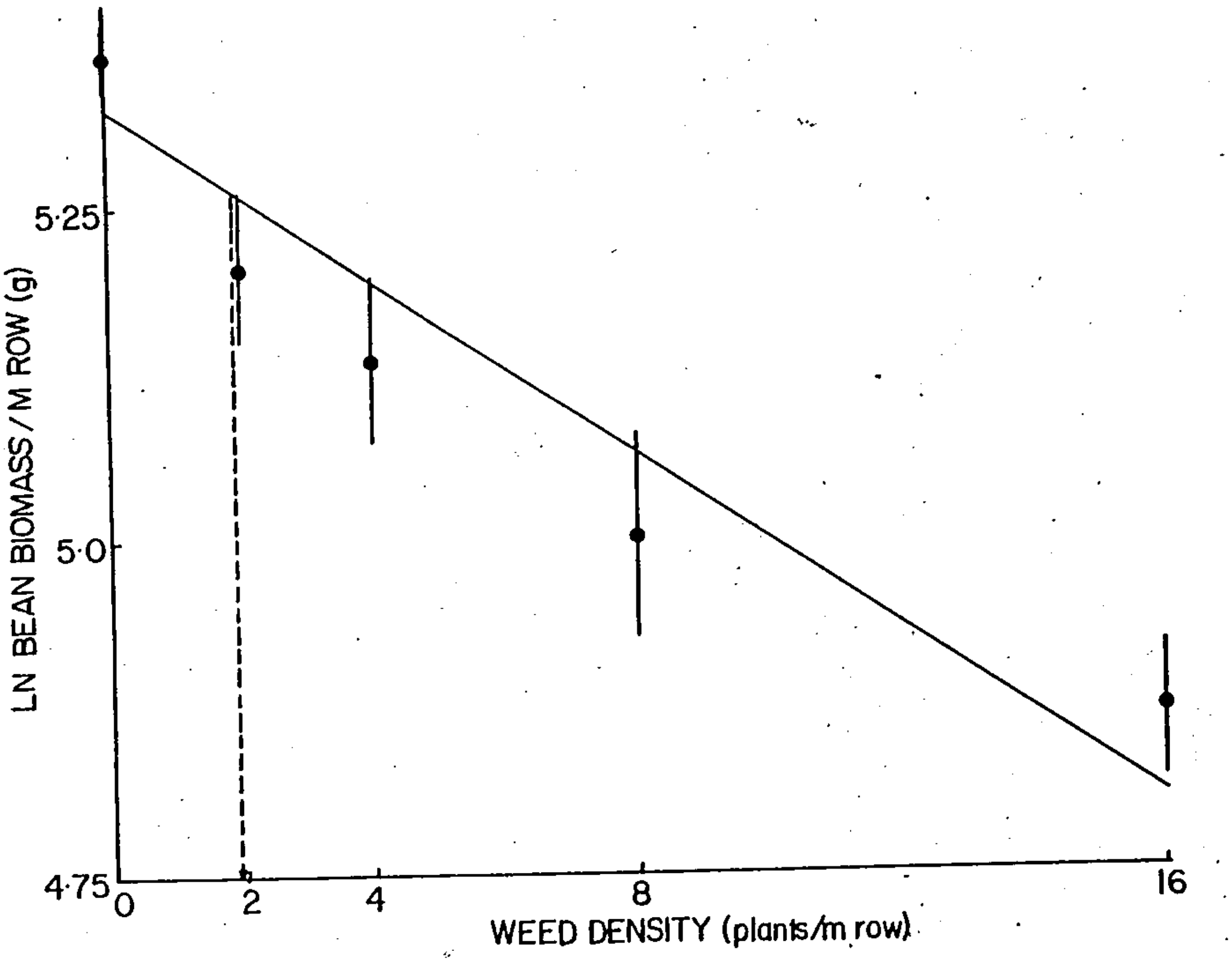
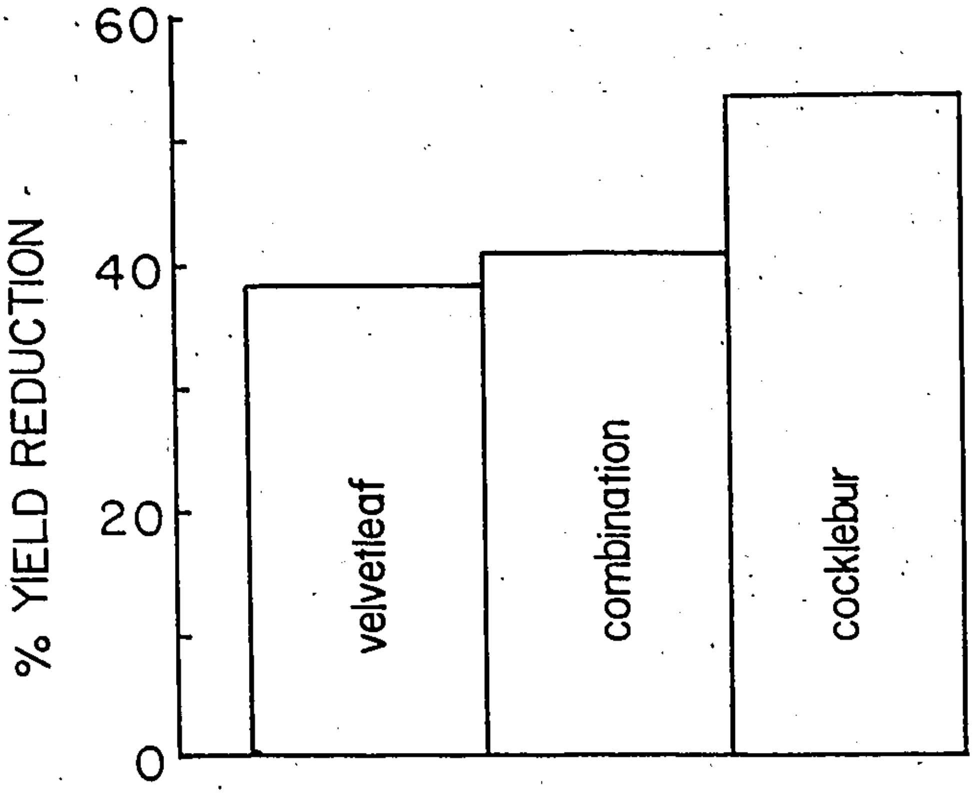

