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Response of two indeterminate soybean cultivars to plant competition induced by altered row widths and plant densities.

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RESPONSE OF TWO INDETERMINATE SOYBEAN CULTIVARS TO PLANT COMPETITION INDUCED BY ALTERED ROW WIDTHS AND PLANT DENSITIES

A Thesis Presented

By

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DEDICATION

To my wife
Esther
whose patience and support allowed me
to complete this project.

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CHAPTER I

INTRODUCTION

Many people have shown a seed yield increase from soybean planted in narrowly spaced rows (less than 50cm) (Lehman and Lambert, 1969; Cooper, 1977; Costa et al., 1980; Herbert and Litchfield, 1982; Taylor et al., 1982). Also, many people have shown a yield increase of soybean seed from plantings at high densities and narrow rows (Shibles and Weber, 1966; Cooper, 1977; Taylor et al., 1982).

Wiggins (1939) reported that within population levels, seed yield increased as the spacing approached a uniform (Square) pattern. Uniformly spaced plants in narrow rows have been shown to intercept more solar radiation late in the season than wide row plants of equivalent density (Shibles and Weber, 1965). Shibles and Weber (1966) suggested that complete canopy closure by the time of rapid pod fill is an important factor for high yields.

Soybean plants flower abundantly but a large portion of the flowers and pods abscise (Lehman and Lambert, 1960). van Schaik and Probst (1957) found flower and pod shed combined to be from 43 to 81 percent, depending on the cultivar. Taylor et al. (1982) found that while pod set was greater in wide rows, final pod number was greater in the narrow rows. They speculate that pod abortion caused by inadequate late season photosynthate supply was the major determinant of yield. In a yield component analysis Herbert and Litchfield (1982) found pod number to be the major component of yield.

This study was undertaken to determine the influence of row widths and plant densitis on the seed yield, yield components and flower production of two short seasoned soybeans of indeterminate growth type.

CHAPTER II

LITERATURE REVIEW

General

Soybean plants (Glycine max (L.) Merr.) are predominantly of two growth types: determinate, those which complete their vegetative growth before flowering and reproductive growth begins; and indeterminate, those which continue vegetative growth while some parts of the plant are in reproductive growth. In the northern United States and Canada the adapted soybean cultivars are almost exclusively indeterminate in growth habit. In the southern U.S. the adapted soybean cultivars are almost exclusively determinate in growth habit. In the middle latitudes of the U.S. both determinate and indeterminate cultivars can be grown.

Soybeans are quite sensitive to day length as a stimulus for flowering. This was recognized by Garner and Allard (1920) and termed photoperiodism. Ten maturity groups have been established in the U.S. and Canada to categorize the response of different cultivars to photoperiodism or time to maturity. These groups range from 00 to VIII with 00 being the earliest to mature and VIII being the latest to mature in the U.S.. Maturity group

OO cultivars normally would be planted in southern Canada or in the northernmost U.S. while maturity group VIII cultivars would normally be planted in the southern part of the Gulf states. A range of ten to fifteen days exists between groups.

In Massachusetts a cultivar trial was conducted which included cultivars from maturity groups OO, O, I, and II (Herbert, 1980). The results showed that the highest yields were from the maturity group I and II cultivars which were the later maturing groups. However, these cultivars did not mature a full crop in all years before the first frost. Further work by Herbert has been limited to cultivars from maturity groups OO and O which produce harvestable crops each year.

For a number of years agronomists have been concerned with the spacial arrangement of soybean plants and its effect on yield. Wiggins (1939) reported that within population levels, seed yield increased as the spacing approached a uniform (square) pattern.

In the northern United States there have been numerous reports of higher yield from narrow row spacing* (Lehman and Lambert, 1960; Shibles and Weber, 1966;

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* Narrow rows are taken to mean 50cm or less between rows.

Timmons et al., 1967; Spilde et al., 1980; Costa et al., 1980; Herbert and Litchfield, 1982; Taylor et al., 1982). Others have found increased yield from narrow row spacing but specified certain other conditions as necessary. Weber et al. (1966) found maximum seed yield occurred in narrow rows (25cm) but only at low plant populations (257,000 plants/ha), and Cooper (1977) found greater yield in narrow rows (17cm) at higher plant populations (375,000 plants/ha). Taylor (1980) reported narrow rows (25cm) to outyield wide rows (100cm) only when seasonal water supply was high. Generally, the response to row width is greater in early maturing cultivars.

Narrowing row spacing has not met with increasing yields in the southern United States (Hinson, 1967; Doss and Thurlow, 1974). It is thought that in the southern U.S., where cultivars are all of determinate growth habit and plants have a longer growing season, the plants have achieved full light interception before the reproductive stage which negates any positive effect of narrow row spacing on yield.

Plant population has received a great deal of attention by researchers over the past twenty years. Reports of increasing yield with increasing plant density were given by Buttery (1969), Dougherty (1969), Cooper (1977), and Dominguez and Hume (1978). Yield response to changing plant density has been studied by many others (Probst, 1945; Shibles and Weber, 1966 (128 and 257 thousand plants/ha); Cooper, 1970 (150,000 plants/ha); Hoggard et al., 1978 (240,000 plants/ha); Herbert and Litchfield, 1982 (800,000 plants/ha). Because of the different plant populations used in each experiment the terms low, medium and high are quite relative. Generally it appears that a minimum population must be established to produce high yields. The minimum population is difficult to establish in absolute terms because of interaction with cultivars (Johnson and Harris, 1967), years (Hinson and Hanson, 1961; Lueschen and Hicks, 1977), and row width (Weber et al., 1966; Basnet et al., 1977; Cooper, 1977). Reports that plant population had no effect on yield have come from both the northern U.S. (Costa et al., 1980) and the southern U.S. (Doss and Thurlow, 1974). Perhaps this lack of response to plant population is because the lowest population used in these experiments was already above the minimum needed for high yields. Recognizing the wide diversity in experimental conditions from the papers cited, the minimum population appears to be in the range of 150,000 to 350,000 plants per hectare. Higher densities than 350,000 plants/ha, while not proving detrimental to yield, have not often been cited as enhancing yield, and increase the cost of production with no additional return.

Dougherty (1969) reported greater dry matter weights in 51cm (20in) rows than 102cm (40in) rows. Weber et al. (1966) observed that planting patterns favoring the rapid attainment of high leaf area index (LAI) were also those having the greatest dry matter production. Shibles and Weber (1966) reported dry matter production to be a function of percent solar radiation interception regardless of planting pattern.

A number of researchers have found increased LAI as population increased (Shibles and Weber, 1965; Hicks et al., 1969; Costa et al., 1980). However, there has been no evidence of an optimum LAI. Shibles and Weber (1965) defined soybeans as a species which has a critical LAI, one in which yield increases up to a certain LAI then remains the same at further increases in LAI. They further defined critical LAI as that LAI required for 95 percent interception of solar radiation. There have been very few reports of LAI values at the critical level and those reports which do exist seem to be specific to each experiment"s conditions (Kokubun and Watanabe, 1982). Jeffers and Shibles (1969) found an interaction occurred between LAI and solar radiation in their effect on photosynthesis, causing the critical LAI to increse as solar radiation incresed.

Shibles and Weber (1966) observed that an increase in population shortened the time to 95 percent solar radiation interception. They postulated that complete (95%) interception must be reached prior to the seed production period in order to attain maximum yields.

Taylor (1980) observed higher LAI in wide (100cm) rows; however, narrow (25cm) rows yielded as well or better than the wide rows. Taylor et al. (1982) reported that radiation interception was greater at 25cm row spacing during most of the season. They believed it was the difference in radiation interception during late seed development which caused the yield differences between narrow and wide rows. The work of Dunphy et al. (1979) gives support to the view that the seed development period is the most critical. They found the length of the seed development period (growth stages R4 to R7; Fehr and Cavines 1977) was more highly correlated with yield than any other period.

Lodging occurs in soybeans and has been associated with increased plant density (Probst, 1945; Cooper, 1971; and Hoggard et al., 1978). It is argued that lodging may be detrimental to yield because of increased self-shading.

Lodging has been reported to reduce yields by 10 to 32 percent (Johnston and Pendleton, 1968; Woods and Swearington, 1977). Cultivar differences in lodging response were recognized by Hoggard et al. (1978) who thought that cultivars of short stature and improved lodging resistance can be developed without lowering yield. The conclusions of Gay et al. (1980) tend to support this view in that they found no relation between lodging and yield in the two old low yielding cultivars and the two new high yielding cultivars that they studied.

Woods and Swearington (1977) found beginning seed stage (R5) to be the most critical time of lodging and accounted for the greatest yield reductions. Noor and Caviness (1980) found significant yield reductions occurred when plants lodged at full pod (R4) but none at vegetative or full bloom stages of development. When plants lodged at stage R5 apical dominance was lost and yield from branches increased (Woods and Swearington, 1977). However, the increased branch yield was not enough to overcome the decrease in yield from the main stem. The main stem yield reduction occurred almost exclusively in the pods per plant component as seeds per pod and seed size were not affected. Woods and Swearington (1977) hypothesized that the altered light relationships were responsible for the changes in yield and yield components.

Changes in the plant's environment have been linked to a number of physiological processes. It is at this level that the real effects of competition expose the factors which are limiting to plant growth and where the possibility of identifying the better adapted or less adapted plants exists. In 1963, Donald defined competition:

> "Competition occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organism".

He further states that,

> "the factors for which competition may occur among plants are water, nutrients, light, oxygen and carbon dioxide; in the reproductive phase, agents of pollination and dispersal must be added".

Soybeans are a self-pollinated crop and therefore do not compete for the agents of pollination nor dispersal. Other factors affect growth such as temperature and humidity but are not in finite supply and therefore are not subject to competition. However, it must be noted that temperature and humidity may change from node to node in indeterminate plants where the development of one node occurs at a different time from the other nodes.

Self shading or shading by other plants is understood to reduce photosynthesis in the shaded leaves. This is well documented. There is however, evidence that unshaded soybean leaves respond to this situation. Increased rates of photosynthesis have been found in unshaded leaves when the other leaves of the plant were shaded (Thorne and Koller, 1974; Peet and Kramer, 1980). Shading treatments caused reduced leaf starch and either increased (Thorne and Koller, 1974) or had no effect on free sugar concentration (Egli et al., 1980). Thorne and Koller (1974) reported that the shading treatments caused an increased assimilate demand resulting in a net photosynthesis increase by means of lower mesophyll resistance in the unshaded leaves.

High irradiance resulted in a similar lowering of leaf starch content in leaves which were acclimated but no differences in CO_2 exchange rates were found (Silvius et al., 1979). They interpret the data to indicate photosynthesis rates stay the same but the photosynthate is transported out of the leaves rather than converted to starch. Under natural conditions leaves at the upper nodes usually have a higher irradiance than lower leaves and these upper leaves have been found to be thicker (Lugg and Sinclair, 1980) and to have more abscisic acid (ABA)(Ciha et al., 1978). Perhaps thicker leaves have more chlorophyll or larger internal surface area with increased CO_2 exchange sites than thinner leaves.

Cultivar differences in photosynthesis rate have been recognized. Sinclair (1980) observed cultivar differences in both maximum carbon exchange rate (CER) and in the duration of high CER throughout the season. Singh et al. (1968) found cultivar differences in net and spectral radiation but no such differences due to row spacing. However, their sampling period was after full cover was attained which excluded any possible early season differences.

Many experiments have been done which either manipulate the photosynthetic sink by pod removal or increase the photosynthetic source material by adding CO_2. Both Koller and Thorne (1978) and Setter et al. (1980) found pod removal to reduce the CO_2 exchange rate by increasing stomatal diffusion resistance. It is quite possible that the increased stomatal diffusion resistance was caused by stomatal closure which was a reaction to greater water loss through the cut surfaces than a response to decreased assimilate demand by sink reduction.

Nafziger and Koller (1975) found increased leaf starch levels after increasing CO_2 supply. Hardman and Brun (1971) found that CO_2 enrichment increased yields when applied at the pod filling stage. The yield increase was the result of larger seed size. CO_2 enrichment at flowering caused a greater number of pods but seed size decreased thus cancelling any effect on yield. CO_2 enrichment at the vegetative stage had no effect on yield or any other of the variables studied.

Flowering

Numerous factors have been found to influence flowering and pod set in soybeans. Among those factors are cultivar, plant density, photoperiod, light intensity, temperature, water supply, humidity and nutrition. Flowering and pod set periods are very sensitive but appear to have a great capacity for overproduction and consequent adjustment in yield components in order to maintain yield levels.

McBlain and Hume (1981) found no cultivar differences in flo-ers produced or flowers and pods aborted in three indeterminate maturity group 00 cultivars. van Schaik and Probst (1957a) using both determinate and indeterminate cultivars and Weibold et al. (1981) using eleven determinate cultivars from maturity groups V through VIII all found cultivar differences in number of flowers, young pods and pods per plant.

Dominguez and Hume (1977) found a decrease in total flowers produced and in initial and final numbers of pods per plant at high densities (densities used were 40, 80, and 120 plants/m^2). In addition, plant densities also affected the distribution of pods as fewer were produced on the bottom third of the plants at high densities. Both Dominguez and Hume (1977) and Hansen and Shibles (1978) observed flowering and pod set to be greatest on the middle section of the plant.

