THE EFFECT OF PLANT POPULATION AND CARBON DIOXIDE CONCENTRATION ON THE GROWTH AND YIELD OF SOYBEANS (*Glycine max* (L.) Merr.) GROWN IN A MODIFIED ENVIRONMENT OF PLASTIC GREENHOUSES.

by

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STATEMENT OF AUTHOR

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ABSTRACT

Soybeans (Glycine max (L.) Merr., cultivar Kino) were grown in a closed environment of a plastic greenhouse. Two experiments were conducted with Experiment I initiated on June 11, 1966 and Experiment II on October 4 of the same year.

Results of both experiments showed that soybeans grew and yielded well under high humidity (80% and above) and high carbon dioxide concentrations (300, 800, 1200, 2400 ppm) in a polyethylene plastic greenhouse.

In Experiment I, soybean plants were grown at four plant densities: 247,097, 494,194, 988,388 and 1,729,679 plants/ha under 800 ppm carbon dioxide. Yields obtained were 3208, 4868, 5792, and 6555 kg/ha respectively. Number of pods per plant decreased as plant density increased.

In Experiment II, soybean plants were grown in a pure sand (4:0), 3 parts sand and 1 part peat moss (3:1), and 2 parts sand and 2 parts peat moss (2:2) and under three levels of carbon dioxide concentrations namely 300, 1200, and 2400 ppm. Soybean plants performed best under 1200 ppm carbon dioxide. Yields obtained under 300, 1200 and 2400 ppm carbon dioxide were 3464, 5037 and 4016 respectively. A carbon dioxide concentration of 1200 ppm increased the number of pods per plant considerably.

INTRODUCTION

During the past several decades man has influenced and modified environmental conditions of crop plants considerably. The ultimate purpose of all his attempts and efforts has been to increase the productivity of crops for his own consumption. Results of greenhouse experiments have contributed a great deal of knowledge to increased production and will continue to be more beneficial and useful in the future.

Increase in world population and the problem of food and water have attracted attention of many investigators to the possibilities of growing agronomic crops under optimum environmental conditions in a closed system. Manufacturers of plastics recently have stimulated and encouraged this idea further by manufacturing plastics suitable for the economical construction of greenhouses on a large scale.

In relation to the world's problem of food shortage the Department of Atmospheric Physics of the University of Arizona has designed a project which, in the near future, could perhaps contribute to the solution of this problem. According to this project, solar energy will be used to convert sea water into fresh water. In conjunction with and supplementary to the desalting plant, the Solar Energy Laboratory staff has speculated on the possibilities of producing food in plastic greenhouses that are cooled and heated by sea water. Future plans for desalting plants may include greenhouses for growing crop plants such as soybeans which will provide an excellent source of protein. In India, for example, children are suffering from mental retardation because of insufficient protein in their diet (53). In order to provide adequate protein, scientists are attempting, through selective breeding, to increase the protein content of wheat. Even in the United States, future food requirements will cause the fat and protein in soybeans to increase in value. Such has been the case in the past (acreage harvested for beans was nearly 14 million in 1950, 24 million in 1961, and 27 million in 1966) and indications are that the future will see greater increases in this trend. On the average, soybeans contain 40 per cent protein; consequently, they are an excellent source of protein which can be substituted for animal protein in human consumption.

The purposes of this experiment were: (1) to study the feasibility of growing soybeans in the enclosed modified environment of plastic greenhouses, (2) to evaluate and compare in a relative way the yield and water used in the greenhouse with those for the same crop grown under field conditions, and (3) to determine the population density that would produce the highest yield of soybeans per unit of soil area under a specifically modified environment.

REVIEW OF LITERATURE

Literature on the growth of agronomic crops under an enclosed environment of plastic greenhouses is very limited. This review will be oriented toward the effects of different components of the environment under which the soybean crop was grown.

There is evidence (38) to show that the Romans were well aware of the advantages of "glass" and heat and used it for the protection and forcing of fruits, inducing the grape and vegetables out of season. The Greeks in a minor way were also familiar with the above practice. It is thought by inference and mentioned by M'Intosh that "The Gardens of Adonis" were forcing houses in miniature. Forcing was done by stoves and the "glass" was "Muscovy glass," actually sheets of mica split thinly.

Effect of Light Intensity and Carbon Dioxide Concentration on Photosynthesis

Light and carbon dioxide are two important factors that affect rate of photosynthesis. Rate of assimilation of photosynthate depends both on light and carbon dioxide concentration (3, 20, 26, 27, 39). There is a direct relationship between carbon dioxide concentration up to a certain level and the rate of photosynthesis.

As the carbon dioxide in a closed system is used by plants, the rate of photosynthesis declines proportionately until the compensation point is reached (36). Moss (45) noted differences among corn, sugar cane, orchardgrass, tobacco, geranium, tomato and Norway maple relative to the minimum level to which they could reduce the concentration of carbon dioxide in a closed glass chamber. Sugar cane and corn grown under 23 C and 2000 ft-c light intensity reduced the carbon dioxide to less than 10 ppm, whereas some other species decreased the carbon dioxide in the system to only 60 ppm.

On the other hand, increasing carbon dioxide in a closed system favors increases in yield (52, 59, 64). Practically all curves (26, 39, 52) relating carbon dioxide concentration to photosynthetic activity show that the normal content in the air (300 ppm) is not sufficient for complete saturation of photosynthesis in moderate and strong light comparable to the amount of sunlight plants receive in a greenhouse.

The first series of experiments concerning the effect of carbon dioxide enrichment initiated in America was by Cummings and Jones (13) in 1909 and continued for 7 years. Their trials resulted in an increase in yield for many crops with an increase in yields of both pods and seeds in peas and beans. All the crops that were used in their experiments produced larger and heavier leaves and flowered earlier and in greater profusion.

During the same time and subsequent to the work of Cummings and Jones, extensive studies were accomplished on this subject in northern Europe (52). In most of these experiments carbon dioxide was provided by burning charcoal, fuels, coal gas, paraffin and purified gases from furnaces. In some cases yields of cucumber and tomatoes were doubled and even tripled. But toxic impurities were all too frequent in the products of combustion and were exhausted into the plant growing structures.

Brown and Escombe (6) conducted a series of experiments on plants grown in closed containers using a carbon dioxide concentration of 11100 ppm. There was downward curling of the leaves, inhibition of flowering, and abortion of buds. They concluded that an increase of carbon dioxide in the air of only 2 to 3 times normal would be lethal to plants. Demoussy (16) stated that the negative results of Brown and Escombe were caused by applying impure carbon dioxide. He proved this point by growing plants under 11500 ppm carbon dioxide. There was an average increase in plant weight of 160 per cent.

The problem of impurities has recently been eliminated, and many investigators (5, 7, 20, 52, 58) have continued to study the effect of high carbon dioxide concentration on the yield of vegetable crops. Robb and Wittwer (52) grew M-O hybrid tomatos and the Bibb variety of lettuce under different levels of light intensity and carbon dioxide concentrations. They obtained the highest dry weight under 1500 ft-c and 1000 ppm carbon dioxide. In another experiment (52), there was an increase in yield of about 70 and 43 per cent for several varieties of lettuce and tomatoes respectively when grown under 800 to 2000 ppm of carbon dioxide. Numerous other investigators (2, 5, 6, 7, 13, 14, 16, 20) have obtained similar results.

Several studies (3, 15, 20, 26, 27, 32, 52, 68) have indicated that there was a linear relationship between the rate of photosynthesis and increase in carbon dioxide concentration and light intensity. Chemical analyses (44, 52) have shown that high levels of carbon dioxide increased the synthesis of sugars rather than organic acids. Also, the contribution of high light intensity to a high rate of assimilation has been postulated (3, 6, 10, 34). These studies indicated that high light intensity not only decreased stomatal resistance to carbon dioxide diffusion, but also increased the liquid phase permeability of the mesophyll cell walls to carbon dioxide transport (rm).

Moolani (43) grew soybeans in the field and studied the final yield as a function of light intensity. The results of his experiment showed that the yield of soybeans was 455 lbs/acre and 1440 lbs/acre under 2560 and 6120 ft-c respectively.