LN BEAN BIOMASS / M ROW (g)
5·25
5·0
4·75
0
2
4
8
16
WEED DENSITY (plants/m row)

Figure 2.17

Comparison of seed yield reductions in soybeans grown in the cocklebur, velvetleaf, and combination weed density treatments at 16 plants/m in 1983.


% YIELD REDUCTION
60
40
20
0
velvetleaf
combination
cocklebur

2.3 DISCUSSION

My study is in agreement with those of Barrentine (1974) and Bloomberg et al (1980) who suggest that cocklebur can cause significant reductions in soybean growth. In my study, cocklebur density stress caused reductions in soybean vegetative biomass, reproductive biomass, pod number, and leaf number.

The previous investigations of crop-weed interaction have largely ignored the temporal aspect of competition, as was noted by Harper (1977). A common strategy employed to determine the period of weed-free maintenance which limits crop yield reductions is the use of delayed weed plantings (Bloomberg et al., 1982). Such an approach is valid if it is not interpreted as a method of determining the "critical time" at which crop-weed interaction elicits significant reductions in soybean growth. Using delayed weed planting strategies can theoretically subject crops and weeds to differing environmental conditions at the time of germination. Using temporal growth models to predict the "critical time" of interaction assumes identical environmental conditions upon germination.

Soybeans grown under high cocklebur density stress (16 plants/m) exhibited evidence of density effects in vegetative biomass and leaf number before the time of floral initiation. Reproductive biomass and pod number were reduced shortly after floral initiation. These temporal trends were consistent over both years of the study. Barrentine (1974) was one of the first to suggest that soybeans can successfully compete with cocklebur up to four weeks after emergence. Bloomberg et al. (1982) also confirms a similar time frame of four weeks. In both years of our study, soybean growth is affected about six weeks after emergence. Perhaps both soybeans and cocklebur were too small to interact up to six weeks after emergence. Although there was some interaction detected between cocklebur in 1982, the inclusion of a weed growth variable exhibiting intraspecific weed interaction did not significantly improve the soybean growth models.

Season-long competition with cocklebur can cause significant reductions in soybean seed yield (Barrentine, 1974; Bloomberg et al., 1982). Coble and Ritter (1978) suggest that the 95% confidence limits of linear regression models can be used to predict the "critical weed density" at which crop yield is significantly reduced. The employment of this approach indicates that two cocklebur/m soybean row can significantly reduce soybean seed yield. Using Tukey's multiple range test to examine differences among density means suggests that four cocklebur/m soybean row are required to significantly reduce soybean seed yield. Advantages of using the linear regression approach include the sensitivity of the detection of density effects. However unlike a multiple range test, one is dealing with predicted rather than real mean values.