Studying photoperiod sensitive lines Shanmugasundaram et al. (1978) found no differences in induction period from ten to sixteen hour daylengths in the insensitive line. However, the sensitive line had an inductive period of twenty-five days; ten days later anthesis occurred. It was nine days after emergence that the sensitive line began the inductive period.

Light intensity also plays a part in flowering and pod set. It is presumed that this effect is through an increase or decrease in the production and availibility of photosynthate. Johnston et al. (1969) found that adding light to different canopy levels increased yield at those levels. The light rich plants produced more seeds, nodes, pods, branches, pods per node, seeds per pod and higher oil content than normal plants. The apparent photosynthesis rates increased in the bottom and middle canopy levels with the supplemental light. Schou et al. (1978) found reflectors increased photosynthetically active radiation by 57 percent and increased pod number by 48 percent. In another experiment relating to improved photosynthesis Hardman and Brun (1971) found increased pod numbers and node numbers in plants enriched with CO_2 during flowering, but no yield increase was found. However, when CO_2 enrichment was given to plants during the podfill stage a slight increase in seed size was found which resulted in greater yield. Shade treatments reducing the amount of light available for photosynthesis were found to decrease pods per plant, seeds per pod and seed yield (Schou et al., 1978; Wahua and Miller, 1978).

Subhadrabandhu et al. (1978) working with dry beans (Phaseolus vulgaris L.) observed the first formed flowers had the highest probability of setting pods and maturing seeds. Hardman (1970) made a similar observation in soybeans stating that pod set success was greater for the first half of flowering period than the second half (50 vs 25 percent success, respectively). Similarly, Gent (1982) found a lower rate of abortion of seeds on branches having fewer pods. Whether these data reflect influences of small seed number, stage of the plants development or other factors is not clear.

Woodward and Begg (1976) found that low humidity from the start of flowering on reduced pod number causing a reduction in yield. They reported that the reduced pod number was related to floret abortion rather than pod abortion. The reason for greater floret abortion at low humidity is not know. Perhaps the reason for the greater abortion at low humidity involved lack of pollination or fertilization. van Schaik and Probst (1957b) reported an increase in flower and pod shedding with high temperatures (32^{0}C). They found sufficient quantities of viable pollen but evidence that fertilization had not taken place. Thomas and Raper (1981) found a greater number of pods per plant with high day (26 to 30^{0}C) and low night (14^{0}C) temperatures than with other combinations of day (14, 18, 22, 26, and 30^{0}C) and night (10, 14, 18, 22, and 26^{0}C) temperatures.

The nutritional status of the plant has been shown to affect pod abortion. Increasing the nitrogen supply from initial bloom to the end of bloom increased seed number and seed size with a resulting increase in yield (Brevedan et al., 1978).

Growth Analysis

The relative growth rate (RGR) has been found to decline throughout the season (Buttery, 1969a; Herbert et al., 1983). Koller et al. (1970) found the RGR of each individual plant fraction steadily decreased as the season progressed and the most recently initiated plant fraction had the greatest RGR. Buttery and Buzzell (1972) observed cultivar differences in RGR and also observed (1970) an increase in RGR with increasing density (80,000 to 640,000 plants/ha). Herbert et al. (1983) observed increased RGR with narrow rows (25 vs 75cm row widths).

The crop growth rate (CGR) is the amount of biomass increase per unit area per day. The CGR has been found to rise to a peak and then decline during the season (Buttery, 1969b; Koller et al., 1970; Herbert et al., 1983). Koller (1971) observed that the leaf component was the first to reach peak CGR. Using altered plant types, Kokubun and Watanabe (1981 and 1982) found CGR at high density was greater in main-stem type (plants without branches) plants than in branch type or control. However, the CGR was higher in the control plants at low density. Buttery (1970) found the CGR decreased with increasing density. The plant density response to CGR has not always been clear and seems to be dependent on the genetic make-up of the plant responding through its branching pattern.

Herbert et al. (1983) found a distinctly greater CGR in narrow rows (25 vs 75cm) regardless of density (21 vs 113 plants/m^2). Kokubun and Watanabe (1982) observed a greater CGR in narrow rows before the beginning of flowering but a greater CGR in wide rows after the beginning of flowering (60 vs 90cm row widths).

The net assimilation rate (NAR) is the rate of increase in plant material per unit of assimilatory material. Herbert et al. (1983) found a higher net assimilation rate in narrow rows. They attribute the increased CGR and RGR of narrow rows to the higher NAR. Buttery (1970) observed that NAR increased with increasing density. Kokubun and Watanabe (1981) found higher NAR in the main-stem plant types at high density but higher NAR in control plants at low density. Self shading from branches in control plants might have reduced the plants ability to produce efficiently new material at high density. Cultivar differences have been detected in NAR by Buttery (1972). A comparison with parents showed that selection for high yield resulted in increased NAR.

Yield Components

Seed yield in soybeans is composed of the following yield components: plants/m^2, pods/plant, seeds/pod and seed size. Alterations of conditions in the plant's environment whether by natural forces or by design cause alterations in yield components. Studying the changes in yield components that result from different row widths, plant densities and cultivars may lead to valuable knowledge on how the plant achieves its yield.

The soybean plant is noted for its ability to produce similar yields under a range of row width and plant density conditions. The stability of yield is achieved through compensation of the yield components. As conditions reduce one component, another often increases. Adams (1967) working with dry beans (Phaseolus vulgaris, L.) believed the negative correlations observed among yield components to be developmental rather than genetic. According to Adams the yield components develop in a sequential pattern but are genetically independent and therefore free to vary in response to either limited constant input or fluctuating input of metabolites such that input is limiting at critical stages in the developmental sequence.

A number of workers have reported the yield component pods/plant to be the most responsive to changes in the environment (Lehman and Lambert, 1960; Pandey and Torrie, 1973; Dominguez and Hume, 1978; Herbert and Litchfield, 1982). Dominguez and Hume (1978) reported an increasing percentage of pod abortions with increasing plant density. Numerous others have reported a decreasing number of pods/plant with increasing plant density (Hicks et al., 1969; Fontes and Ohlrogge, 1972; Enyi, 1973; Lueschen and Hicks, 1977; Stivers and Swearington, 1980; Herbert and Litchfield, 1982).

Johnston et al. (1969) found that plants with supplemental light had more pods/plant. Wahua and Miller (1978) found that increased shade decreased the number of pods/-plant. Lodging reduced the number of pods/plant especially if it occurred at the beginning seed stage (R5)(Woods and Swearington, 1977).

There is evidence that row spacing affects the number of pods/plant. Herbert and Litchfield (1982) using 25, 50 and 75cm row spacing found the number of pods/plant decreased with increasing row spacing. Taylor et al. (1982) found pod set was greatest in 100cm rows but final pod number was greatest in 25cm rows. They attribute the difference to late season abortion of pods in the 100cm rows which resulted from a smaller late season LAI as compared to the 25cm rows.

The yield component seeds/pod is much more stable than pods/plant. Herbert and Litchfield (1982) and Taylor et al. (1982) both found no effect on the number of seeds/pod from narrowing row width. Lehman and Lambert (1960) reported that row width and plant population had little effect on seeds/pod. However, Pandey and Torrie (1973) reported that row width and plant population had influenced the number of seeds/pod in four out of nine data sets with which they were working. Stivers and Swearington (1980) found that with three populations (136, 107 and 79 thousand plants/ha) the yield was constant due to compensation of yield components which included the number of seeds/pod on branches.

Johnston et al. (1969) observed that by increasing the amount of light available the plants responded by producing a greater number of seeds/pod. Kokubun and Watanabe (1982) using an experimental procedure which increased light interception throughout the canopy by artificially holding the upper leaves in a vertical position observed a yield increase which depended on a greater number of pods per unit area and seeds/pod. Wahua and Miller (1978) however, did not observe any change in seeds/pod with increasing degrees of shade.

Seed size is the yield component affected the least by changes in row width and plant density. However, slight changes in average seed size have been observed and in some instances these slight changes may account for significant differences in yield. Herbert and Litchfield (1982) found significant differences in seed size as a response to row width and plant density treatments in one year but not in the other of their experiment. Also, it was the difference in seed size which accounted for the difference in yield between the two years. Taylor et al. (1982) found no effect of row spacing on seed size.

There are many reports of plant density not affecting seed size (Probst, 1945; Wilcox, 1974; Dominguez and Hume, 1978; Kokubun and Watanabe, 1982). There are also reports of seed size increasing with increasing plant density (Costa et al. , 1980; Stivers and Swearington, 1980), as well as reports of seed size decreasing with increasing plant density (Hinson and Hansen, 1961; Johnson and Harris 1967; Enyi, 1973).

Johnson and Harris (1967) found the decrease in seed size with increasing plant density was only true in one of the four cultivars they used. All the reports citing a decrease in seed size with increasing plant density were using the determinate cultivars and were either from the southern U.S. or the tropics. Egli et al. (1978)

observed a slight difference in seed size on late pods of indeterminate plants. The reports of increasing plant density causing larger seed size seem to be from the more northerly latitudes in which indeterminate cultivars predominate. However, the growing conditions from one year to the next may play a large part in the seed size component of seed yield.

CHAPTER III

FLOWERING

Introduction

Many researchers have observed the loss of substantial numbers of soybean flowers and pods throughout the growing season (van Schaik and Probst, 1957b; Hardman, 1970; Breveden et al. 1977).

Various environmental factors such as inadequate nitrogen (Breveden et al., 1977), water stess (Ashley and Ethrdge, 1978), temperature extremes (van Schaik and Probst, 1957b; Thomas and Raper, 1981), low light levels (Wahua and Miller, 1978) and increased plant density (Dominguez and Hume, 1977) have been cited as adversely affecting flower and pod set. Other factors have been shown to increase soybean pod set: CO_2 enrichment (Hardman, 1970; Hardman and Brun, 1971), light enrichment (Johnson et al. 1969; Schou et al., 1978) and the number of trifoliate leaves and short days (Shanmugasundaram and Tsou, 1977).

van Schaik and Probst (1957a) considered flower numbers per node and percent flower shedding as quantitatively inherited traits. The position that genotypic differences for abscission exist among cultivars was supported by Wiebold et al. (1981). However, using three maturity 00 cultivars, McBlain and Hume (1981) did not find any cultivar differences in flowers produced or abortion of reproductive structures.

In three experiments with indeterminate soybean cultivars, flower, pod and seed production were greatest in the middle portion of the plant (Dominguez and Hume, 1977; Hansen and Shibles, 1978; Breveden et al., 1977). Wiebold et al. (1981) concluded that abscission was greatest in those sections of the canopy where light penetration was lowest.

The object of this study was to observe the effects of different row widths and plant densities on flower and pod production of two short season soybeans of indeterminate growth type.

Materials and Methods

Two soybean cultivars, Evans, of maturity group 0, and Altona, of maturity group 00, were planted on May 28, 1981. Each cultivar was planted in two row widths and at two plant densities. The row spacings were 25 and 75cm between rows. The plant densities were 25 and 75 plants per square meter (250,000 and 750,000 plants per hectare). The three treatments of cultivar, row width and plant density were arranged factorially in a randomized complete block experiment. Three of the four replications were used for monitoring flowers.

The experiment was located at the University of Massachusetts Agricultural Experiment Station farm in South Deerfield, Massachusetts. The soil was a Hadley fine sandy loam, mixed mesic, Typic Udifluvent.

The site received 0-44-83 kg/ha of elemental N-P-K in the spring after plowing and before secondary tillage.

Seeds with 90 percent germination were inoculated with a commercial granular inoculant and machine planted. Weeds were controlled by a preemergence application of 1.7 kg/ha a.i. alachlor ((2-chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide)) and 0.85 kg/ha a.i. linuron (3-(3,4-dichlorophenyl)-1-methoxylurea).

The first flower was noticed on 'Altona' 35 days after planting. Full sampling began on July 7, fourty days after planting.

Five plants, contiguos within a row, were used from each plot. The initial plant was selected randomly and the plants were identified so that the same plants were counted at each sample date. Plots were 7.6m long and 4m wide.

Sample dates were initially twice weekly and gradually lengthened to once a week as flowering activity slowed down. Identification of flowers and pods for counting purposes followed the procedure of Dominguez and Hume (1977) were "a floral bud was considered a flower when colored petals were visible and a pod when the swelling of the ovary extended beyond the calyx". Plants were harvested and final pod number determined along with the larger yield component experiment reported in Chapter V.