Effect of Temperature on Photosynthesis and Growth

It has been postulated that there is an optimum temperature for maximum assimilation (15, 34, 48). Ormrod (48) studied the effect of temperature on rate of assimilation in *Phaseolus vulgaris* L. His data showed that the trend lines were broadly semi-circular with a drop in carbon dioxide assimilation from 32 to 38 C and a somewhat greater drop from 16 to 4 C. An experiment conducted at the University of Jerusalem on *Pinus halepensis* (68) showed a peak in net carbon dioxide uptake in light at 22 C. and a steady decline with increasing temperature. Respiration on the other hand continued to increase as temperature increased to 36 C (15, 34, 48). An increase in respiratory carbon dioxide output apparently enhanced decarboxylation and so may be considered as contributing to an increase in resistance to photosynthetic carboxylation (34).

Results of Van Dobben's experiment (60) conducted in the Netherlands showed that shoot/root ratio increased with temperature. There is strong evidence to indicate that response of growth to temperature is mainly governed by shifts in the shoot/root ratio. Van Dobben has also mentioned that shoot/root ratio is probably the most important factor regulating growth rate, and that differences in growth between varieties can be explained by a different shoot/root ratio and dry matter distribution. He therefore concluded that faster growth was not caused by higher assimilation.

Effect of temperature on development of plants has been studied extensively (19, 47, 60). According to Van Dobben a warm climate (for instance 25 C) shortened the period of development of temperate zone crops (rye, wheat, peas and flax) without giving sufficient compensation by faster growth. In crops of subtropical origin (maize and beans) the growth rate was stimulated to such an extent under warm conditions that the plants grew larger despite the short growth period. Friend (19) found that floral initiation of Marquis wheat was earlier with each increase in light intensity from 200 to 2500 ft-c, and with each increase in temperature between 10 and 30 C.

Effect of Humidity on Transpiration and Photosynthesis.

The agricultural industry has been the largest consumer of water in the United States. As an average for the nation, about 21 inches of the 30 inches of annual precipitation is evaporated or transpired from land and crop curfaces (62). Research on water requirements and water-use efficiency can be roughly divided in two periods (62). The early period began with the work of Sir John Lawes at Rothamsted before 1850. The second period is the present, in which new concepts of energy exchange and radiation efficiency in carbon dioxide assimilation are being introduced.

It is well known that transpiration is greatly reduced by increasing humidity. Bierhuizen and Slatyer (3) measured:

$$\frac{\text{Transpiration}}{\text{Apparent Photosynthesis}} = \frac{E}{A}$$

as a function of vapor pressure gradient. They observed that the ratio E/A increased linearly with increasing leaf-air vapor pressure difference (Δe), values ranging from 100 to 500 E/A obtained as Δe increased from 5 to 25 mmHg. The ratio E/A decreased with increasing light intensity (1000 to 2000 ft-c), carbon dioxide concentration and decreasing wind speed. Similar results have been obtained by others (1, 34).

Data have been reported (3, 34) to show that an increase in vapor pressure gradient caused a decline in photosynthetic rate. Such dehydration possibly reduced activity of enzyme systems involved in carbon dioxide metabolism (3, 34).

Bierhuizen and Slatyer (3) suggested as a first approximation, that variability in transpiration ratio (E/A) from region to region is due largely to variability in Δe. This proposition is well supported by data from a number of crops in different climatic zones. It has also been found (29, 62) that fertilization for an adequate nutrient supply of all crops plays a major role in the efficient use and conservation of water resources.

Effect of Spacing and Plant Population on Yield.

It has long been established that one of the major factors limiting the amount of growth per unit area is the density of the stand. The nature of competition in field crops and how the density of a plant community affects the growth of each individual plant are of considerable interest.

Many experiments have been conducted (28, 32, 51, 64, 67) to study the effect of spacing on the final yield of soybeans. Wiggans (67) stated that optimum rates and spacings for soybeans should be determined not only for the various soybean producing areas, but also for varieties to be grown.

Generally speaking, results of various experiments (28, 32, 51, 64, 67) have indicated that plant height decreased, while yield per plant, seed size, and dry matter per plant increased under wider spacing and lower density. Weber et al. (64) found highest seed production of the Hawkeye cultivar occurred with a population of 104,544 plants per acre. Thompson and McKee (59) working with Chippewa and Merit cultivars received the highest yield from a population of 99,000 plants per acre. Cultivars

Illin, Mandell, Dunfield and Mulden (51) produced maximum yield in a density of 190,000 plants, and finally Wiggans (67) found the highest yield for Cayuga soybeans was at 261,360 plants per acre.

Burnside and Colville (8) stated that germination tended to increase with increasing row spacings. Weber et al. (65) and Hinson and Hanson (28) obtained results that showed spacing influenced height and that the change in height from flowering to maturity was less at wide spacings than at close spacings. They also stated that the decrease in height with increased spacings was not associated with reduced node number but was the result of shorter internode length.

Hinson and Hanson (28) found that plants of the cultivar Lee flowered earlier at 32-inch within row spacing than at 4-inch. Probst (55) reported that spacing plants 2 to 5 inches apart (30 inches between rows) hastened maturity in comparison with 1-inch spacing in each variety each year. Weber et al. (65) stated that maturity date tended to increase at the higher population densities. However, Hinson and Hanson (28) working with four varieties of soybeans found that all varieties matured later at 32-inch spacing than 2-inch spacing within rows (38-inch rows).

Data obtained by Lehman and Lambert (37) in Minnesota indicated that there were more seeds per pod at 40-inch spacing than at 20-inch when plants were grown at St. Paul, but no differences were found at Waseca. Weber et al. (65) found the greatest number of seeds per pod at 20-inch row spacings. Weber and Shibles (63) stated that reducing row width from 40 to 20 inches increased yields an average of 15 per cent.

Hinson and Hanson (28) reported that seed weight varied with spacing and varietal treatments, but was not consistent in response to spacings. They found no differences in seed weight of Lee variety at 2-inch and 32-inch spacing within rows.

Weber et al. (65) working with soybeans, cultivar Hawkeye, found that seed protein was slightly increased, and seed oil content slightly decreased by increasing the plant population.

According to Kamel (32), efficiency of solar energy conversion to chemical energy is greatly influenced by density. He obtained 2.3 per cent conversion for dense planting of barley (500 plants/m^2), 2.9 per cent for normal planting (250 plants/m^2) and 1.8 per cent for thin planting (125 plants/m^2). However, in this experiment he found that 500 plants/m^2 could not counter balance the decrease in yield per plant.

METHODS AND MATERIALS

Experiment I

Soybeans (Glycine max (L.) Merr., cultivar Kino) were selected for this study. Plants were grown under a closed environment of a 6.1m x 12.2m polyethylene plastic greenhouse. The polyethylene used, transmitted 87 per cent of the visible light and is transparent to ultraviolet and infrared (11).

Seeds were inoculated and planted in river-bottom sand contained in wooden frames .91m x 1.22m x .33m deep. The bottom and sides of each frame were covered with plastic and a 1.3 cm hole was drilled at the bottom in order to check the drainage. Each plot was also sterilized with Captan before planting. Ten grams of Captan were dissolved in one gallon of water and applied to each plot. Two seeds per hill were planted at the depth of 3.8 cm on June 11, 1966. Four plant populations were chosen for this experiment: 247,097, 494,194, 988,388 and 1,729,679 plants per hectare. Since some of the seeds in plots of 1,729,679 plants did not emerge, the final population of this group was 1,729,679.

Sixteen plots were planted and each treatment replicated four times in a complete randomized block design. Data were statistically analyzed using Duncan's multiple range test (41) to determine significant differences among treatments.

Description and Measuring Devices of the Environment

The closed environment of the greenhouse was cooled with a packed tower. The packed tower consisted of a vertical plastic shell set on a foundation and filled with Pall Rings (polypropylene) with the diameter of 8.9 cm. Water was circulated from an exterior cooling tower and through the packed tower in the greenhouse, while air in the greenhouse was blown through the wet packing countercurrent to the water stream. Therefore, the circulating air was cooled in the wet packed tower by exchanging heat with the previously cooled water.