The competitive effects of velvetleaf have been studied in many crop situations including sugarbeets (Schweizer and Bridge, 1982), cotton (Elmore et al., 1983), and soybeans (Eaton et al., 1976; Oliver, 1979). In my experiment, increases in velvetleaf density elicited major reductions in soybean height, vegetative biomass, reproductive biomass, pod number, and leaf number.

The same approach as previously described for cocklebur was utilized to determine the "critical time" at which soybean-velvetleaf interaction became significantly in alterations in soybean growth.

The first evidence of crop-weed interaction appeared at the time of floral initiation (8 weeks) in the highest density velvetleaf treatment. The major decline in vegetative biomass was due to leaf senescence. Interestingly, pod number is significantly reduced only under the highest density regime although reproductive biomass is reduced over a much wider range. This appears to suggest that density stress may affect the rate of pod-filling rather than the rate of pod formation (or pod abortion for that matter). Hagood et al. (1980) used a similar approach in his study of soybean-velvetleaf interaction. Significant reductions in soybean leaf biomass, leaf area index, and vegetative biomass were detected between seven and nine weeks after emergence over both years of his study. Reproductive biomass was reduced between nine and eleven weeks after emergence. My findings are entirely consistent with those of Hagood et al. (1980).

Earlier researchers found little evidence of soybean-velvetleaf interaction at infestation rates as high as 20 plants/square meter (Staniforth and Weber, 1956). Hagood et al. (1980) found evidence of significant reductions in soybean yield at a velvetleaf density of 2.5 plants/square meter. Apparently velvetleaf can be quite competitive in some crop situations as evidenced by Schweizer and Bridge's (1982) study of interaction with sugarbeets. Using 95% confidence intervals of linear regression equations for crop yield predicted from weed density, the "critical densities" of velvetleaf required to significantly reduce sugarbeet yield were found to be between 9 and 12 plants/30 m of row over the two years of their study. Employing this methodology, I determined the "critical density" of velvetleaf required to significantly reduce soybean seed yield to be 2 plants/m of soybean row. Conversely, when approaching the same data using a multiple range test (Tukey's), I arrived at a "critical density" of 4 velvetleaf/m of row. The "critical density" predicted through linear regression does closely approximate that determined by Hagood et al. (1980).

The study of weed species combinations in a potentially competitive situation with a crop plant raises a few interesting questions. The ultimate question that must be addressed is "are the competitive effects of each weed species additive when grown in combination?". We found no evidence of cocklebur-velvetleaf interaction when grown in combination. There were slight differences in relative growth rates of both weed species; with cocklebur having the greater rate (Fig. 1.10). However, the differences in relative growth rates between the two weed species were of insufficient magnitude to elicit significant density effects. Other researchers have found interaction in weed-mixture experiments (Elmore et al., 1983). Schweizer and Bridge (1982) found minimal interaction between sunflowers and velvetleaf when grown with sugarbeets. The combined weed species treatments elicited sugarbeet yield reductions of a magnitude approximately intermediate to those obtained in the single weed species treatments at the same total densities. This tends to support the theory that competitive effects may be additive.

If competitive effects can be additive, the possibility remains that the temporal aspect or "critical time" of significant interaction may also be additive. In the combination treatments, density effects in soybean vegetative biomass were detected almost at the same time as in the cocklebur treatments. Reproductive biomass, pod number, and leaf number all showed similar temporal trends. In terms of absolute reduction in soybean growth at maturity, the temporal growth equations predict reductions in vegetative biomass, total biomass, reproductive biomass, and pod number, of a magnitude only slightly greater than the single species treatments. In the reduction of leaf number under density stress, the combination treatment is intermediate between that obtained for cocklebur and velvetleaf grown alone with soybeans. The temporal growth models do very little to conclusively support the theory that the competitive effects of cocklebur and velvetleaf are additive when grown in combination.

Season-long interaction indicates that soybean yield reduction in the combination treatments is intermediate between those for cocklebur and velvetleaf (Fig. 2.17). This may indicate that the competitive effects of cocklebur and velvetleaf are additive when grown in combination.

Utilizing the 95% confidence intervals of the linear regression equation of soybean seed yield versus weed density, a "critical density" of 2 weeds/m soybean row was determined to significantly reduce soybean yield. This corresponds exactly with that obtained for cocklebur and velvetleaf grown alone. An alternative approach, testing for significant density effects with Tukey's multiple range test, indicates that 4 weeds/m row can cause significant soybean yield reductions.