Results and Discussion

The Evans cultivar began flowering a few days after 'Altona' but rapidly caught up and surpassed the flowering capability of 'Altona' (Figures 1 and 2). Comparing the cultivar responses to plant density, 'Evans' equalled or surpassed 'Altona', having the most flowers on a plant at any one time (Fig. 1). However, the time of peak flower production of 'Evans' was earlier than 'Altona' (Fig. 1). These observations are partially accounted for by their differences in maturity group, 'Altona' being maturity group OO and 'Evans' being group O. But at final harvest

Figure 1. Plant Density Affect on Flower and Pod Formation

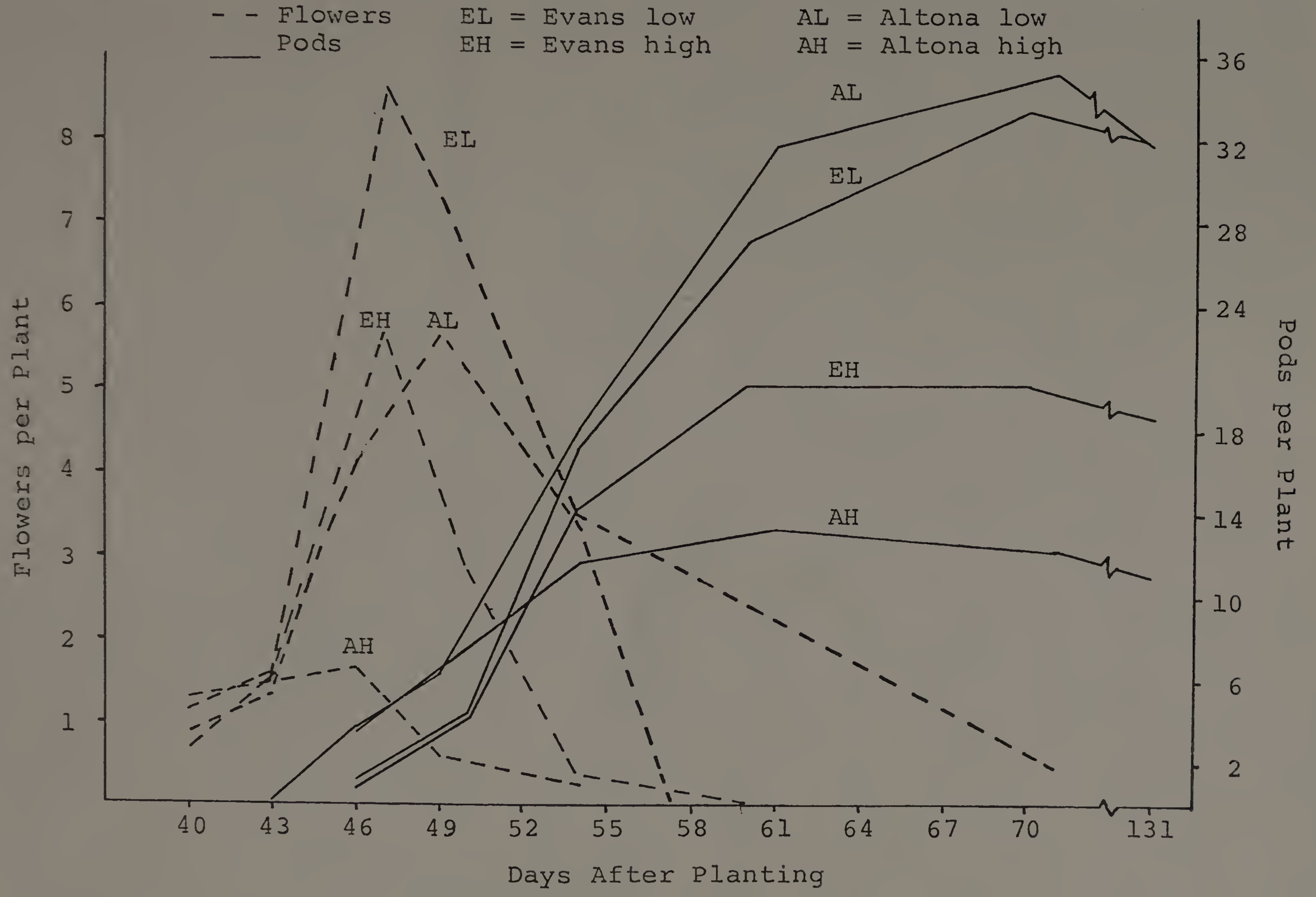
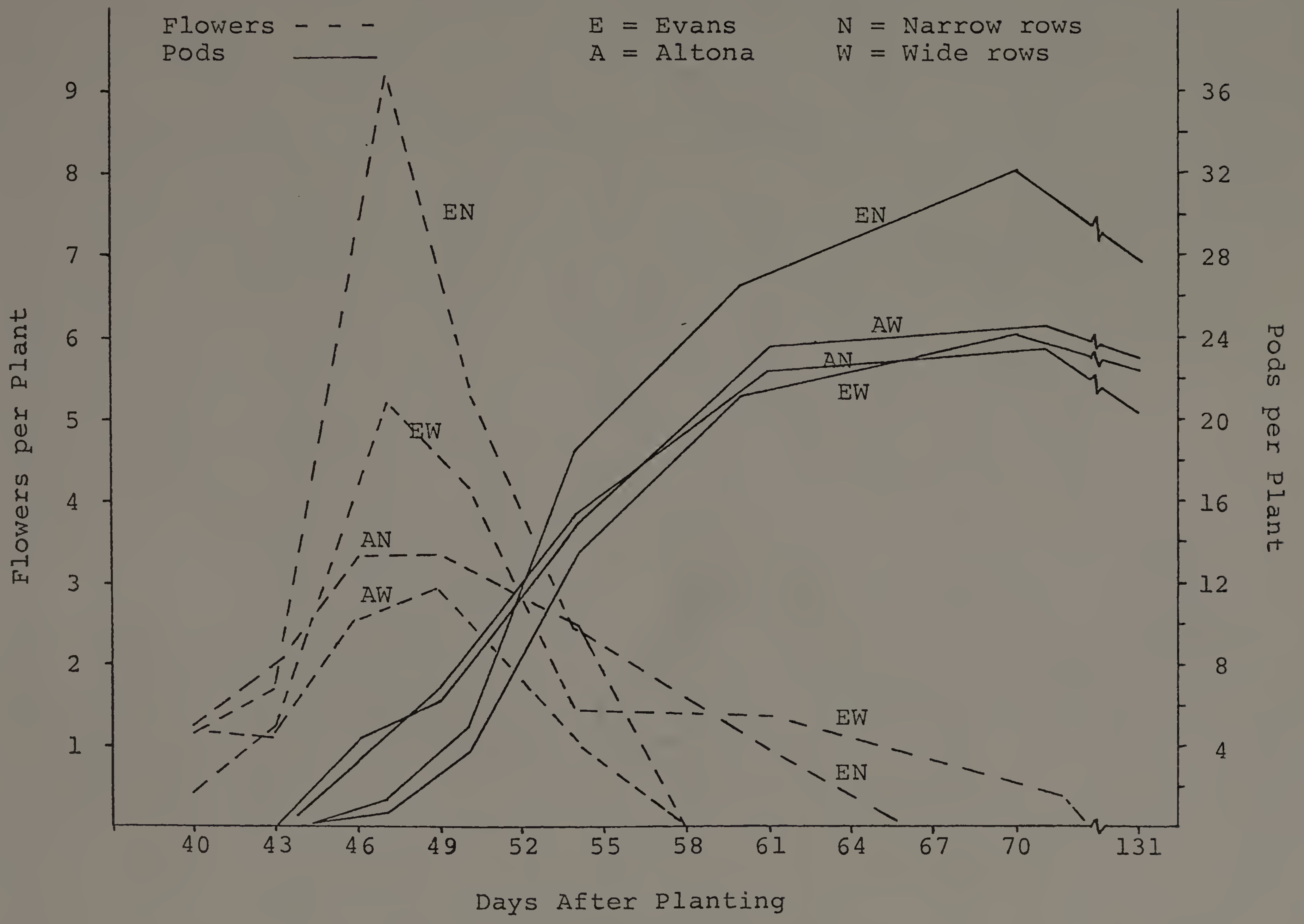


Figure 2. Row Width Affect on Flower and Pod Formation



seed yield was not affected (Table 3, Chapter V).

The flowering response was greater in narrow than wide row environments (Fig. 2). The magnitude of the increased flowering response in narrow rows was greater in the Evans cultivar but was also observed in 'Altona'. In 'Evans' the wide row plants maintained flower production later into the season than the narrow row plants. Most of this prolonged flowering was at the upper nodes of the main stem and branches which did not contribute much to overall plant yield. There was not sufficient time for all the upper nodes to mature pods and seeds before leaf senescence and cold weather. Flowering later into the season did not compensate for the early advantage in flower production of the narrow row plants which quickly became a difference in pods per plant (Fig. 2) and was maintained until harvest.

The final pods per plant sample taken at harvest on those plants which had been followed throughout the season showed a cultivar by row width interaction (Fig. 2). There was a clear advantage in pod production in the narrow rows of 'Evans' compared with the wide rows. In 'Altona' the wide rows produced more pods per plant than the narrow rows (Fig. 2). However, the difference in pod production in 'Altona' as affected by row width was not great. When a larger sample ($2m^2$) at final harvest was analysed the narrow row 'Altona' plants had a greater number of pods than wide row plants and the cultivar by row width interaction was not statistically significant (P=0.63649) (Table 3, Chapter V).

There is a strong similarity between the different cultivar's flowering response to row width treatments and leaf area index (LAI) (Fig. 8, Chapter IV). Perhaps maximum LAI is reached when maximum flower production is reached. Flower production is dependent on LAI for photosynthate especially when the plant is having maximum ontological competition from flower development and new vegetative growth above and pod set and development on the lower and lower-middle nodes. This suggests that a production potential exists for each cultivar under a given set of environmental conditions and that the plant has a certain flexibility to attain this potential via branches or individual nodes as the environment dictates. Gent (1982) found in a depodding study of Y-shaped plants that long distance transport of carbohydrates readily occurred.

Figures 3 and 4 both show the number of flowers on the top, middle, and bottom sections of the plant. In all cases flowering progressed from the bottom to the top

Figure 3. Number of Flowers on Bottom, Middle and Top of Plant as Affected by Row Width (averaged for density)

Wide rows ———
Narrow rows - - -

B = bottom, nodes 1 - 5
M = middle, nodes 6 - 10
T = top, nodes 11+

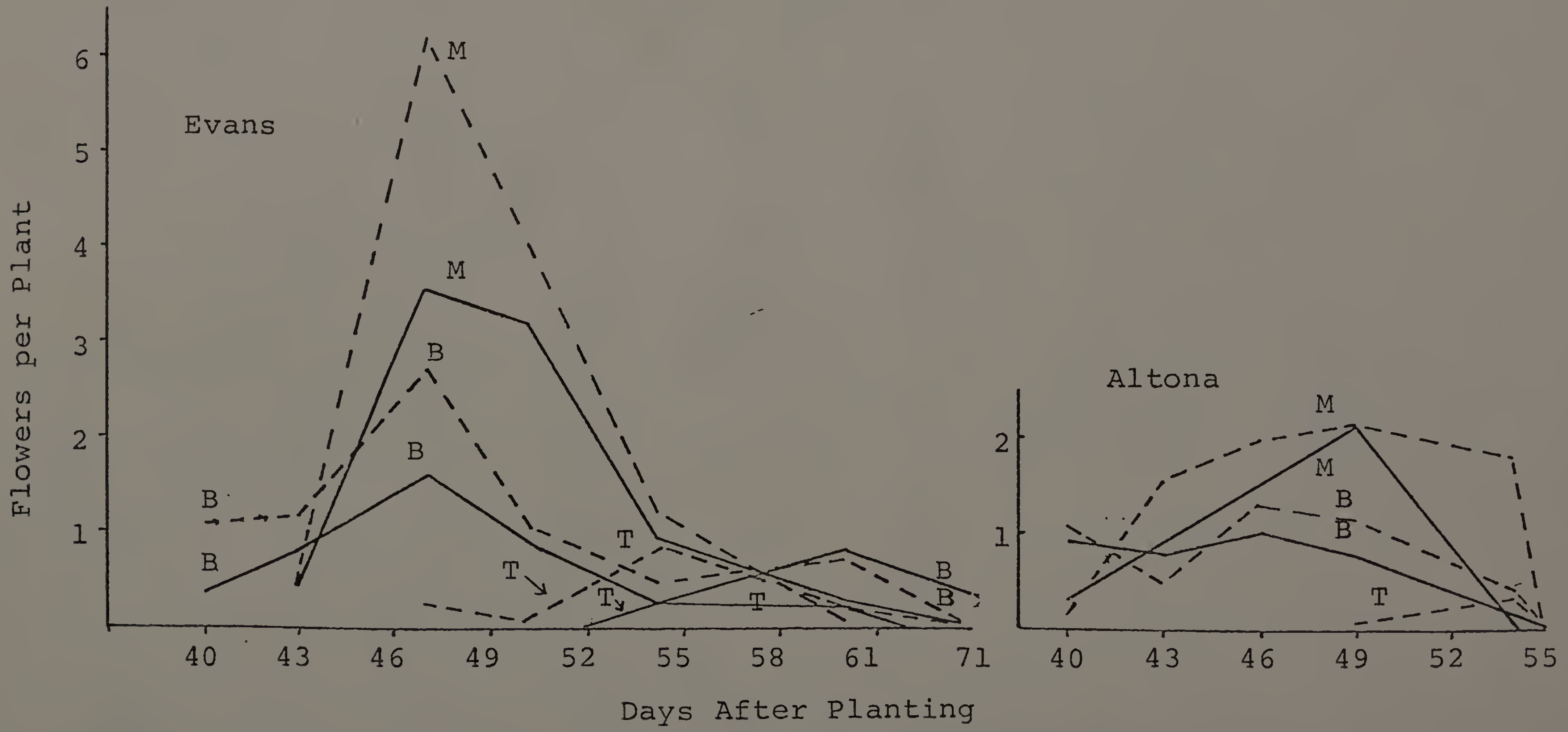


Figure 4. Number of Flowers on Bottom, Middle and Top of Plant as Affected by Plant Density (averaged for row width)