The air temperature was measured by copper-constantan thermocouples and recorded constantly on the thermograph. Also, a wet bulb was used for obtaining data on the relative humidity. The mean maximum day temperature was 28 C and the mean minimum temperature at night was 18 C. Leaf and soil surface temperatures were measured by an infrared thermometer and thermocouples, respectively. The atmosphere of the greenhouse was kept under a high relative humidity of 80 per cent during the entire growing season.

Carbon dioxide of the air inside the greenhouse was monitered and controlled by a Beckman Model 215 infrared carbon dioxide gas analyzer and kept at a constant level of 800 ppm. The gas analyzer and tanks of carbon dioxide were installed outside of the greenhouse. The analyzer measured the carbon dioxide concentration of samples of the greenhouse air. If the concentration in the sample was below the desired level the analyzer would signal another mechanism which would automatically inject carbon dioxide into the greenhouse.

To measure the amount of solar energy received daily, a pyrheliometer was installed inside the greenhouse at a horizontal position. The amount of energy received was automatically recorded (in micro volts) on a rotating chart outside of the greenhouse. Micro volts later were converted to cal/cm^2/hr or day, using a conversion table.

Application of Water and Nutrients.

Equal amounts of water were applied to each plot by hand through a sprinkler connected to a water meter with a minimum accuracy of 4 gal. per minute. The application of water depended on the moisture status of the sand medium. At times water was applied daily, occasionally the plants were watered every two days, and frequently they were watered at longer intervals. The quantity of water applied each time varied from a minimum of 1/2 gallon to a maximum of 2 gallons. Five irrometers were installed at the depth of 6 inches, but only one performed accurately. Soil moisture tension in the plot of 1,729,679 plants per hectare was kept at less than 1/2 atmosphere at a depth of 15 cm. An attempt was made to prevent drainage; but when drainage occurred, the water was collected in a plastic container and reapplied to the plots. Drainage was infrequent during the entire experiment.

The application of water by a sprinkler system was initiated on July 29, and water continued to be applied thereafter by a Chapin Dew Hose, manufactured by Chapin Watermatics, Inc. (Fig. 1). The reason for this change was to prevent excess shedding of flowers and pods and also to preclude the possibilities of pollen inactivation and deterioration. The amount and type of nutrients used are shown in Table 1.

Growth and Yield Measurements.

The rate of growth was recorded by measuring the plant's height from the soil level to the apical bud. Two plants per plot were selected for these measurements.

Pods of each plant were harvested by hand and the seeds were separated from the pods and dried in an oven for 29 hours at 47 C. After drying, seeds were weighed on an analytical balance and yield determinations were made.

Figure 1. A view of part of Experiment I showing the watering system by Chapin Dew Hose, and necrotic areas on the leaves resulting from high temperature.

Table 1. Experiment 1. Data on nutrients applied, source of nutrients and time and method of application for soybean plants grown in a plastic greenhouse.

Total nutrients applied (kg/ha)	Source	Date of application (1966)	Methods of application
596.47	20,20,20 (all macro and micro nutrients present)	June 18,23 July 4,15,26 Aug. 5	15 gm. dissolved in one gallon of water and applied to each plot.
277.20	23,19,17	June 28 July 9,13,20,22 Aug. 3,8,9,15,17 Sept. 12,27 Oct. 2	Foliar spray with 45 gm dissolved in 2.5 gal. water per application for entire experiment.
56.03	KH_2PO_4	Aug. 20	Dissolved in 16 gallons of water and one gallon applied to each plot.
17.93	$MgSO_4$	Aug. 24	Same as for KH_2PO_4.
1/2 tsp / 1/2 gal water per application	Iron-chelate	July 1 Aug. 13,21,30 Sept. 2,4,7	Foliar spray.
280.15	10,10,10 (all macro nutrients present)	Aug. 27	Dissolved in 16 gallons of water and pumped through Chapin Dew Hose on entire experiment.
106 gal/17.84m^2	Hoagland Solution (69)	Sept. 1,6,10,15 19,23,27	In each application 16 gallons pumped through Chapin Dew Hose for entire experiment.

Total N,P,K used without Hoagland solution: N=211.07 kg/ha, P_2O_5=236.67 kg/ha, K_2O=213.77 kg/ha.

Experiment II

Seeds of soybeans, cultivar Kino, were planted on October 4, 1966. Seeds were planted at a depth of 3.8 cm in sand mixtures in wooden frames .91m x .91m x .30m at the rate of 494,194 plants per hectare. Plants were grown in three different greenhouses under 3 levels of carbon dioxide concentrations; 300 ppm, 1200 ppm and 2400 ppm. Each greenhouse (14.3m x 14.3m) contained a different carbon dioxide concentration. The same method was used to control the carbon dioxide concentrations in the greenhouses as described for Experiment I. During the course of this experiment other crops were also growing in these greenhouses.

Three types of sand mixtures were used as mediums of growth. These were: pure sand, 3 parts sand and one part peat moss, 2 parts sand and 2 parts peat moss. In this experiment the sand mixture ratios will be referred to as follows:

Pure sand = 4:0
3 parts sand and 1 part peat moss = 3:1
2 parts sand and 2 parts peat moss = 2:2

Water and Hoagland solution were applied by hand spray. The amount and type of nutrients used in this experiment are shown in Table 2.

Each plot was steam sterilized and fumigated by methyl bromide before planting. Steam was injected into the sand by fork shape pipes having two nozzles (2.5 cm

Table 2. Experiment II. Data on nutrients applied, source of nutrients and time and method of application for soybean plants grown in a plastic greenhouse.

Total nutrients applied (kg/ha)	Source	Date of application (1966)	Methods of application
956.75	23,19,17	Oct. 24 Nov. 9 Nov. 27	Dissolved in 1 gallon of water and applied to each plot by hand.
1124.18	10,10,10 (all micro nutrients present)	Oct. 28 Nov. 5	Applied directly to the soil surface
117 gal./15/05m^2	Hoagland Solution (69)	Oct. 16,20,27,28 Nov. 2,18,17,22	Sprayed by hand.

Total N,P,K used without Hoagland solution:

$N = 332.46$ kg/ha

$P_2O_5 = 294.20$ kg/ha

$K_2O = 275.07$ kg/ha

in dia.). Pipes were left in the sand until the temperature reached approximately 90C. Then sand was carried into the greenhouse and placed in the wooden frames.

As for methyl bromide, the wooden frames were covered tightly with plastic and then methyl bromide was injected underneath at a rate of .5 kg/m^3 and left there for 40 hours. Seeds were planted two weeks after the fumigation process was completed.

The temperature control systems of the greenhouses were based on the same principle as the one used in Experiment I, except in this experiment water was heated and then pumped into the greenhouses. Each greenhouse had its own packing tower. The average maximum and minimum temperatures were 27C and 17C respectively. Average relative humidity was more than 90 per cent, with a considerable amount of condensation. Evaporation was negligible during the entire experiment. Solar energy was measured by a pyrheliometer.

Pods of each plant were harvested by hand and then dried in an oven at 43C for 26 hours. After separation of seeds from pods, seeds were dried at 43C for 22 hours.

The experiment was 3x3 factorial with two replications (12). Data were statistically analyzed using Duncan's multiple range test (41) to determine significant differences among treatments.

RESULTS AND DISCUSSION

Experiment I

Emergence

The first seedling emergence was observed at 3 days after planting and continued for 4 more days. In the field, soybean seedlings normally begin to emerge within 5 to 7 days (47). Earlier emergence in the greenhouse was perhaps mostly due to high temperature and adequate moisture (47).

Temperature

Necrotic areas were observed on the first true leaves two weeks after planting. As new leaves formed, they also started to show deficiency symptions, despite application of what seemed to be an adequate amount of nutrients.

Generally speaking, leaves started to become yellowish at the tips and on the margins (Fig. 1). Contemporary and subsequent to the appearance of chlorosis on the margins and between the viens, spots of dead tissue showed up, gradually enlarged, and finally the tips of the leaves were completely covered with dead tissue. At the beginning it was thought that the symptoms were the result of salt burn on leaves, but deficiency symptoms continued to show up, and soil conductivity tests did not show a high salt concentration in the soil. Hence, it was concluded that salt could not have been the problem.