2.4 GENERAL SUMMARY

In this study of crop-weed interaction, I have concentrated upon two main areas of ecological and agricultural interest: the establishment of "critical times" at which significant crop-weed interaction is first detected, and the establishment of "critical weed densities" at which significant density effects are detected through alterations in crop growth. Specifically, I have investigated potential density effects of two weed species; cocklebur (Xanthium strumarium L.), and velvetleaf (Abutilon theophrasti Medic.), and their combination, upon various components of soybean growth.

Temporal growth models for each weed density were developed for soybean vegetative biomass, total biomass, reproductive biomass, pod number, leaf number and height. The "critical times" of crop-weed interaction predicted from the temporal growth models are in agreement with Harper (1977) who suggested that density effects should be detectable in plants grown under high density stress before plants grown under lesser density stress. Cocklebur density stress elicited significant reductions in soybean growth at six weeks after emergence; about two weeks prior to detection in velvetleaf treatments. The temporal trends in the combination treatment paralleled those using cocklebur.

Variability in the temporal growth models makes it difficult to address the question of the potential additivity of the temporal aspects of the competitive effects of cocklebur and velvetleaf upon soybean growth.

Soybean seed yield models were developed to explain the effects of season-long competition between the weed treatments and soybeans. The order of competitiveness, as evidenced by soybean seed yield reductions are as follows: cocklebur> combination> velvetleaf. The competitive effects of cocklebur and velvetleaf do appear to be additive in the combination treatments. The predicted "critical weed densities" were identical for all three weed treatments. Two weeds/m of soybean row, regardless of weed species, caused significant reductions in soybean seed yield. Thus cocklebur, velvetleaf, and their combination do pose a real threat to soybean crop production

To remain workable, crop-weed interaction models must remain simple. The models I have developed are specific for the environmental conditions that were encountered. There is a distinct need to include environmental data in these models in order to expand upon their predictability. Conducting crop-weed interaction experiments under a wide range of environmental conditions would require considerable time and effort, yet would lead to the development of workable crop-weed interaction models of maximum predictability.

The findings I have presented here represent but a very small section of a holistic approach towards weed control known as Integrated Weed Management. It is of primary importance to define the ecology of crop-weed interaction before variables of economic concern can be addressed.

LITERATURE CITED

Alex, J. F. and C. M. Switzer. 1974. Ontario weeds. Ont. Min. of Agric. and Food Publ. 505. Ottawa, Ont.

Barrentine, W. L. 1974. Common cocklebur competition in soybean. Weed Sci. 22:600-603.

Bloomberg, J. R., B. L. Kirkpatrick and L. M. Wax. 1982. Competition of common cocklebur (*Xanthium pensylvanicum*) with soybean (*Glycine max*). Weed Sci. 30:507-513.

Chancellor, R. J. 1981. The manipulation of weed behavior for control purposes. Phil. Trans. R. Soc. Lond. 295:103-110.

Chandler, J. M. 1977. Competition of spurred anoda, velvetleaf, prickly sida, and Venice mallow in cotton. Weed Sci. 25:151-158.

Coble, H. D. and R. L. Ritter. 1978. Pennsylvania smartweed (*Polygonum pensylvanicum*) interference in soybeans (*Glycine max*). Weed Sci. 26:556-559.

-----, F. M. Williams and -----. 1981. Common ragweed (*Ambrosia artemisiifolia*) interference in soybeans (*Glycine max*). Weed Sci. 29:339-342.

Dew, D. A. 1972. An index of competition for estimating crop loss due to weeds. Can. J. Plant Sci. 52:921-927.

Eaton, B. J., O. G. Russ and K. C. Feltner. 1976. Competition of velvetleaf, prickly sida, and Venice mallow in soybeans. Weed Sci. 24:224-228.

Elmore, C. D., M. A. Brown and E. P. Flint. 1983. Early interference between cotton (*Gossypium hirsutum*) and four weed species. Weed Sci. 31:200-207.

Fryer, J. D. 1981. Weed management: fact or fable? Phil. Trans. R. Soc. Lond. 295:185-197.

Gressel, J. B. 1978. Factors influencing the selection of herbicide-resistant biotypes of weeds. J. Theor. Biol. 25:283-287.

Hagood, E. S., T. T. Bauman, J. L. Williams and M. M. Schreiber. 1980. Growth analysis of soybean (*Glycine max*) in competition with velvetleaf (*Abutilon theophrasti*). Weed Sci. 28:729-734.