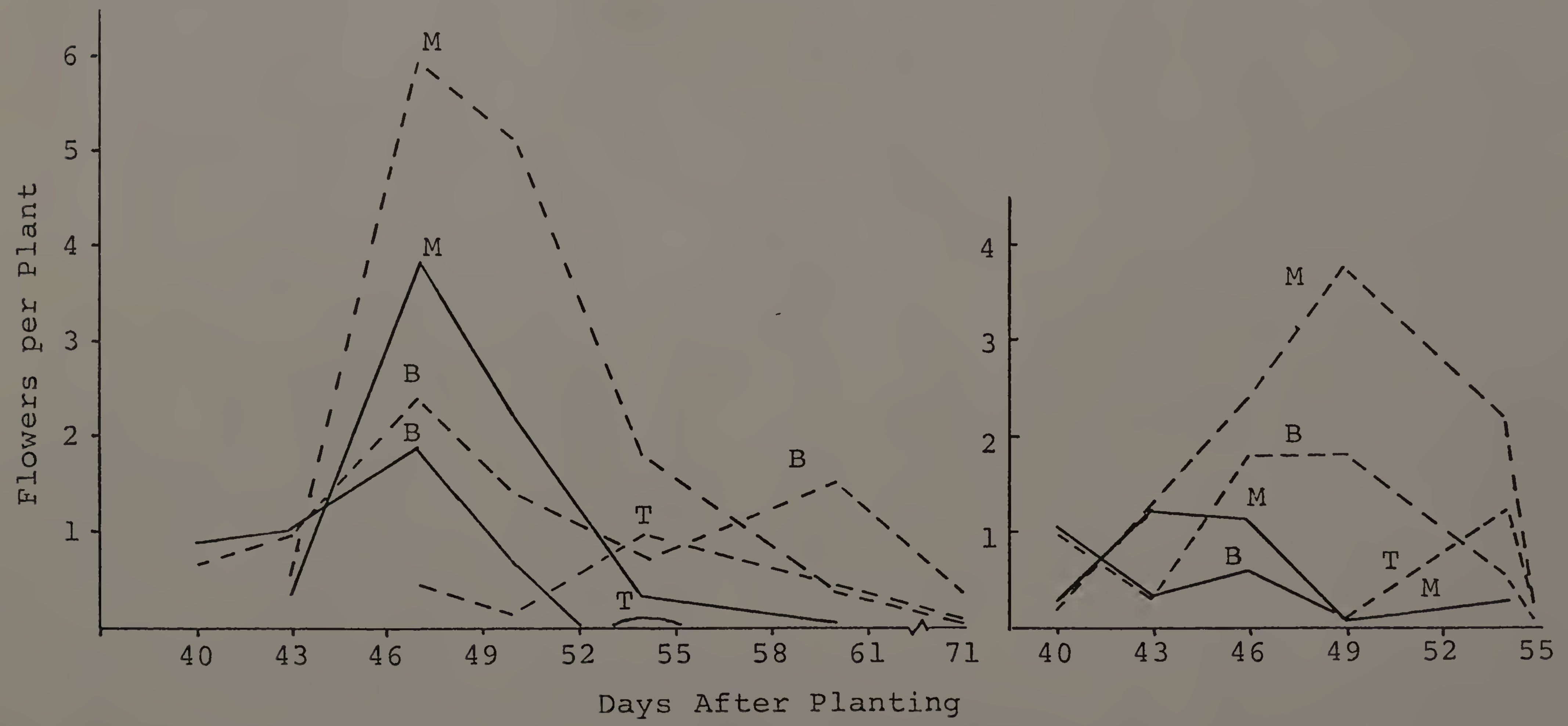
Wide rows ———

Narrow rows - - -

B = bottom, nodes 1 - 5

M = middle, nodes 6 - 10

T = top, nodes 11+



of the plant which is characteristic of indeterminate cultivars. 'Altona' plants flowered on the middle nodes before 'Evans' plants, and narrow row plants flowered on the top nodes before wide row plants.

Narrow row plants had a greater number of flowers in all sections of the plant than the respective wide row plants in the Evans cultivar (Fig. 3). 'Altona' also had a greater number of flowers in narrow rows but the difference was not as great as in 'Evans' (Fig. 3).

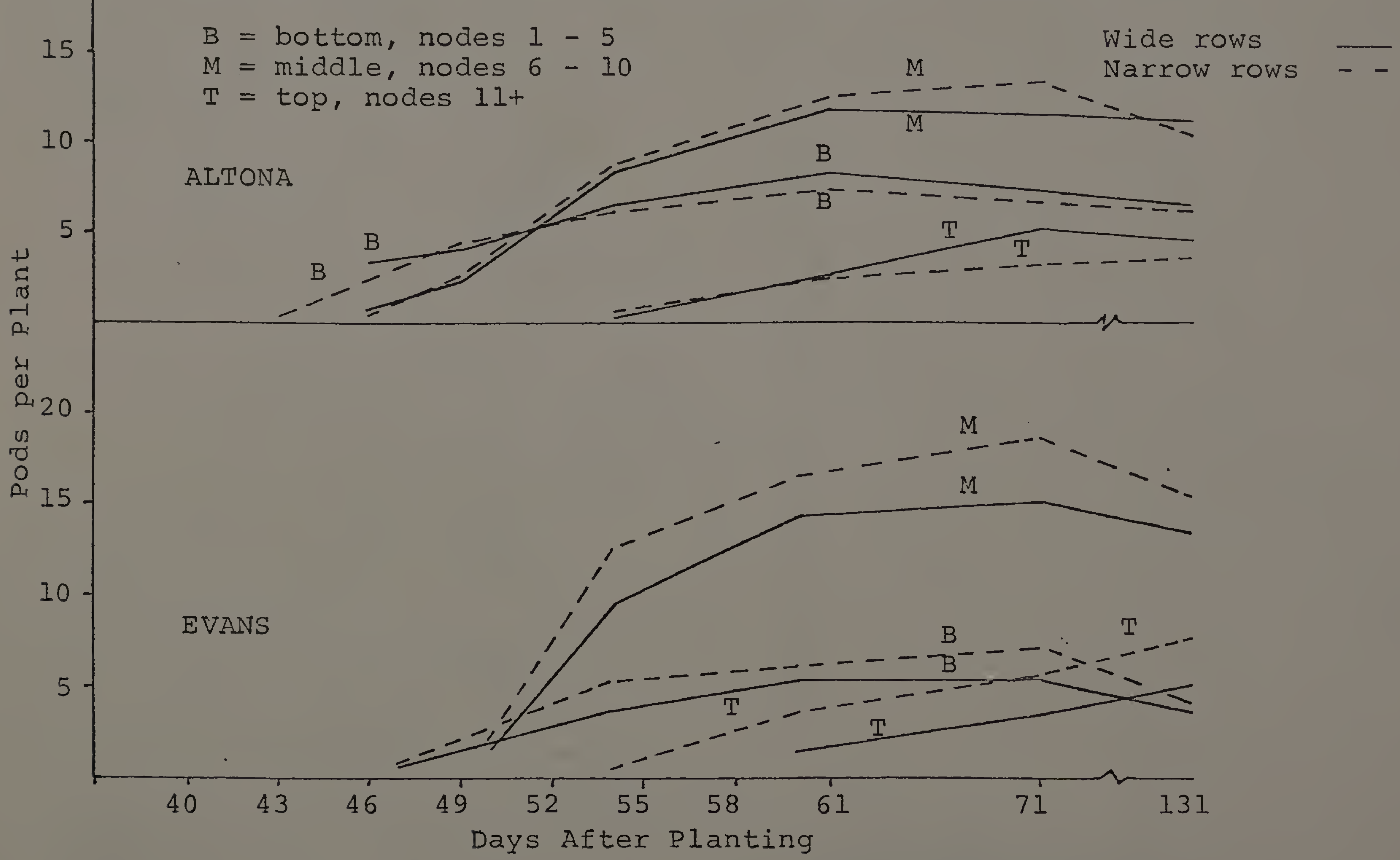
The low density plants of both cultivars had greater peak flower production and sustained that production for a longer time than their high density counterparts (Fig. 1). Dominguez and Hume (1977) also observed a decrease in flowers and pods per plant at high densities. Yield per unit area was not affected by density (Table 3, Chapter V).

Flower production of the bottom (nodes 1 through 5) section of the plant began earlier than the middle or top sections in 'Evans' regardless of density (Fig. 4). In 'Evans' the middle section (nodes 6 through 10) began flowering a few days later (Fig. 4) and was followed by the top (nodes 11+) section of the plant. The middle section had the greatest percentage of flowers for most of the reproductive season (Figures 3 and 4). In experiments using soybeans with indeterminate growth habit both Dominguez and Hume (1977) and Hansen and Shibles (1976) found the middle section of the plant to have the largest percentage of yield.

We observed a rejuvenation in flower production from the bottom section of 'Evans' plants at the later sample dates (Figures 3 and 4). In this study, branch production is defined as any flowers or pods occurring on branches and have attributed that production to the node from which the branch arose. Close inspection of Figures 3 and 4 in conjunction with our field observations confirm that the increase in bottom section flower production at the late sample date is attributable to the low density condition under which the branches were produced.

'Altona' high density plants never showed open flowers in the top section on any sampling dates (Fig. 4), although pods were observed on that section (Fig. 5). This is an anomoly of the sampling procedure which appears when flowers open and pods are produced between sample dates. Thus the flowering data should be looked at as if they were instantaneous readings taken at different points in time throughout the plant's reproductive phase. The pod production data are an integration in that they progress from one sample date to the next by including

Figure 5. Number of Pods on Bottom, Middle and Top of plant as Affected by Row Width (averaged for plant density)



what has come before.

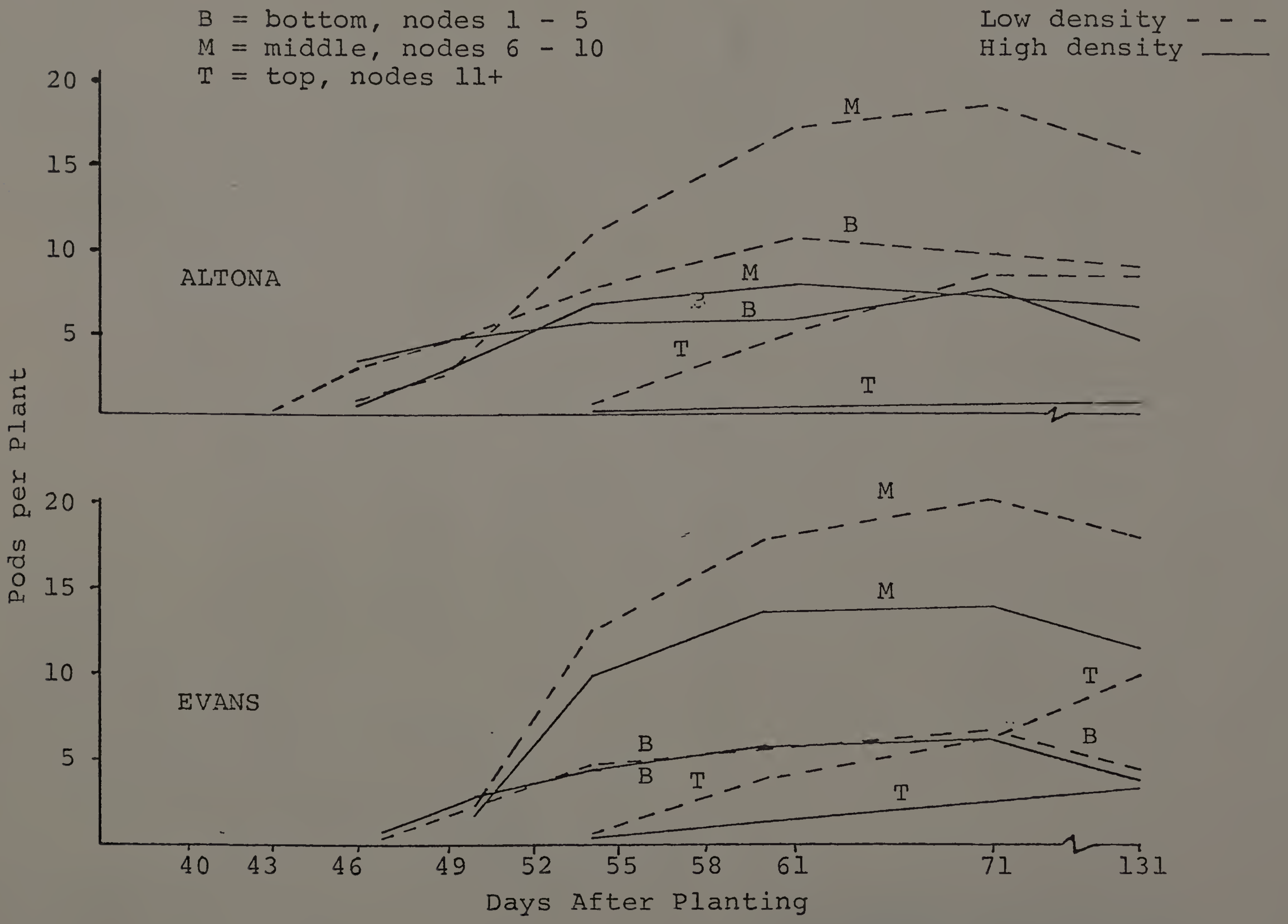
The row width effect on pods/plant did not vary from one section of the plant to another. The middle section produced the most pods followed by the bottom section and lastly the top section (Fig. 5). However, with the Evans cultivar the top section surpassed the bottom section during the last part of the growing season (Fig. 5).