Results of disease culture showed that there was no pathogen present that would have caused this mottling effect. At the same time, problems of aeration were considered, but aeration was not the cause for three reasons: (1) A good root system was an indication of an ample amount of oxygen, (2) the medium in which plants were growing was pure sand, (3) after plants of one replication were shaded by Saran screen shade on July 19, all new leaves that were formed later showed no such necrotic areas (Fig. 2).

Formation of new and healthy leaves under the shade, together with leaf and soil temperature recordings, leads one to believe that the primary problem was high temperature. The maximum temperature at one cm below soil surface of shaded plots was 9 C less than unshaded plots. In one instance on August 13, leaf temperature of 47 C was recorded by an infrared thermometer. High leaf temperatures in the greenhouse were the result of (a) low evaporation, (b) direct sunlight, (c) and reflection and irradiation from the sand surface. The average temperature of the surface of the bare sand inside the greenhouse was 48 C on August 20.

Figure 2. Experiment I. A view of soybean plants showing the new leaves formed after Saran screen shade was placed over the plants of one complete replication.

Figure 3 & 4. A view of soybean plants in Experiment I showing the increase in rate of growth under the shade compared with plants without shade. Photo taken 11 days after shading was initiated.

High temperatures over 38 C early in the season may have adverse effects on the physiological processes of the soybean plant (33, 36, 47). High temperature may have affected the enzyme system of the leaves and caused enzyme denaturation; and as a result, the leaves were not able to metabolize the nutrients that were available to them (4, 33). Symptoms appeared as a combination deficiency of iron, manganese, magnesium, nitrogen and potassium, with potassium prevailing (57).

The first visible symptoms of high temperature injury were noted on June 25, (14 days after planting) and continued approximately to August 1. These injuries probably retarded the development and growth of the crop and also may have affected the final yield.

Growth Rate

The rate of growth and final height were directly proportional to plant densities. As found by other investigators (28, 37, 49, 51) height was decreased by wider spacing and lower density (Fig. 5). The growth curves for different population densities are presented in Fig. 6. Data from the statistical analysis are presented in Tables 3 and 4. There was no significant difference in height between populations of 247,097 and 494,194 plants per hectare. Plants at populations of 247,097 and 494,194 were significantly shorter than those

Figure 5. Soybean plants growing in Experiment I. Plants on the left and right are at a population density of 1,729,679 and 247,097 plants per hectare respectively. Note difference in height and general condition of the plants.

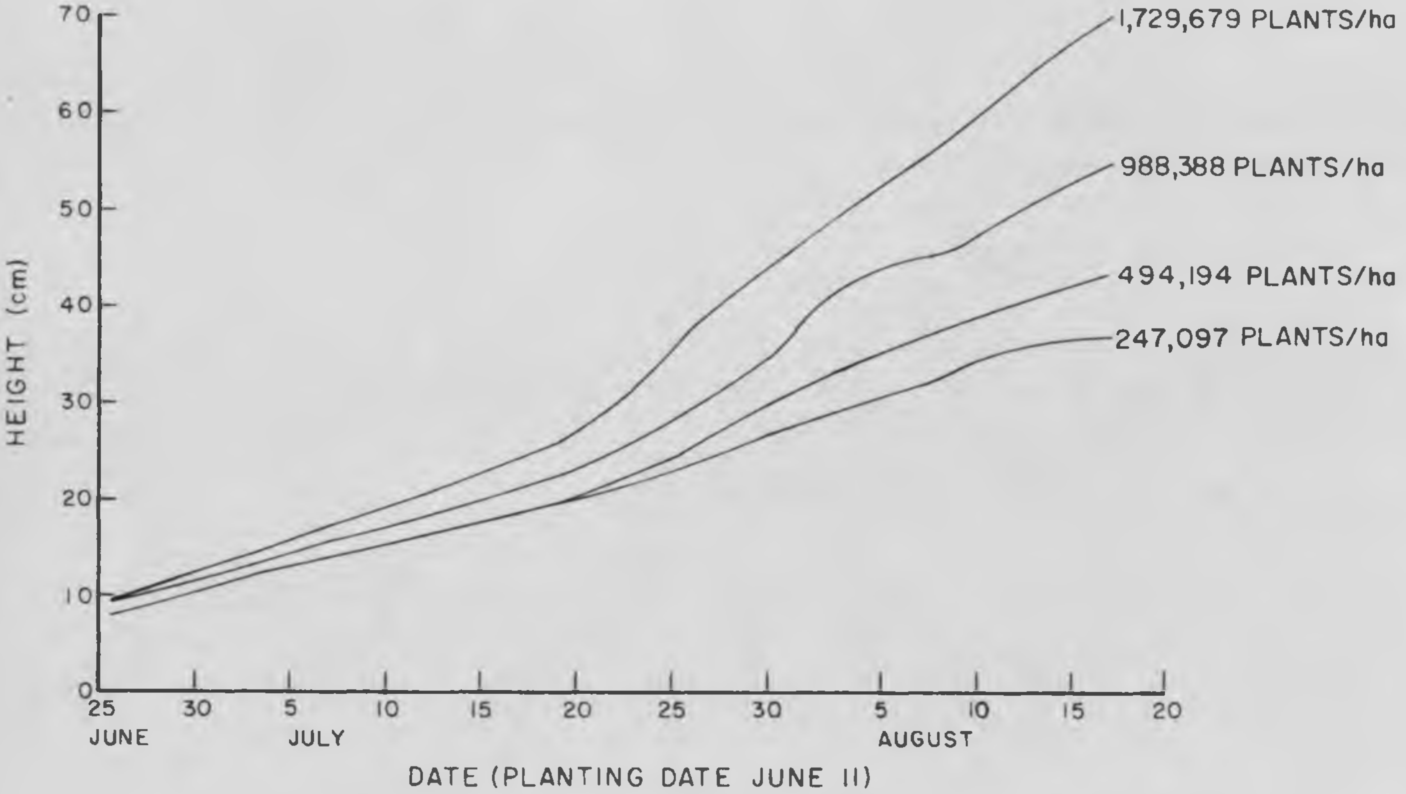


Figure 6. Experiment I. Increase in height of soybean plants when grown at four plant densities in a plastic greenhouse.

Table 3. Experiment I. Height of Kino soybean plants, in cm, at maturity when grown at four plant densities in a plastic greenhouse.

Plant density per hectare	Replication 1	2	3	4	Average
247,097	33.50	40.00	34.75	42.50	36.43a[1]
494,194	38.00	35.50	36.00	61.50	42.75a
988,388	44.50	58.50	51.25	64.00	54.56b
1,729,679	54.25	74.00	65.00	84.50	69.44c

Standard error of the treatment mean $s\bar{y}=3.3$.

[1] Mean values followed by the same letter are not significantly different at the 55 per cent level using Duncan's multiple range test (41).

Table 4. Experiment I. Analysis of variance for height of Kino soybean plants at maturity when grown at four plant densities in a plastic greenhouse.

Source	d.f.	SS	MS	F
Replication	3	944.67	314.89	9.68**
Plant	3	2530.39	843.46	25.94**
Error	9	292.72	32.52	
TOTAL	15			

**Indicates significance at 1 per cent level.

$$c.v.=\frac{\sqrt{32.52}}{50.79}\times 100\%=11.2\%.$$

at 988,388 and 1,729,679. Plants at population of 988,388 were also significantly shorter than those at 1,729,679.

The difference in height among different plant populations was not due to number of nodes per plant, but rather to longer internodes (Table 5). The fact that plants grew taller and had a more rapid rate of growth at higher plant populations was probably the result of greater competition for light (51).

Flowering

Flowering first occured on July 24 (43 days after planting) and ended on September 10 (80 days after planting). In Table 6, four developmental stages of cultivars grown in the field are compared with the Kino cultivar used in this experiment. Plots with a high plant population of 1,729,679 and 988,388 flowered later but reached the peak of flowering 6 days earlier than the plots with a population of 494,194 and 247,097. Hinson and Hanson (28) obtained similar results. These differences in time of flowering were perhaps due to variations in light intensity and/or temperature.

Productivity

Pods were harvested when they turned brown. Generally speaking, plants at populations of 1,729,679 and 988,388 matured earlier than those at 494,194 and 247,097. This early maturity was perhaps due to increased

Table 5. Experiment I. Number and length of internodes of Kino soybean plants grown at four plant densities in a plastic greenhouse.