-----, -----, ----- and -----. 1981. Growth analysis of soybeans (*Glycine max*) in competition with jimsonweed (*Datura stramonium*). Weed Sci. 29:500-504.

Harper, J. L. 1977. Population biology of plants. Academic Press, London.

Hicks, A. J. 1971. Systematic studies of *Xanthium* (Compositae: Ambrosieae): the cockleburs of Tazewell County, Illinois. Ph. D. thesis. University of Illinois, Champaign Urbana, Ill.

Hunt, R. 1982. Plant growth curves: The functional approach to plant growth analysis. Edward Arnold, London.

Kaul, V. 1965. Physiological ecology of Xanthium strumarium L. II. Physiology of seeds in relation to its distribution. J. Indian Bot. Soc. 44:365-380.

Kirkpatrick, B. L., L. M. Wax and E. W. Stoler. 1983. Competition of jimsonweed with soybean. Agron. J. 75:833-836.

Lee, T. D. and F. A. Bazzaz. 1980. Effects of defoliation and competition on growth and reproduction in the annual plant Abutilon theophrasti. J. of Ecol. 68:813-821.

Love, D. and P. Dansereau. 1959. Biosystematic studies on Xanthium: Taxonomic appraisal and ecological status. Can. J. Bot. 37:173-208.

Leuschen, W. E. and R. N. Andersen. 1980. Longevity of velvetleaf (Abutilon theophrasti) seeds in soil under agricultural practices. Weed Sci. 28:341-346.

Marra, M. C. and G. A. Carlson. 1983. An economic threshold model for weeds in soybeans (Glycine max). Weed Sci. 31:604-609.

McMillan, C. 1975. Experimental hybridization of _Xanthium strumarium_ (Compositae) from Asia and America. I. Response of F1 hybrids to photoperiod and temperature. Am. J. Bot. 62:41-47.

McWhorter, C. G. and W. C. Shaw. 1982. Research needs for integrated weed management systems. Weed Sci. 30:40-45.

Oliver, L. R. 1979. Influence of soybean (_Glycine max_) planting date on velvetleaf (_Abutilon theophrasti_) competition. Weed Sci. 27:183-188.

Schreiber, M. M. 1982. Modeling the biology of weeds for integrated weed management. Weed Sci. 30:13-16.

Schweizer, E. E. 1981. Broadleaf weed interference in sugarbeets (_Beta vulgaris_). Weed Sci. 29:128-133.

----- and L. D. Bridge. 1982. Sunflower (_Helianthus annuus_) and velvetleaf (_Abutilon theophrasti_) interference in sugarbeets (_Beta vulgaris_). Weed Sci. 30:514-519.

-----. 1983. Common lambsquarters (_Chenopodium album_) interference in sugarbeets (_Beta vulgaris_). Weed Sci. 31:5-8.

Smith, R. J. 1983. Competition of bearded sprangletop (_Leptochloa fascicularis_) with rice (_Oryza sativa_). Weed Sci. 31:120-123.

Snipes, C. E., G. A. Buchanan, J. E. Street and J. A. McGuire. 1982. Competition of common cocklebur with cotton. Weed Sci. 30:553-556.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co. San Francisco, Cal.

Staniforth, D. W. and Weber. 1956. Effects of annual weeds on growth and yield of soybeans. Agron. J. 48:467-471.

Thurlow, D. L. and G. A. Buchanan. 1972. Competition of sicklepod with soybeans. Weed Sci. 20:379-384.

Walker, R. H. and G. A. Buchanan. 1982. Crop manipulation in integrated weed management systems. Weed Sci. 30:17-24.

Weaver, S. E. and M. J. Lechowicz. 1983. The biology of Canadian weeds. 56. _Xanthium strumarium_ L. Can. J. Plant Sci. 63:211-225.

Zimmerman, J. K. 1983. Competition in natural and experimental monocultures of _Xanthium strumarium_ L. MSc. thesis. University of Windsor. Windsor, Ont.

VITA AUCTORIS

Jeffrey Leonard Larson

Born: January 29, 1958
Windsor, Ontario

Elementary School:	Colonel Bishop School LaSalle, Ontario 1972
Secondary School:	Sandwich Secondary School Windsor, Ontario 1977
Bachelor of Science (Hon.):	Biology University of Windsor Windsor, Ontario 1981
Master of Science:	Biology University of Windsor Windsor, Ontario 1984