Pod production of the two cultivars did not differ greatly in the low density conditions; however, the 'Altona' was less productive than 'Evans' under the high density conditions in this study. Under high density conditions fewer branches were observed and therefore the cultivar with the greatest number of productive nodes would result in a greater number of pods and yield (Table 1).

In both cultivars the middle and top sections of the plant produced more pods in the low density conditions (Fig. 6). The top section increased ('Evans') or maintained ('Altona') its number of pods throughout the season while the bottom and middle sections lost pods between the 71st and 131st (harvest) day after planting (Fig. 6).

There was a larger percentage of pods on the bottom section of 'Altona' compared to the bottom section of

Figure 6. Number of Pods on Bottom, Middle and Top of Plant as Affected by Plant Density (averaged for row width)



'Evans' (Fig. 5). This is attributable to the greater number of nodes in 'Evans' (Table 1) which allowed the yield to be divided among a greater number of nodes and reduced the percentage at the bottom. In both cultivars by far the greatest number of pods is from the middle section of the plant (Figures 5 and 6). As previously mentioned, both Dominguez and Hume (1977) and Hansen and Shibles (1976) found the middle section of the plant to have the highest percentage of yield. Because of the greater number of top section nodes and branch activity, the low density plants continue pod production throughout the season (Fig. 6).

In summary, the low density environment stimulates greater flower production per plant. The greater flower production is converted into greater pod production. Branches are promoted by the low density environment and they produce flowers longer into the season than the main axis sections from which they arise. The row width effect seems to be cultivar specific to some degree and was more pronounced in 'Evans' than in 'Altona' plants. The narrow row environment caused a greater number of productive nodes to be formed in plants from the Evans cultivar than the wide row environment.

Table 1

Total nodes, productive nodes and number of branches per plant

	Total nodes	Productive nodes	Number of branches
Altona			
Low Density	13.4	12.8	2.2
High	9.2	7.3	0.5
Evans			
Low	14.3	13.2	3.7
High	10.7	8.0	0.8
Altona			
Narrow rows	11.5	10.5	1.6
Wide	11.1	9.6	1.1
Evans			
Narrow	13.2	11.7	2.3
Wide	11.7	9.6	2.1

Total nodes: density*

Productive nodes: density** row width*

Number of branches: density**

---

* and ** indicate significance at 5% and 1% levels, respectively.

CHAPTER IV

GROWTH ANALYSIS

Introduction

The field of growth analysis has been developed over the past sixty years by plant physiologists, agronomists and other plant scientists in an attempt to quantify the basic growth processes of plants.

Plants compete for a variety of resources and there are complex interactions between plants and their environment. Inevitably one resource is most limiting. Solar radiation is a key resource for photosynthesis. To produce an economic seed crop the plants must have a means of production - the leaf - and must be able to move the products of the leaves into the seeds. The plants are dependent on leaves to intercept solar radiation in order to photosynthesize and supply energy for growth.

Sakamoto and Shaw (1967) found light interception occurred primarily at the periphery of the canopy which resulted in the lower leaves being shaded. Also, as the space between rows closed, interception was primarily at the top of the canopy (Sakamoto and Shaw, 1967; Luxmoore et al., 1971). Although not parasitic, because of shading, lower leaves reportedly contribute little to photosynthesis (Shibles and Weber, 1965; Johnston et al., 1969). Closely spaced plants are more competitive for light and lower apparent photosynthesis rates have been found in lower leaves (Beuerlein and Pendleton, 1971). Adding light to the bottom and middle of the canopy increased yields (Johnston et al., 1969).

The higher the position of the leaves on the plant, the higher the rate of photosynthesis and the higher the light saturation intensity (Kumura, 1969). Also, higher rates of photosynthesis have been correlated with thicker leaves (Dornhoff and Shibles, 1970).

Cultivar differences in CO_2 uptake rates have been reported (Dornhoff and Shibles, 1970), as well as differences in stomatal frequency (Ciha and Brun, 1975). Ciha and Brun (1975) also indicated that stomatal frequency increased with high light intensity and with water stress. Dornhoff and Shibles (1970) considered cultivar differences in net photosynthesis to be the result of differences in diffusive resistances.

While leaf area index (LAI) is a measure of the potential photosynthetic area, large LAI has not necessarily been correlated with high yield (Shibles and Weber, 1966; Taylor, 1980; Taylor et al., 1982).

Sakamoto and Shaw (1967) suggested an increase in yield could possibly be obtained by selecting cultivars which allowed greater penetration of radiant energy into the canopy. However, in a study comparing plants with normal and narrow leaflets, leaflet type did not significantly affect net carbon exchange or yield (Hiebsch et al., 1976). On the other hand, Kokuban and Watanabe (1981) showed that if upper leaves were arranged more vertically the lower leaves could contribute to an increase in photosynthesis and yield due to a greater crop growth rate. The greater crop growth rate resulted from an increase in net assimilation rate (i.e. greater photosynthetic efficiency) while the LAI stayed the same.

The object of this experiment was to apply growth analysis descriptions to the 'Evans' and 'Altona' soybeans at narrow and wide row spacing and three populations in order to gain some insight into the physiological mechanisms involved in crop responses to field conditions.

Materials and Methods

Two cultivars of soybeans, Altona and Evans, were planted on May 28, 1981. In addition to the two cultivars, treatments consisted of two row widths (25 and 75cm), and three plant densities (25, 50 and 75 plants/m^2).

The soil was a Hadley fine sandy loam. The site received 0-44-83 kg/ha elemental N-P-K in the spring after plowing and before secondary tillage. Weeds were controlled by a pre-emergence application of alachlor and linuron (see Materials and Methods, Chapter III for description of chemicals and rates).

Seed with 90 percent germination were machine planted and were inoculated with a commercial soil incorporated granular inoculant. There were four replicates in a randomized complete block design. Plots were 7.6m long and 4m wide. The plots consisted of 16 rows for the 25cm row width and 6 rows for the 75cm row width.

Sampling for growth analysis cmmenced on June 30th and continued at two week intervals throughout the season. Samples of 0.25m^2 were taken from the center rows of each plot. Plants were cut at ground level and leaf area, leaf dry weight and total dry weight were determined.

The values for leaf area, leaf dry weight and total dry weight were transformed into natural logarithms, thus making the variances independent of the means. Second degree polynomials,

$$\log_e W = a + bt + ct^2$$

and

$$\log_e A = a' + b't + c't^2$$

were fitted by the least squares method to express the weight (W) and area (A) as functions of time. Relative growth rate (RGR) at any instant in time was derived directly by differentiation:

$$RGR = d(\log_e W)/dt = b + 2ct \qquad \text{(Buttery, 1969b)}$$

and

$$NAR = (b + 2ct)e^{(a-a') + (b-b')t + (c-c')t^2}$$

and

$$CGR = NAR \times LAI \qquad \text{(Watson, 1958)}$$

Final seed yield was determined after maturity by harvesting plants in a $2m^2$ area from the center two rows of each plot.

Results and Discussion

Seed yield was greater in narrow rows (25cm) than wide rows (75cm), 400 g/m^2 versus 324 g/m^2, respectively.

This relationship held true in both cultivars: 'Altona', 399 g/m^2 versus 301 g/m^2, and 'Evans', 400 g/m^2 versus 346 g/m^2 for the 25 and 75cm row widths respectively. All yields are averaged over density because no significant density response and no significant interactions of density with other variables were found.

The total dry weight per meter square was higher in the narrow than the wide rows (Fig. 7). Dougherty (1969) also found greater dry matter production in narrow rows. Differences in the narrow and wide rows' total dry weight began to occur near the beginning pod stage (R3) (day 48), however, there was no clear advantage to either row width. By the beginning seed stage (R5) (day 62) the greater total dry weight in narrow rows had become visible and it remained so for the rest of the season.

Leaf area index (LAI) was greater in narrow rows than wide rows (Fig. 8). Differences between row width treatments began to become apparent by beginning pod stage (R3)(day 48). The most pronounced advantage of LAI in narrow rows was at the beginning seed stage (R5)(days 62 and 76). Narrow rows maintained a higher leaf area later into the season than wide rows. 'Evans' had a greater maximum leaf area and maintained it longer than 'Altona'.

Figure 7. Total Dry Weight per Meter Square

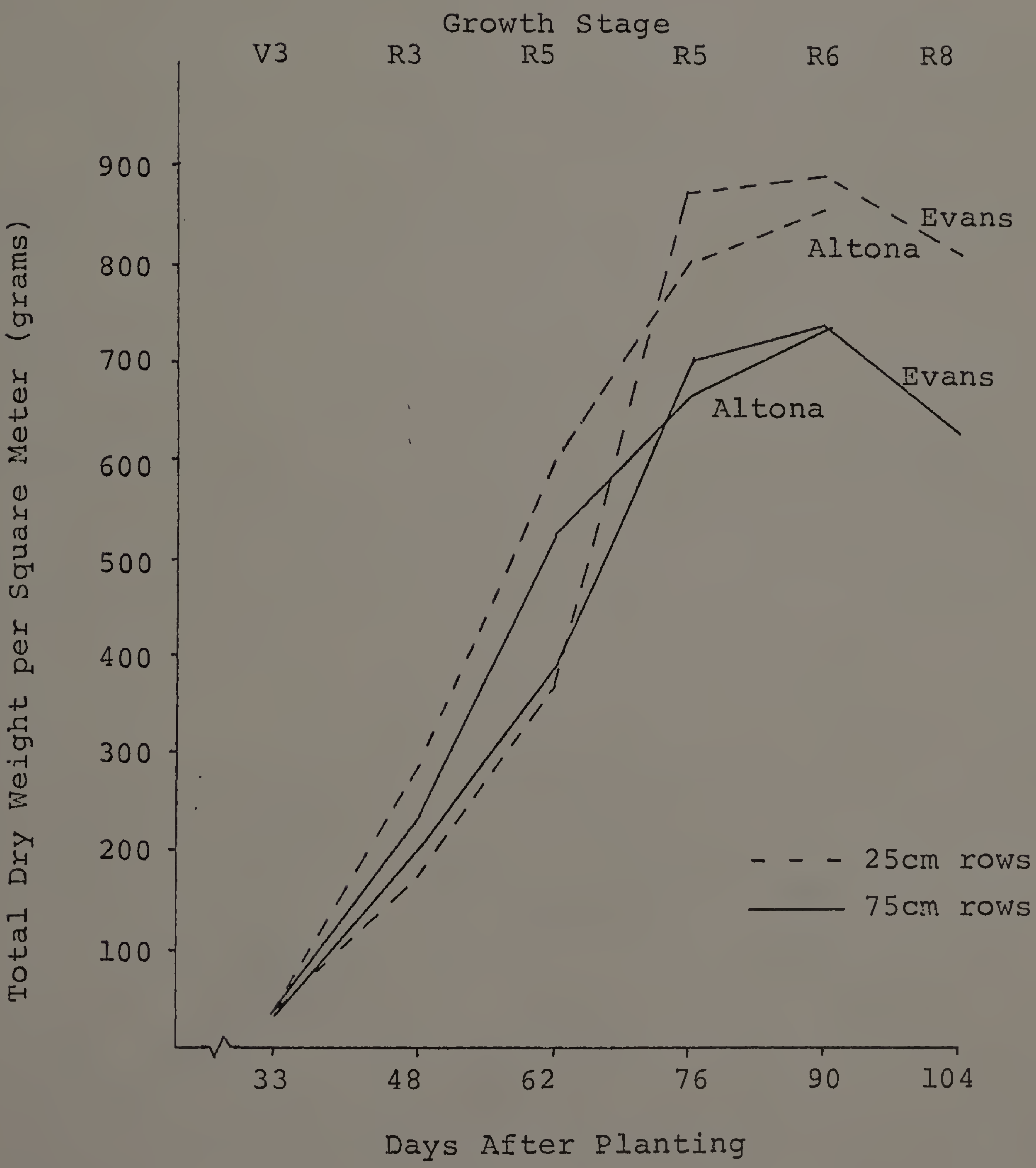
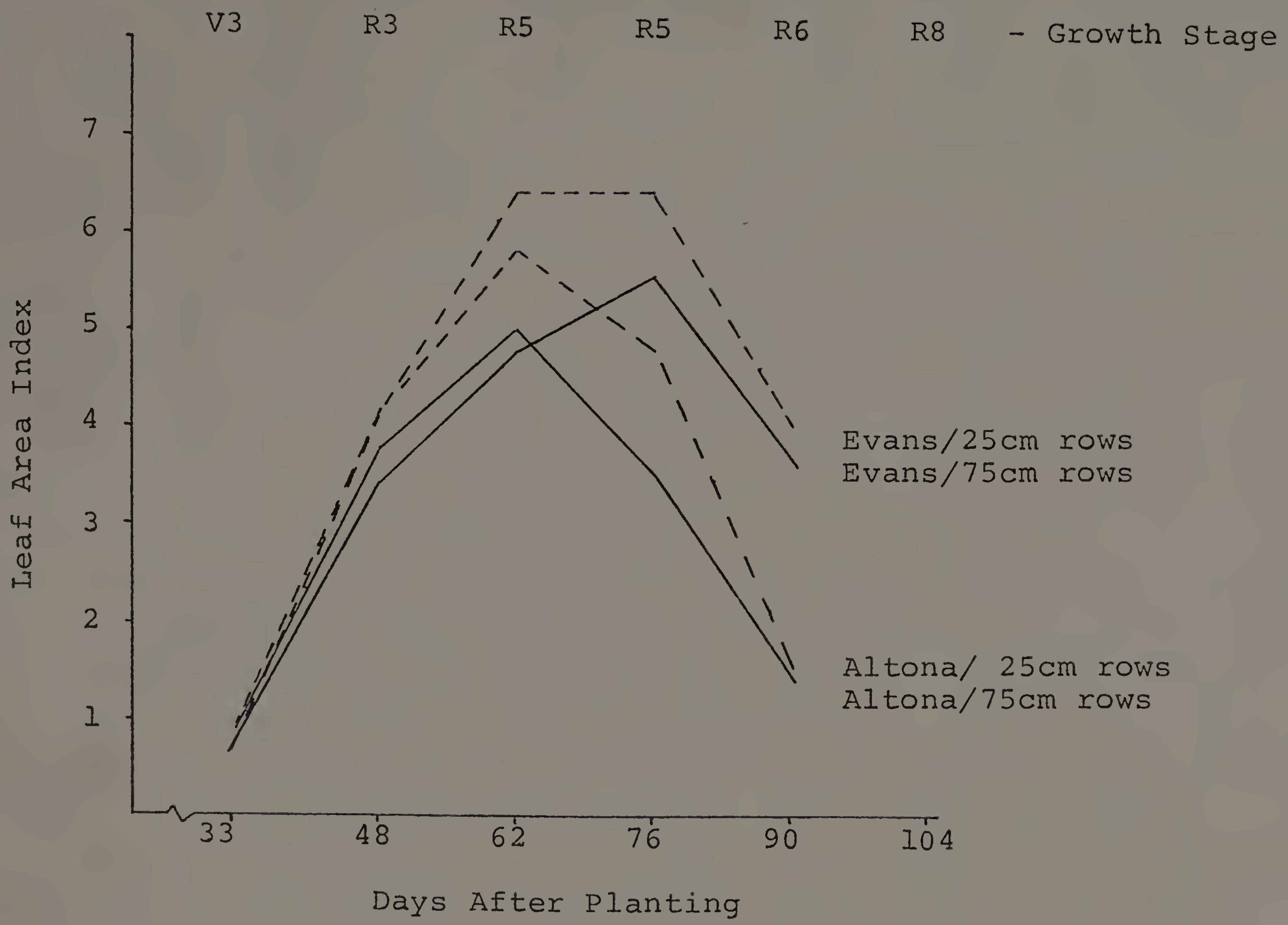