Plant density per hectare	Number of Nodes	Length of Internodes
247,097	11.2[a]	2.9
494,194	10.6	3.2
988,388	10.4	5.3
1,729,679	10.2	5.6

[a] Each value is the mean of 4 replications.

Table 6. A comparison of days from planting to first flower, last flower, and maturity of four varieties of soybeans grown in the field (55) with Kino soybeans grown in a plastic greenhouse.

Variety	First flower (Days)	Full bloom (Days)	Last flower (Days)	Maturity (Days)
T 109	60	65	77	121
Mukden	49	56	78	118
Midwest	67	74	78	148
A11-2300-2	73	79	100	144
Kino (Experiment I)	43	64	80	138

competition for nutrients and for water with increasing density and therefore, vegetative growth was restricted and shortened. The harvesting date extended from October 14 to October 22. The growing season ranged from 134 to 142 days (Table 6).

Results of this experiment showed that the productivity of soybeans under this modified environment was directly proportional to the range of population density employed; namely, 247,097, 494,194, 988,388 and 1,729,679 plants per hectare (Fig. 7). The average yield in kilograms per hectare was 3208, 4868, 5782 and 6555, respectively (Table 7). Data in Figure 7 show that the increase in plant number (up to 1,729,679 plants/ha) per unit area did counterbalance the decrease in the final yield per plant and the curve is still going up with a decreasing rate. The results of previous experiments on plant density of soybeans (50, 55, 58) seem to show that under field conditions the highest plant population corresponding to the maximum yield obtained was 261,360 plants per hectare (59, 64, 67).

The analysis of variance was based on actual yield measured in grams per plot (Table 8). Two of the plots with densities of 988,388 and 494,194 plants per hectare in the southern part of the greenhouse constantly received water spray from the cooling tower. Consequently, this excess water affected the uniformity of the environment.

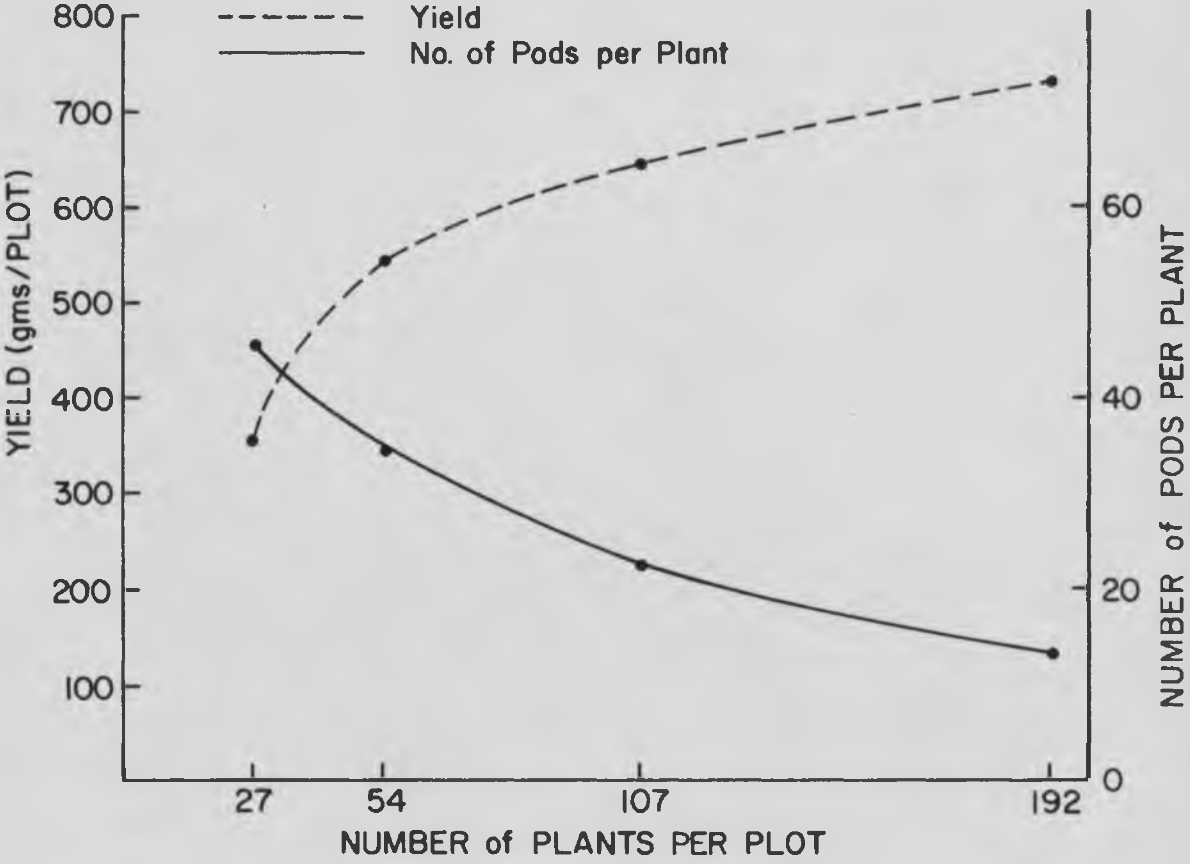


Figure 7. Experiment I. The seed yields (gms/plot) of soybeans and number of pods per plant as a function of plant population when grown in an enclosed environment.

Table 7. Experiment I. Yield of soybean plants, in grams per plot, when grown at four plant densities in a plastic greenhouse.

Plant density per hectare	1	2	3	4	Average	Average kg/ha
247,097	473.90	452.35	268.50	235.70	357.61	3208a[1]
494,194	476.60	394.10	741.9	558.30	542.72	4868b
988,388	586.25	866.10	525.10	601.00	644.61	5782b
1,729,679	726.70	962.75	699.40	534.50	730.84	6555c

Standard error of the treatment mean: $s\bar{y}=33.3$.

[1] Mean values followed by the same letters are not significantly different at the .05 per cent level using Duncan's multiple range test (41).

Table 8. Experiment I. One way analysis of variance of yield of soybean with plot densities of 494,194 and 988,388 with replications 2 and 3 omitted.

Source of Variation	d.f.	SS	MS	F
Plant Density	3	293439.38	97813.12	6.29**
Error	10	155359.09	15535.91	
Total	13	448798.47	34522.96	

**Indicates significance at 1 per cent level.

$$\text{c.v.}=\frac{\sqrt{15535.91}}{533.89}\times 100\%=23.3\%.$$

For this reason, these plots were considered as missing data and the analysis of variance was calculated as a one-way classification.

There was no significant difference in the yield when plants were grown at densities of 494,194 and 988,388 plants per hectare (Table 7). This insignificant difference was partially due to the production of fewer pods per plant in the 988,388 plant population compared to the 494,194. In other words, the increase in plant number from 494,194 to 988,388 plants per hectare did not significantly counter balance the decrease in number of pods per plant. Plants at densities of 1,729,679 yielded significantly more than those at 988,388, 494,194 and 247,097 plants per hectare. Plants at densities of 988,388 and 494,194 also yielded significantly more than those at 247,097 plants per hectare.

The number of pods per plant decreased as population density increased (Fig. 7). The average number of pods per plant as a function of population densities was 45.1, 34.8, 22.4, and 13.2 for 247,097, 494,194, 988,388 and 1,729,679 plants per hectare respectively (Table 9). Statistical analyses of these data are presented in Table 10. There was rather high variation in number of pods per plant with the coefficient of variation being 34.1 per cent. The increase in number of pods per plant at lower populations was mostly due to more branching which apparently

Table 9. Experiment I. Data on number of pods per plant of Kino soybean plants when grown at four plant densities in a plastic greenhouse.

Plant density per hectare	Replication 1	2	3	4	Average
247,097	57.0	57.0	33.6	32.4	45.1
497,194	32.5	26.2	47.5	33.0	34.8
988,388	22.4	30.1	18.4	19.2	22.5
1,729,679	12.6	17.2	12.8	10.3	13.2

Table 10. Experiment I. Analysis of variance of number of pods per plant when analyzed as a completely randomized block design.

Source of variation	Degrees of freedom	Sum of square	Mean square	F-value
Replications	12	147187.33	12265.61	126.35**
Plant density	5	46409.31	15469.77	159.36**
Error	1507	146287.36	97.07	
Total	1522			

**Indicates significance at 1 per cent level.

$$c.v. = \frac{\sqrt{97.07}}{28.88} x\ 100\% = 34.1\%.$$

was caused by greater light interception by leaves and less competition for light. During a bright day at noon, the light intensity at soil level for plots containing 247,097 plants per hectare was 28,751 lux while it was 7,147 lux for plots containing 1,729,679 plants.

Greater light intensity also caused thicker and shorter stems on plants grown in the lower populations. Similar results have been obtained by other investigators (28, 32, 37, 51).

Weight of seeds was not affected by plant population (Table 11). Lehman and Lambert (37) also found no correlation between weight of seeds and plant spacing, but Hinson and Hanson (28) reported that seed weight increased at wider spacings. Hinson and Hanson further reported that cultivars were not consistent in their response to spacing as far as seed size was concerned. Therefore, the size of seeds produced by the cultivar used in this experiment (Kino) was not perhaps affected by spacing.

The high carbon dioxide concentration (800 ppm) in the greenhouse undoubtedly had an effect on the final yield and resulted in an increase in productivity. Experiments by other investigators (7, 26, 69) support the above conclusion.

It is believed that the high carbon dioxide concentration was the primary reason for the population of 1,729,679 plants per hectare producing the highest yield.

Table 11. Experiment I. Weight of 100 seeds, in grams, of Kino soybean plants when grown at four plant densities in a plastic greenhouse.

Plant density per hectare			Replication		
	1	2	3	4	Average
247,097	13.8	13.6	13.1	12.4	13.2
494,194	13.1	13.1	12.8	13.8	13.2
988,388	11.4	13.1	13.9	13.4	12.9
1,729,679	13.2	14.8	13.7	12.7	13.6

Table 12. Experiment I. Data on the weight of empty pods, in grams, of Kino soybean plants per plot when grown at four plant densities in a plastic greenhouse.

Plant density per hectare	1	2	3	4	Average
247,097	179.3	155.9	103.9	106.9	136.5
497,194	185.9	155.9	266.6	231.0	209.8
988,388	255.8	329.4	230.5	261.4	269.3
1,729,679	314.4	391.2	291.3	256.6	313.4

Usually when plant population increases, competition for light increases and photosynthetic efficiency of the lower leaves in the shade decreases considerably (32, 46). Under such conditions where light is limited, photosynthetic efficiency of the leaves in the shade can be increased by increasing the carbon dioxide concentration of the environment (39, 52).

The average humidity of the greenhouse was kept at 80 per cent during the entire experiment. Later in the season, cool temperatures of the early morning caused condensation, and the atmosphere of the greenhouse was saturated.

The advantage of high humidity was the decrease in evapotranspiration. The total amount of water used in this experiment was 2,318 gallons, which is about 64 per cent of the amount of water that would have been used if plants had been grown under field (47), conditions. It has been postulated that a good crop of soybeans requires about 30 inches of water (47). Another advantage of high humidity was that it prevented considerable shedding of flowers and pods. It has been postulated that 75 per cent of the flowers fall from plants grown in the field (47). Also considerable shedding of pods occurs at the end of the season, especially when temperatures are high (47). According to the results of some previous experiments (3, 20), decreases in vapor pressure gradient keep the stomata open and therefore decreases the resistance for carbon dioxide diffusion.

Contrary to what was expected, there was no serious disease problem. At the end of the season, there was a slight fungus attack by Alternaria species, but it was easily controlled by Zineb.

There are also indications that a concentration of carbon dioxide higher than that found in normal air might prevent disease problems (5, 52).

Experiment II

Emergence

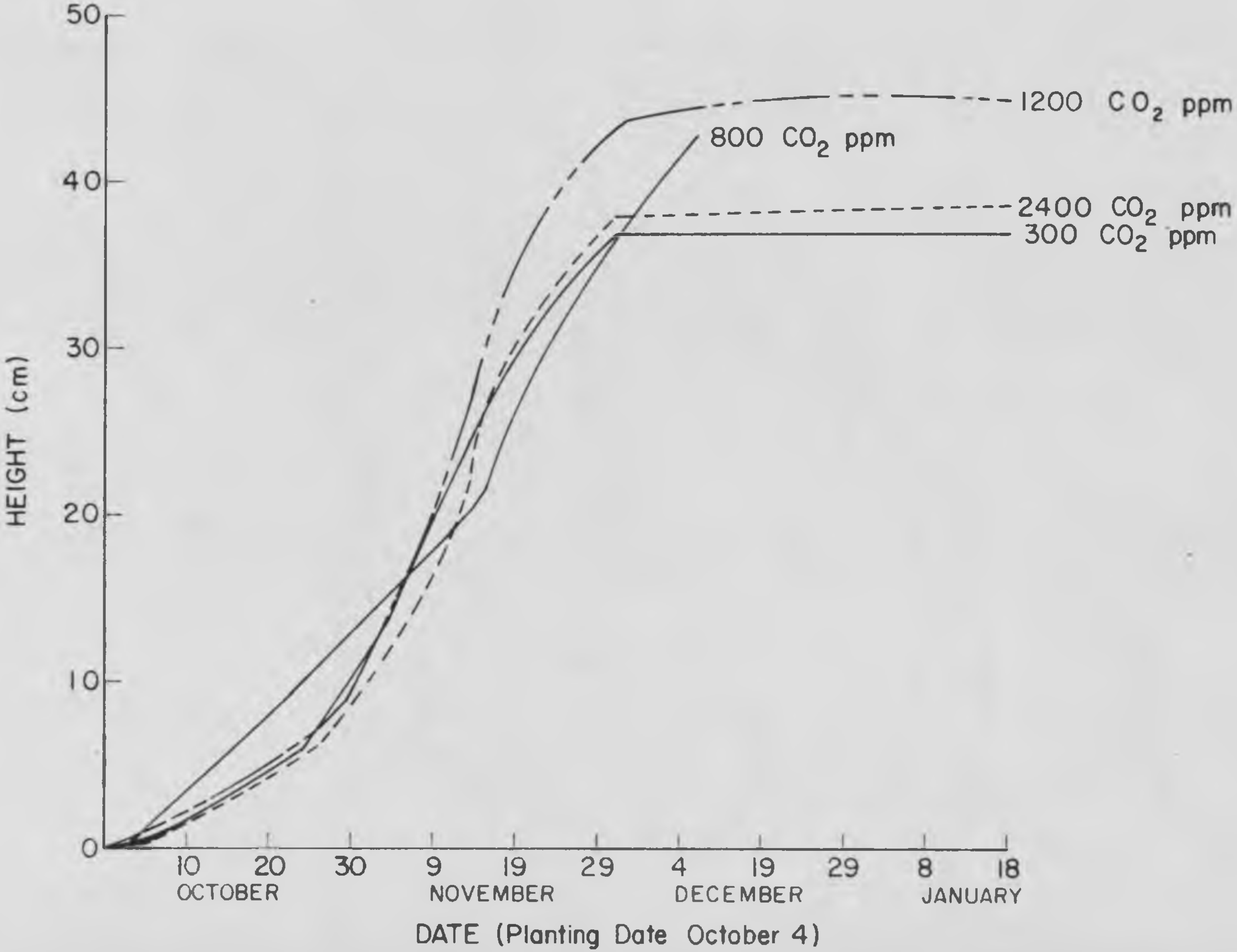
The first seedling emergence was observed 5 days after planting. Generally speaking, seedlings under 1200 ppm carbon dioxide emerged more rapidly than those under 300 and 2400 ppm. Time of emergence was about 2 days later than in the first experiment, possibly because of lower temperature at this time of year.

Growth Rate

Growth curves are presented in Fig. 8. Plants under 1200 ppm carbon dioxide concentration responded best to the environment as far as rate of growth and final height were concerned. Previous experiments (13, 52, 69) have shown that most plants grow far more rapidly and luxuriantly in an atmosphere that contains more than the normal (300 ppm) level of carbon dioxide. According to the results obtained in this experiment, growth rate and final height were not directly proportional to increasing levels of carbon dioxide. The concentration of 2400 ppm carbon dioxide somehow retarded the rate of growth.