Figure 8. Leaf Area Index



Taylor et al. (1982) reported that radiation interception was greater at 25cm row spacing during most of the season. However, they felt it was the difference in radiation interception during late seed development which gave the yield advantage to the narrow rows.

The relative growth rate (RGR) is a growth parameter which indicates the rate of increase in plant material for each unit of plant material present at any point in time of the growing season. The relative growth rate has been reported to vary with plant density (Buttery, 1970), but no significant differences were observed in this experiment. Therefore, the data in Table 2 are for the medium density (50 plants/m^2) which was representative of all the densities used.

The narrow rows had a greater RGR earlier in the season than the wide rows (Table 2). This indicates that early in the growing season the narrow rows were adding biomass faster than the wide rows. The small differences in daily increments of additional biomass due to higher RGR in narrow rows later became larger differences in total dry weight (Fig. 7). The RGR's at day 70 were the same for narrow and wide rows (Table 2). After day 70 the rate of increase of biomass in wide rows was greater than narrow rows but relative increases were small during

Table 2. Growth Analysis Components[1].

Cultivar	Days After Planting	Row Width	Crop Growth Rate	Relative Growth Rate	Net Assimilation Rate
		cm	g/m^2/day	g/g/day	g/cm^2/day
Evans	50	25	18.4	0.076	0.00047
		75	12.5	0.066	0.00041
	70	25	22.1	0.032	0.00033
		75	17.3	0.033	0.00034
Altona	50	25	26.8	0.091	0.00073
		75	22.9	0.086	0.00062
	70	25	31.2	0.030	0.00066
		75	25.8	0.031	0.00054

[1] Values given are for medium density (50 plants/m^2).

this period.

Crop growth rate (CGR) is a growth parameter which indicates the rate of increase in plant material for each square meter of ground surface area at any point in time during the growing season. The general relationship of CGR to time is one in which early in the season CGR increases moderately, then increases rapidly, peaking somewhere in the middle of the season and followed by a rapid decline (Buttery, 1969; Koller et al., 1970).

The CGR was higher in the narrow rows than the wide rows at all times of the growing season (Table 2). As the plant grows early in the season there is relatively little competition from the surrounding plants and therefore the rate of growth increases unimpeded. As the plants get larger there are more areas of the plant actively dividing to produce new growth thus causing the CGR to increase rapidly. Later, resources, mainly light, become scarce and both inter- and intraplant competition check the CGR. The intraplant competition is often characterized by competition between the shaded understory leaves and the more exposed upper and peripheral leaves as well as the competition between the vegetative and reproductive parts for the products of photosynthesis.

Because of higher within row populations interplant competition begins earlier for plants in the wide row plots. This is reflected in both the lower CGR and the lower early season RGR. The between row space remains available until late in the season for light interception by the canopy periphery. Plants in wide rows had fewer flowers (Chapter III) and fewer pods (Chapter V) and ultimately lower yield than the narrow row plants. The narrow row plants where able to intercept more light around the periphery earlier in the season. But the earlier closure of the interrow spaces caused a competitive situation and reduced the RGR in the late season.

The CGR and the RGR are gross terms for trying to gain some insight into physiological processes. CGR is obtained from its two components: the net assimilation rate (NAR) and the leaf area index (LAI)(Watson, 1958). The NAR is also a component of RGR. The NAR is the rate of increase in plant material per unit of assimilatory material (i. e. the leaf) at any point of time in the growing season. The NAR can be interpreted as giving the relative efficiency of photosynthesis. The NAR behaved differently in the two cultivars. In 'Evans' the NAR is similar in the narrow and the wide rows throughout the growing season. Whereas, in 'Altona' the NAR is greater in the narrow rows than in the wide rows and the advantage is maintained throughout the season. In addition, the values for the NAR and CGR are consistantly higher for 'Altona' than for 'Evans' (Table 2). Buttery (1972) found cultivar differences in the NAR and found that selection for higher yield resulted in increased NAR. No significant cultivar difference in yield was detected (Chapter V). Although 'Evans' plants have a slightly longer growing period than 'Altona' the higher NAR and CGR of 'Altona' indicate that 'Altona' is more efficient during its growth period.

Although the crop growth rate of both cultivars is greater in narrow rows it appears they were achieved in a different manner. The greater narrow row CGR of 'Evans' was dependent exclusively on the higher leaf area index. On the other hand, the higher CGR of 'Altona' in the narrow row environment was due to a combination of higher leaf area index and higher net assimilation rate than the 'Altona' wide row plants. Perhaps in 'Altona' the canopy allows greater light penetration because of less branching and lower LAI (Fig. 1).

In summary, the narrow row environment produced larger leaf area, a greater increase in biomass per unit area (CGR), and throughout most of the season (until after day 70) a greater increase in biomass per unit of plant material present (RGR). The combination of these factors represent the capture of more radiant energy and the more efficient conversion of that energy into photosynthate in order to support a larger number of pods in the narrow row environment.

CHAPTER V

YIELD AND YIELD COMPONENTS

Introduction

Seed yield in soybeans is composed of the following yield components: plants/m^2, pods/plant, seeds/pod and seed size. Changes in row width or plant density can cause changes in the yield components.

In the northern United States narrowing row width has lead to higher yields in some years (Herbert and Litchfield, 1982; Taylor et al., 1982). Yield has also been altered by changes in plant density (Buttery, 1969; Duogherty, 1969; Cooper, 1977; Dominguez and Hume, 1978; Herbert and Litchfield, 1982).

A number of workers have reported the yield component pods/plant to be the most responsive to changes in row width and plant density (Lehman and Lambert, 1960; Pandey and Torrie, 1973; Dominguez and Hume, 1978; Herbert and Litchfield, 1982). There are numerous reports of pods/plant decreasing with increasing plant density (Hicks et al., 1969; Fontes and Ohlrogge, 1972; Enyi, 1973; Lueschen and Hicks, 1977; Stivers and Swearington, 1980; Herbert and Litchfield, 1982).

There is also evidence that row spacing affects the number of pods/plant (Herbert and Litchfield, 1982; Taylor et al., 1982). Herbert and Litchfield (1982) using 25, 50 and 75cm row spacings found the number of pods/plant decreased with increasing row spacing.

The other yield components are more stable and contribute much less to the explanation of variation in seed yield due to row width and plant density alterations. However, if metabolites are limiting at the time when one yield component is developing, a later developing component may compensate as metabolites become sufficient (Adams, 1967).

The object of this experiment was to observe the effects of different row widths and plant densities on the yield and yield components of two short season soybeans of indeterminate growth type.

Materials and Methods

The experiment was planted on May 28, 1981 at the University of Massachusetts Agricultural Experiment Station farm in South Deerfield, Massachusetts. Treatments consisted of two indeterminate soybean cultivars, Altona (maturity group 00) and Evans (maturity group 0), two row widths, 25 and 75cm between rows, and three plant densities, 25, 50 and 75 plants/m^2. The experimental design was a 2 x 2 x 3 factorial randomized complete block, replicated four times. Individual plots were 7.6m long and 4m wide.

The soil was a Hadley silt loam, course-loamy, mixed, mesic, Typic Udifluvent. Previous to planting the site received 0-44-83 kg/ha of elemental N-P-K and 4.5 t/ha of agricultural limestone. Alachlor and Linuron were applied as pre-emergence herbicides for control of weeds (see Materials and Methods section of Chapter III for details).

Both cultivars were hand harvested after reaching full maturity, growth stage R8 (Fehr and Caviness, 1977). An area 2m^2 was threshed and oven dried to determine yield. A subsample of ten plants from each plot was divided on a whole plant and node by node basis into yield components. 1, 2, 3, and 4-seeded pods were counted for each node. Analysis of variance was performed on the yield and yield components.

Results and Discussion

The seed yield relationships are summarized in Table 3. Narrow rows had a highly significant yield advantage over wide rows. 'Evans' tended to have a

Table 3. Seed Yield and Seed Yield Components

	Seed Yield (g/m^2)	Pods/ Plant	Seeds/ Pod	Seed Size
Cultivar				
Altona	350	23	2.17	173mg
Evans	373	27	2.20	149
Signif.#	ns	**	ns	**
S_x	5.7	10.5	0.08	56.9
Row Width				
Narrow	400	28	2.18	158
Wide	324	22	2.19	164
signif.	**	**	ns	ns
S_x	18.6	15.5	0.02	13.6
Plant Density				
Low	374	42	2.21	164
Medium	364	19	2.21	153
High	346	14	2.14	167
Trend	ns	Q	ns	Q
S_x	3.3	35.6	0.09	15.1

#. * significant at 5 percent level
** significant at 1 percent level
Q = quadratic trend
ns = non significant

higher yield than 'Altona' but this was not significant. Seed yield showed a slight decrease with increased plant density but both linear and quadratic trends were not significant. However, plant density affected the distribution of seed yield per plant and its distribution among nodes within the plant. No significant interactions were found.

Both cultivars responded to increasing density by maturing fewer pods per plant (Table 3). This is a well documented response of soybeans to increased density (Dominguez and Hume, 1977; Herbert and Litchfield, 1982; Hicks et al., 1969).

While figures 9 and 10 show the decrease in pods/-plant with increasing density they also show that the number of pods on the lower nodes, including pods contributed by branches, are considerably suppressed by increasing density. Similar suppression of branching and reduction of pods on lower nodes has been found by others (Dominguez and Hume, 1977; Stivers and Swearington, 1980; Herbert and Litchfield, 1982).