During the initial stages of growth, soybeans grown at a density of 494,194 plant per hectare grew more rapidly in Experiment I than in Experiment II (Fig. 8). Rapid

Figure 8. Experiment II. Increase in height of Kino soybean plants grown under 300, 1200 and 2400 ppm of carbon dioxide concentration, compared with the rate of growth of the preceding experiment at 800 ppm. Plant density in both experiments was 494,194 plants per hectare.



1200 CO$_2$ ppm
800 CO$_2$ ppm
2400 CO$_2$ ppm
300 CO$_2$ ppm
HEIGHT (cm)
50
40
30
20
10
0
10
20
30
9
19
29
4
19
29
8
18
OCTOBER
NOVEMBER
DECEMBER
JANUARY
DATE (Planting Date October 4)

growth was probably due to the higher temperature and greater solar energy during Experiment I (47, 60).

Flowering and Maturity. The first flowers occurred 41 days after planting, which was 2 days earlier than in Experiment I. The growing season ranged from 112 days to 119 days, which on the average was 23 days shorter than the first experiment. This shortening of the growing season was regulated by the shorter daylength in the fall. In addition to furnishing energy, light also serves an important function in flowering and maturity. According to Norman (47) data obtained by Mooers show that there is not only a steady shortening of the season of growth as the date of planting is made late, but also this shortening is much more marked in some cultivars of soybeans than in others.

Productivity

Effect of carbon dioxide concentration: The average yields of soybeans were: 3,464, 4,016, and 5,037 kilograms per hectare under 300, 2400 and 1200 ppm of carbon dioxide concentrations respectively (Table 13). The highest yield was obtained under 1200 ppm carbon dioxide. Data in Fig. 9 and 10 show that yield, weight of empty pods and number of pods per plant were highest under 1200 ppm carbon dioxide. Data indicate that number of pods produced per plant influenced yield more than the weight of seeds of number of seeds per pod (Tables 14, 15, 16). The effect of carbon dioxide

Table 13. Experiment II. Yield of Kino soybean plants, in grams per plot, as affected by carbon dioxide concentration and medium of growth.

Medium of growth	Carbon dioxide concentration (ppm) 300	2400	1200	Average	Average kg/ha
4:0	335.8[a]	423.1	474.3	411.0	4940a[1/]
3:1	265.2	300.5	399.1	321.6	3846ab
2:2	267.7	283.9	383.2	311.9	3731 b
Average	289.6a	335.8ab	419.2b[1/]		
Average kg/ha	3464	4016	5037		

Standard error of the treatment mean $s\bar{y}=28.0$.

[a] Each value is the mean of two replications.

[1/] Mean values followed by the same letters are not significantly different at the .05 per cent level using Duncan's multiple range test (41).

Table 14. Experiment II. Number of pods per plant of Kino soybeans as affected by carbon dioxide concentration and medium of growth.

Medium of growth	Carbon dioxide concentration (ppm) 300	2400	1200	Average
4:0	24.4[a]	32.1	35.4	30.6
3:1	25.2	29.9	33.9	29.7
2:2	22.4	27.8	30.5	26.9
Average	24.0a	29.9b	33.3b[1/]	

Standard error of the treatment mean $s\bar{y}=1.5$.

[a] Each value is the mean of 2 replications.

[1/] Mean values followed by the same letters are not significantly different at the .05 per cent level using Duncan's multiple range test (41).

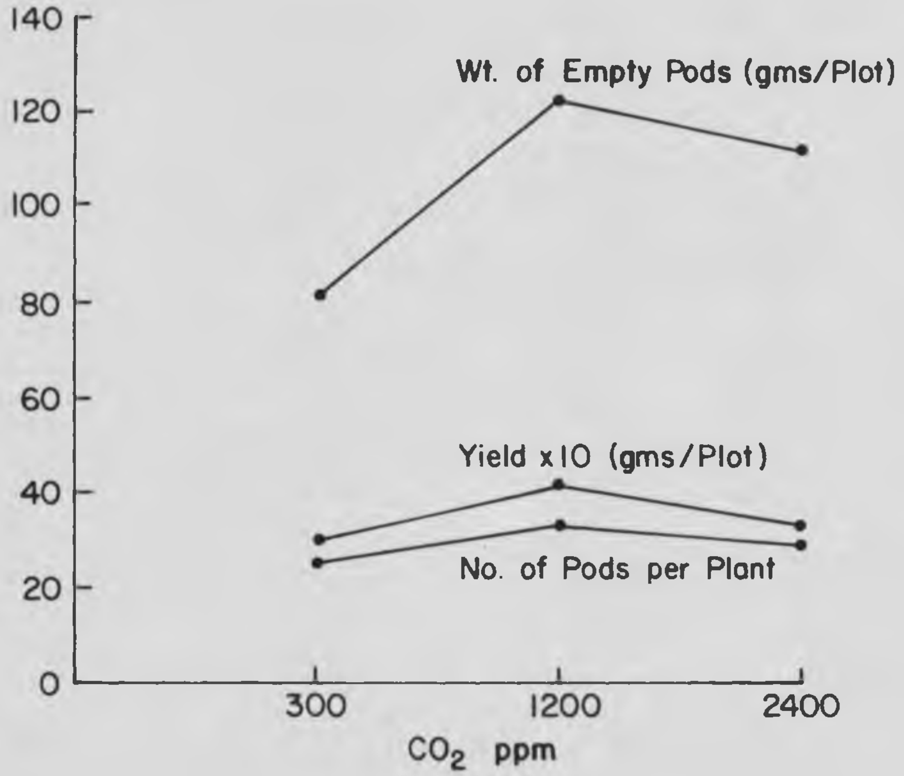


Figure 9. Experiment II. The seed yields (gms/plot) weight of empty pods (gms/plot) and number of pods per plant of Kino soybeans grown in 300, 1200, 2400 ppm carbon dioxide concentration.