Less light penetration to lower levels of the plant canopy was documented by Sakamoto and Shaw, (1967). Wahua and Miller (1978) observed fewer pods/plant with increased shading. Both experiments confirm the impor-

Figure 9. Pods per plant - ALTONA

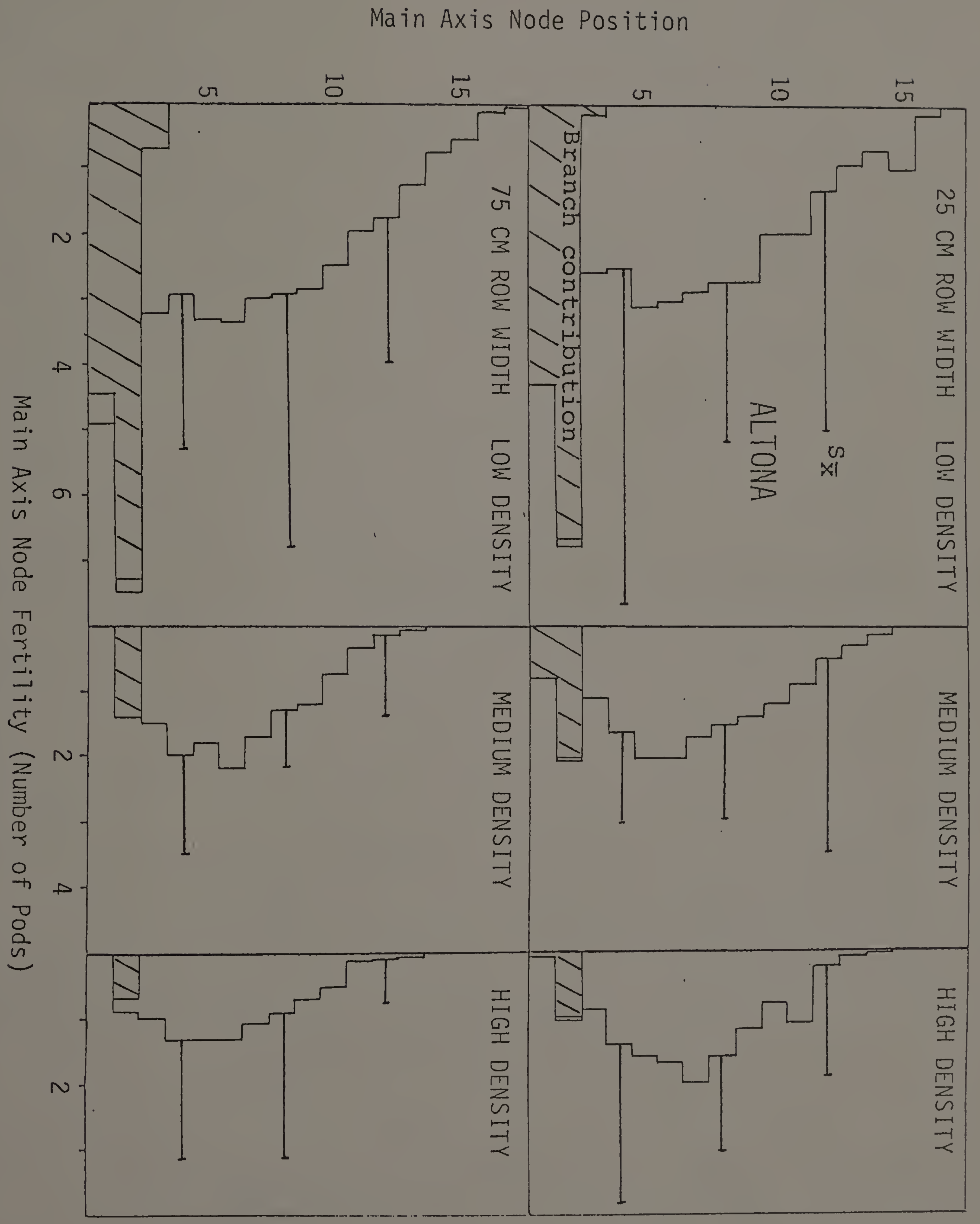
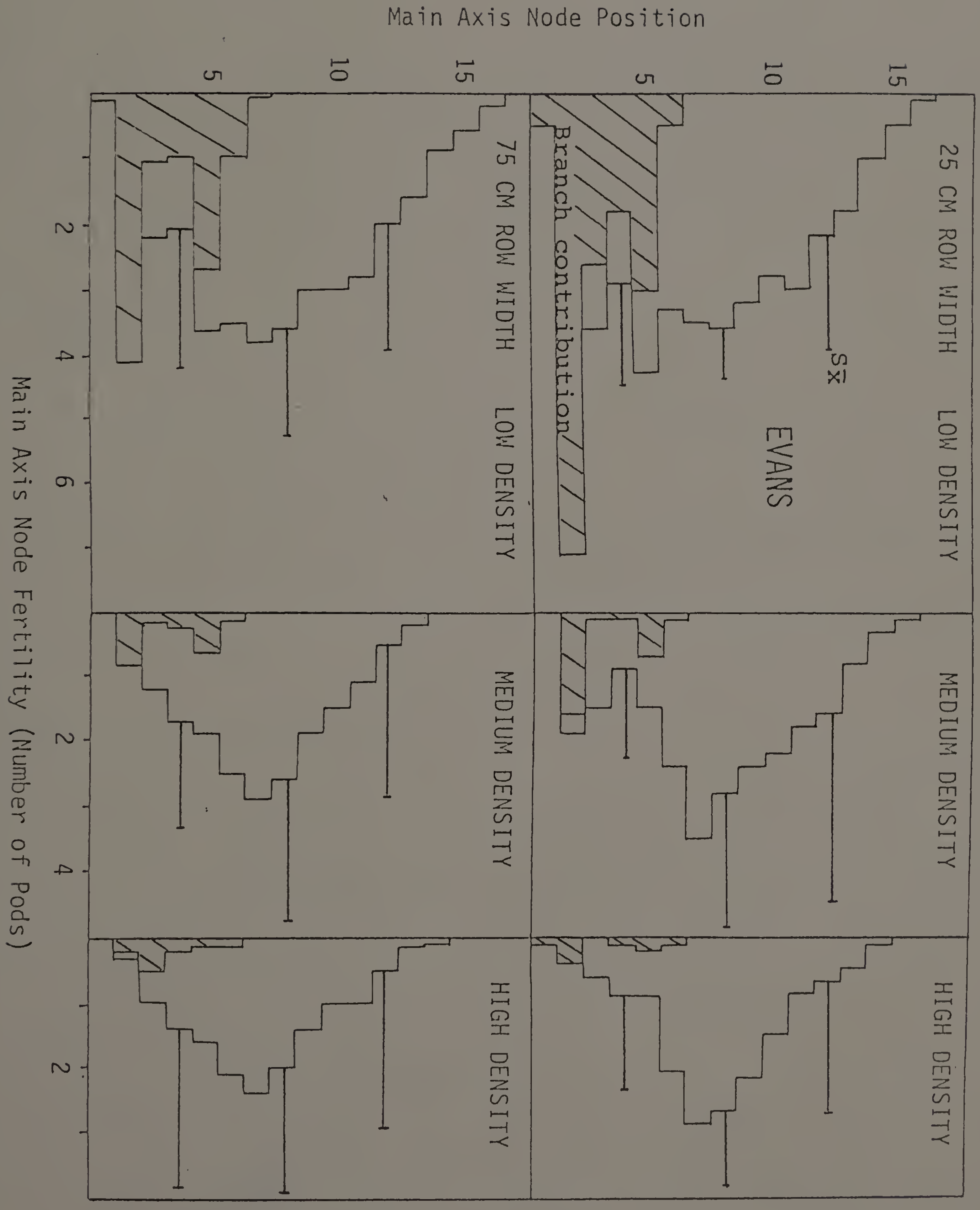


Figure 10. Pods per plant - EVANS



tance of light on the number of pods/plant. Johnston et al. (1969) found supplemental lighting affected the lower and central nodes more than the upper nodes. It is, therefore, possible that in a more competitive situation, resulting from increased plant density, less light would penetrate to the lower levels resulting in less photosynthate to support pods at the lower nodes.

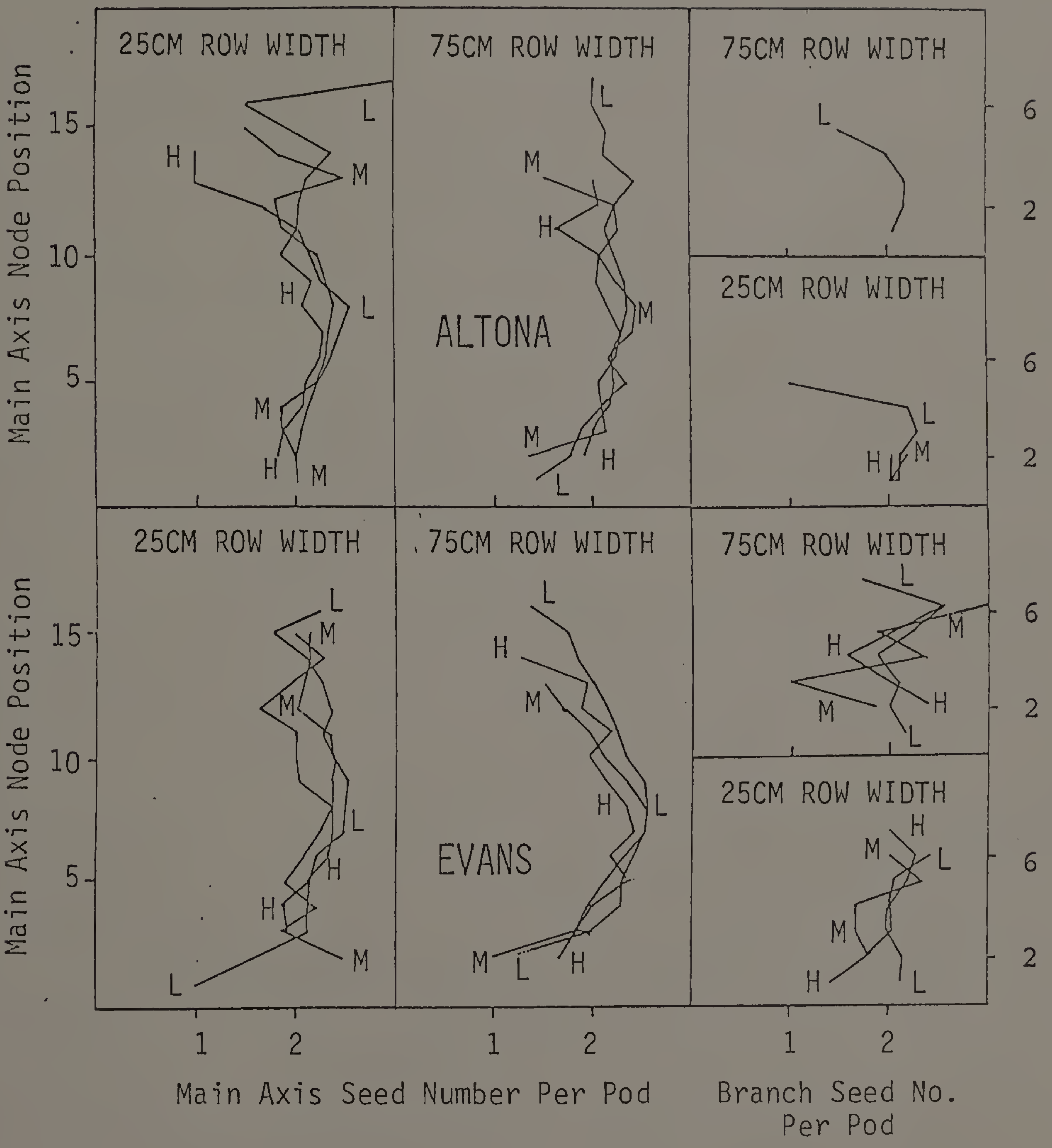
Another line of thought is that the level of production of photosynthate is not reduced but that its distribution is extended over both reproductive and vegetative growth. Egli and Leggett (1973) observed that in indeterminate soybean plants, while the lower nodes are flowering, only 57 percent of the plant's total dry weight had been accumulated. Therefore, there is greater competition between vegetative and reproductive parts of the plant. The data from South Deerfield in 1981 shows this competition of vegetative and reproductive parts and shows that it is more pronounced during the flowering and pod set periods of growth (Chapter IV, Flowering).

The two previous explanations for fewer pods on lower nodes are two aspects of the same process. Adams hypothesized in 1967 that as interplant competition became sufficiently intense, limitations were imposed on resources available to individual plants, resulting in intraplant competition for nutrients and metabolites, which leads to compensation among yield components. Not only does intraplant competition lead to compensation among components, but also affects the distribution of those components on the plant.

The number of seeds/pod was a much more stable component of yield than the number of pods/plant (Table 3 and Figure 11). Along the main axis most of the seed number per pod variation was on the upper and lower nodes. There were fewer pods contributing to the averages at these positions and therefore there was more variability. There were no significant effects of cultivar, row width or plant density on the number of seeds per pod (Table 3).

Fontes and Ohlrogge (1972) in a depodding study where treatments were imposed at full pod stage (R4), found greater seed size at higher nodes in response to less demand for photosynthate at the middle and lower nodes. Collins and Cartter (1956) found smaller seed size and lower oil content on the higher nodes, while finding larger seeds and higher oil content on the central and lower nodes. Both of these studies indicate differences in the seed fill conditions at different sections of the plant.

Figure 11. Seed number per pod



L = low density
M = medium density
H = high density

There was no significant difference in seed size due to the row width treatment (Table 3). There was a difference between cultivars ('Altona' greater than 'Evans') and a small difference between densities (Table 3). A similar seed size relationship to plant density as shown in Table 3 was observed previously at this experimental site (Herbert and Litchfield, 1982). We could speculate that low density plantings, which had lower leaf area index (LAI) but greater leaf area per plant, provided more available photosynthate to seeds during the seed filling period than medium density plantings, resulting in larger seeds in the low density plantings. In the high density plantings. pod set was lower than in medium densities. Although leaf area per plant was lower in high densities than in medium densities, total LAI's were similar, creating more favorable filling conditions for those seeds which remained in the high density crop.

Wilcox (1974) observed in one of three soybean strains a larger seed size as plant density increased. Differences in seed size occuring from row width treatments (51 vs 102cm row widths) have been observed by Lehman and Lambert (1960) at one of two locations.

In our experiment there was a tendency for seed from wide rows to be heavier than seed from narrow rows

(Table 3). This tendency was more pronounced in 'Evans' than in 'Altona'. These differences may be a response to fewer seeds per plant in the wide rows. It was concluded by Johnson and Harris (1968) that the increased seed size was the result of fewer seeds per plant. Their results indicate seed size does respond to environmental conditions. However, significant year to year variations in seed size have been reported by Herbert and Litchfield (1982). Figure 4 shows seed size was stable over all nodal positions suggesting seed size is the most stable component of seed yield.

Figures 12 and 13 show the relationship of average seed size of seeds from 1, 2, 3, and 4-seeded pods. Seed size was very stable across node positions and similar irrespective of how many seeds were filled in a pod. This indicates that seed filling is independent of seed number per pod and position on the plant. It appears that regulatory mechanisms as yet unknown control seed number through flower and pod abortion. Egli et al. (1978) suggested that the rate of seed growth is largely controlled by mechanisms in the seed and not simply by the supply of photosynthate to the seed. Gent (1982) has recently shown that the transport of carbohydrate occurs freely throughout the plant. This finding supports our data

Figure 12. Seed size for seed from 1, 2, 3, and 4-seeded pods - ALTONA

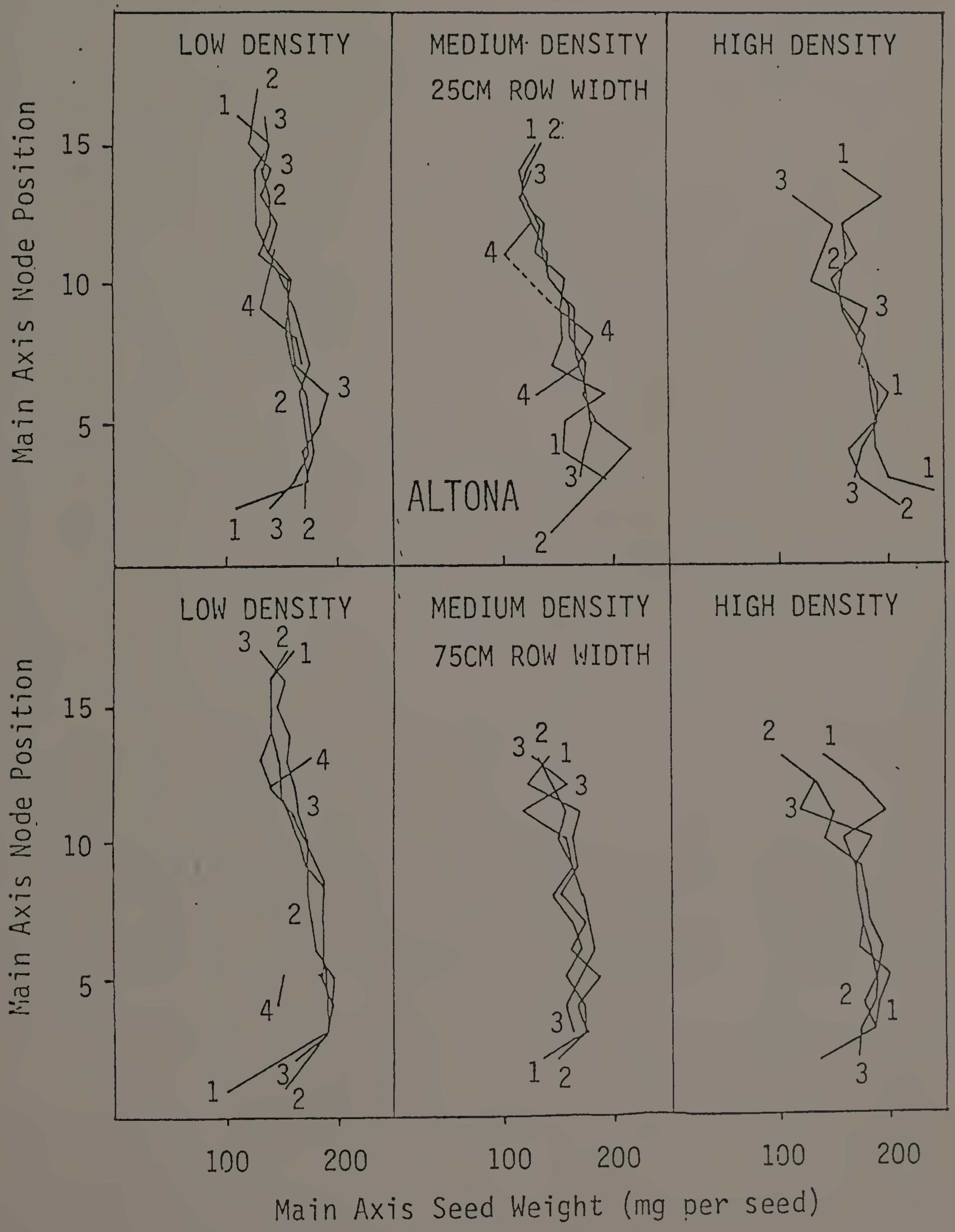
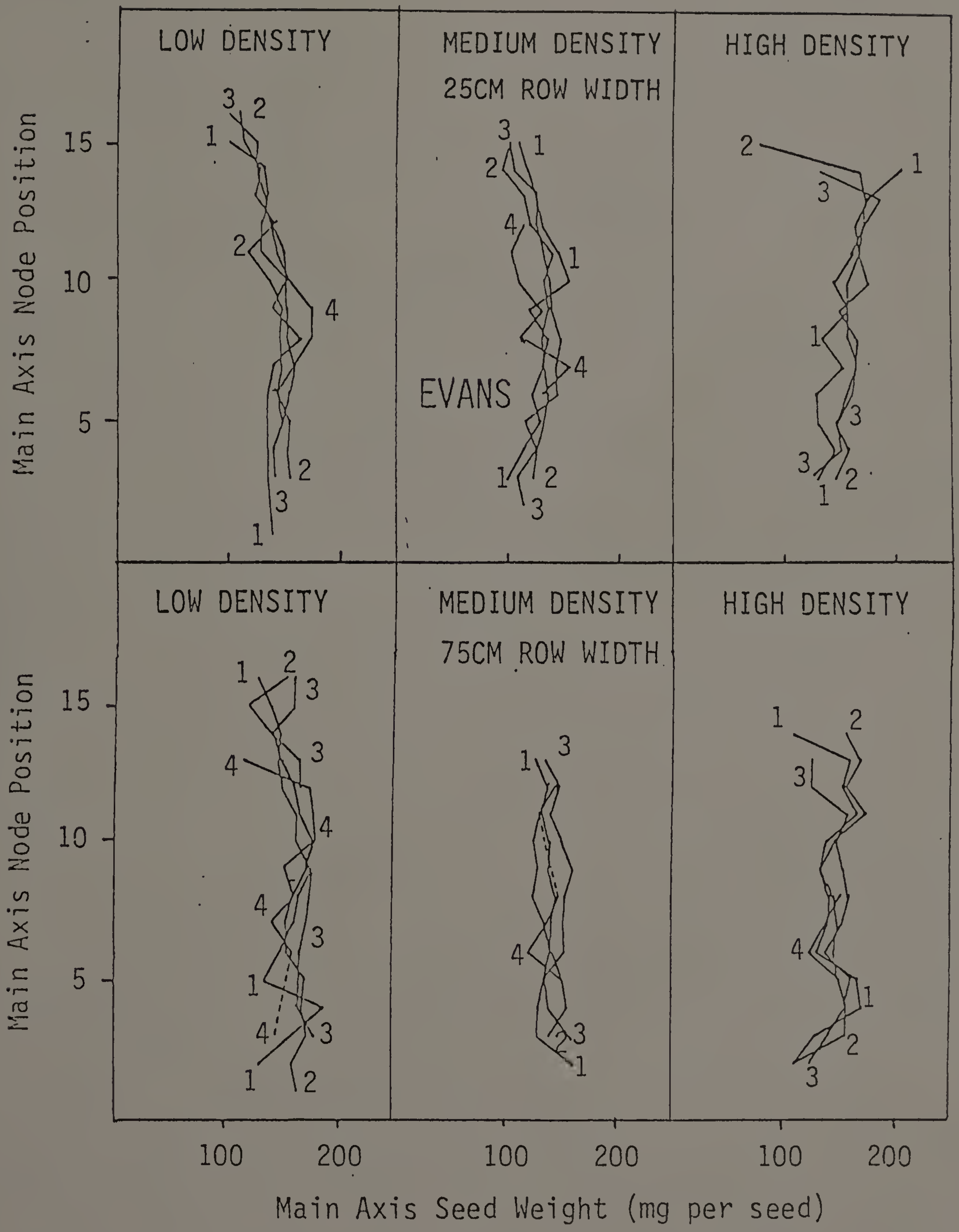


Figure 13. Seed size for seed from 1, 2, 3, and 4-seeded pods - EVANS



(Figs. 12 and 13) and shows that the seed is dependent on the whole plant for photosynthate. When photosynthate is being distributed during the seed fill period, the plant responds on a whole plant rather than a node by node basis, and all pods and seeds compete for the available resources. This does not preclude that some pods compete more successfully than others through advantages of earlier development, production of greater quantities of hormones, or through mechanisms which effect the dynamics of energy flow in the plant throughout the reproductive stages.

The percentages of 1, 2, 3, and 4-seeded pods per node are given in Table 4. The percent 1-seeded pods are less than either the 2 or 3-seeded pods. The 2 and 3-seeded pods were similar to each other in percent contribution to yield. The 4-seeded pods contributed little to the overall yield of the plants. There was a significant cultivar effect (P=0.004) on 4-seeded pods, with 'Evans' having the greater number than 'Altona', but still the contribution was small. The number of 4-seeded pods was shown by Weiss (1970) to be genetically controlled.

The altering of row width and plant density caused very little effect on the relative percent of 1, 2, 3, and 4-seeded pods (Table 4).

Table 4. Percent 1, 2, 3, and 4-seeded Pods per Plant

ALTONA

Narrow Rows

Density	Seeds per Pod			
	1	2	3	4
Low	19%	42	38	1
Medium	19	42	38	1
High	21	46	32	1

Wide Rows

Density	Seeds per Pod			
	1	2	3	4
Low	20	44	36	1
Medium	21	41	37	1
High	19	48	32	1

EVANS

Narrow Rows

Density	Seeds per Pod			
	1	2	3	4
Low	19	39	40	2
Medium	19	44	35	2
High	25	39	33	2

Wide Rows

Density	Seeds per Pod			
	1	2	3	4
Low	19	40	39	2
Medium	19	40	39	2
High	20	41	38	1

No distinction was made in this study among the seed positions within the pod, and therefore, seed size in our data for 1, 2, 3, and 4-seeded pods was averaged for all positions within the pod. Egli et al. (1978) found only small differences in seed growth rates and seed size related to the position of the seed within the pod.

In this study it has been noted that within the soybean plant environmental influences, such as light distribution as affected by row width and plant density, have more effect on pod set than on seed size. The number of seeds carried to maturity is regulated by the number of flowers which become pods and by the number of pods which remain to maturity. Ultimately, it is the number of seeds per unit area which determines yield. Although the number of seeds per pod averaged over the entire plant was more stable than the number of pods per plant, the number of pods with 1, 2, 3, and 4 seeds did fluctuate with position on the plant. Increases in yield might result if a higher percentage of 3-seeded pods were induced by plant breeding techniques. However, the chances of consistently increasing the percentage of pods having 3 seeds as opposed to 1 and 2-seeded pods that might occur by manipulating the crop's environment through management techniques does not seem practical. Our efforts would be better spent trying to identify those factors which would result in an increase in the number of pods held to maturity. Thus a better understanding of ovule formation and abortion, and the competition for resourses within a node and within a pod, as well as, identifying the plant's mechanism for recognizing how many seeds it has the potential of filling are needed at this time.

CHAPTER VI

CONCLUSIONS

Flower production was greater in narrow rows than in wide rows. The greater flower production of narrow rows was converted into greater pod production. Although narrow row plants had a similar number of total nodes as wide row plants the number of productive nodes (nodes with one or more pods containing a minimum of one seed) was significantly greater in narrow row plants.

Low density environments stimulated greater flower production per plant and greater pod production per plant as well as promoting more branches.

Early in the season narrow rows had a greater relative growth rate (RGR) than wide rows. The crop growth rate (CGR) was higher in narrow rows at all times of the growing season. In the Evans cultivar the higher CGR in plants from narrow rows was dependent exclusively on the higher leaf area index. Whereas in the Altona cultivar the higher CGR in plants from narrow rows was due to a combination of higher leaf area index and higher net assimilation rate.

Narrow rows had a highly significant seed yield advantage over wide rows. There were a greater number of pods per plant in narrow rows.

Plant density did not affect seed yield per unit area, however, increasing plant density resulted in fewer pods per plant and fewer pods on the lower nodes.

The number of seeds per pod did not differ with changes in cultivar, row width or plant density.

Seed size did not differ with row width but there was a small but significant difference in seed size as plant density changed. A significant cultivar difference in seed size was detected. 'Altona' was found to have larger seeds than 'Evans'.

Approximately 80 percent of all pods contained either 2 or 3 seeds. Most of the remainder had 1 seed/-pod while a very small percentage of pods had 4 seed/pod. The percentage of 4-seeded pods was significantly greater in 'Evans' than in 'Altona'.

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