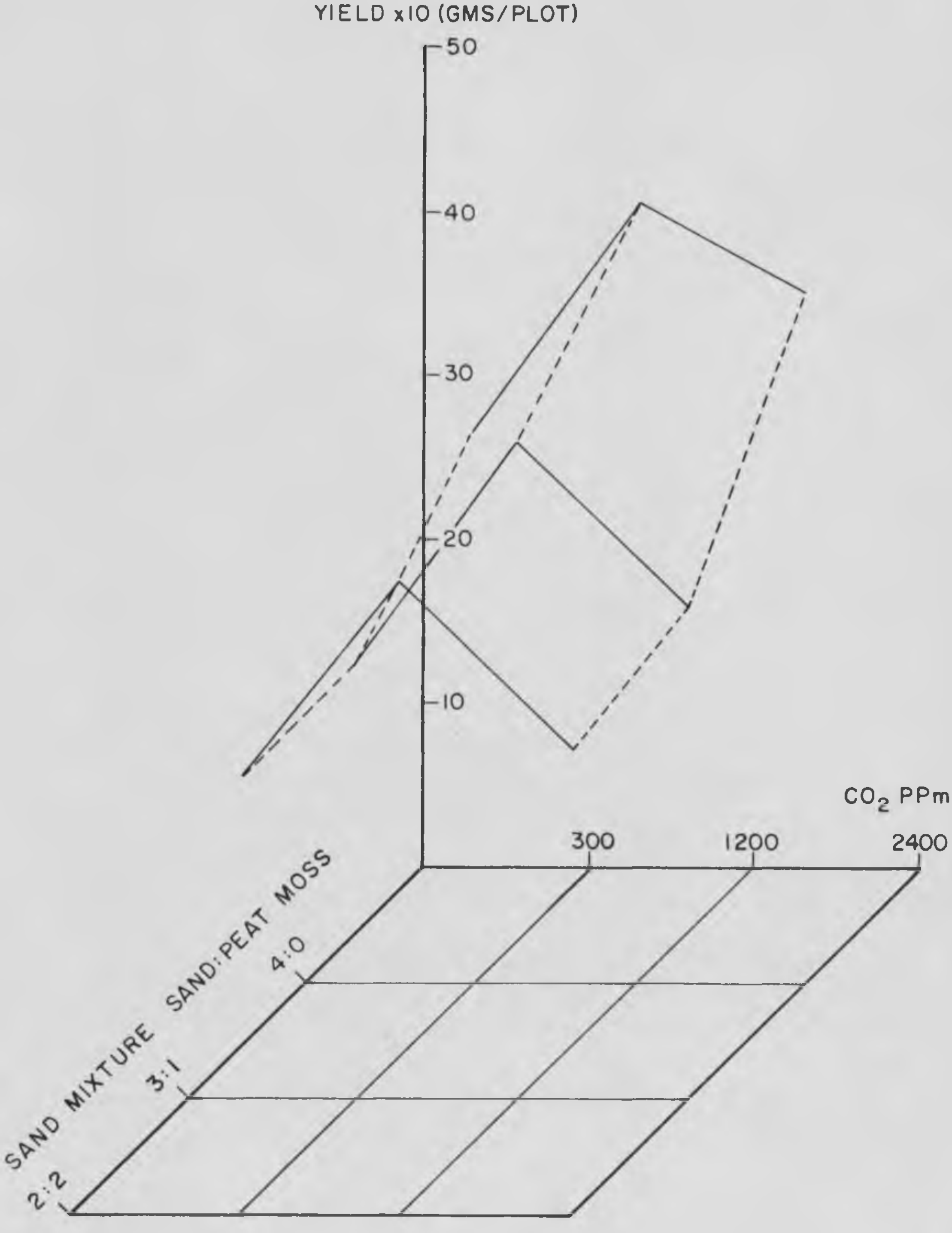


Figure 10. Experiment II. A three dimensional view of the seed yield of Kino soybean plants as a function of carbon dioxide concentrations and medium of growth.

Table 15. Experiment II. -Weight per 100 seeds, in grams, of soybean plants as affected by carbon dioxide concentration and medium of growth.

Medium of growth	Carbon dioxide concentration (ppm) 300	1200	2400	Average
4:0	16.8[a]	17.1	17.5	17.15
3:1	13.8	16.5	16.3	15.6
2:2	16.1	18.2	16.8	17.1
Average	15.6	17.3	16.9	

[a] Each value is the mean of 2 replications.

Table 16. Experiment II. Number of seeds per pod of Kino soybean plants as affected by carbon dioxide concentration and medium of growth.

Medium of growth	Carbon dioxide concentration (ppm) 300	1200	2400
4:0	-	2.4	2.3[a]
3:1	2.3	2.2	2.2
2:2	-	-	2.2

[a] Each value is the mean of 2 replications.

concentrations on the weight of the seeds was not pronounced (Table 15), but it affected the number of pods per plant considerably (Table 14).

Statistical analyses are presented in Tables 17, 18, and 19; the quadratic effect of carbon dioxide treatments on yield was significant at the 5 per cent level of probability (Table 17). The quadratic effect of carbon dioxide on the weight of empty pods and number of pods per plant was also significant at 5 per cent level of probability (Tables 18, 19). The differences in yield, weight of pods, and number of pods per plants when grown under 1200 and 2400 ppm carbon dioxide were not significant at the 5 per cent level of probability (Tables 13, 14, 20). A carbon dioxide concentration of 2400 ppm may have had some adverse effects on the physiological processes of the soybean plants. Plants did respond to 2400 ppm of carbon dioxide when compared with 300 ppm, but their yield did not surpass those grown at 1200 ppm.

Two factors may have been responsible for the low yield of soybean plants under 2400 ppm carbon dioxide concentration. One may be that this concentration of carbon dioxide had some toxic effects on the plants. This seems to be unlikely because even concentrations higher than 2400 ppm have not damaged plants (22, 52). The other factor, which is more convincing, may be stomatal closure under 2400 ppm carbon dioxide concentration. Gaastra (20)

Table 17. Experiment II. Analysis of variance of soybean yield data as 3^2 factorial analysis.

Source of variation	Degrees of freedom	Sum of square	Mean square	F-value
Replications	1	127.79	127.70	.27
Treatment	8	90644.63	11330.58	2.41
S_ℓ	1	29470.36	29470.36	6.26*
S_q	1	6368.57	6368.57	1.35
C_ℓ	1	6421.81	6421.81	1.36
C_q	1	45368.29	45368.29	9.63*
$S_\ell C_\ell$	1	2523.34	2523.34	.53
$S_\ell C_q$	1	123.49	123.49	.26
$S_q C_\ell$	1	179.09	179.09	.38
$S_q C_q$	1	190.38	190.38	.40
Error	8	37666.22	4708.28	
Total	17	128438.64		

*Indicates significance at 5 per cent level.

S-soil, C=carbon dioxide, ℓ=linear, q=quadratic

$$c.v.=\frac{\sqrt{4708.28}}{348.2}\times 100\%=19.7\%.$$

Table 18. Experiment II. Analysis of variance of the weight of the empty pods of soybean plant per plot as 3^2 factorial analysis.

Source of freedom	Degrees of freedom	Sum of square	Mean square	F-value
Replications	1	257.04	257.04	
Treatment	8	8991.90	1123.99	4.92*
S_ℓ	1	1719.85	1719.85	7.53*
S_q	1	1617.11	1617.11	7.08*
C_ℓ	1	2750.03	2750.03	12.04**
C_q	1	2573.19	2573.19	11.26**
$S_\ell S_\ell$	1	4.38	4.38	.02
$S_\ell C_q$	1	4.00	4.00	.02
$S_q C_\ell$	1	315.23	315.23	1.38
$S_q C_q$	1	8.09	8.09	.03
Error	8	1827.34	228.42	
Total	17			

*Indicates significance at 5 per cent level.

**Indicates significance at 1 per cent level.

S=soil, C=carbon dioxide, ℓ=linear, q=quadratic

$$c.v.=\frac{\sqrt{228.42}}{105.14}x\ 100\%=14.4\%.$$

Table 19. Experiment II. Analysis of variance of number of pods per plant of Kino soybeans as 3^2 factorial analysis.

Source of variation	Degrees of freedom	Sum of square	Mean square	F-value
Replications	1	14.66	14.66	1.10
Treatment	8	316.69	39.59	2.98
S_ℓ	1	41.40	41.40	3.11
S_q	1	3.19	3.19	.24
C_ℓ	1	105.97	105.97	7.97*
C_q	1	158.76	158.76	11.93**
$S_\ell C_\ell$	1	2.79	2.79	.21
$S_\ell C_q$	1	2.11	2.11	.16
$S_q C_\ell$	1	2.45	2.45	.18
$S_q C_q$	1	.01	.01	.00
Error	8	106.38	13.30	
Total	17	437.93		

*Indicates significance at 5 per cent level.

**Indicates significance at 1 per cent level.

S=soil, C=carbon dioxide, ℓ=linear, q=quadratic

$$\text{c.v.}=\frac{\sqrt{13.30}}{29.08}\times 100\%=12.6\%.$$

Table 20. Experiment II. Weight of empty pods of soybean plants, in grams per plot, as affected by carbon dioxide concentration and medium of growth.

Medium of growth	Carbon dioxide concentration (ppm) 300	1200	2400	Average
4:0	96.6[a]	139.2	135.6	123.8a[1]
3:1	74.7	110.0	90.5	91.7b
2:2	73.3	116.9	109.4	99.9b
Average	81.5a	122.0b	111.8b[1]	

Standard error of the treatment mean $s\bar{y}=6.2$.

[1] Mean values followed by the same letters are not significantly different at the .05 per cent level using Duncan's multiple range test (41).

and Hesketh (26) reported that high carbon dioxide concentrations caused stomatal closure. Gaastra (20) working with turnips, found complete stomatal closure at 1000 ppm and 4790 ft-c. light intensity. Stomatal closure depended also on the species of plants used (26,72). The degree of closure depends also on light intensity; therefore, low light intensity together with 2400 ppm carbon dioxide during this experiment might have been the limiting factors for carbon dioxide diffusion through partial or complete closure of stomata.

The average yield in the first experiment with 800 ppm carbon dioxide for a population of 497,194 plants per hectare was 4868.0 kg per hectare (Table 11) while for the second experiment in pure sand medium at 1200 ppm the yield was 5743.8 kg per hectare (Table 13). Despite the lower solar energy during the second experiment (Figs. 11, 12; Table 21), the yield was higher than in the preceding experiment, which indicated that high carbon dioxide concentration increases the efficiency of solar energy conversion. The average solar energy at noon for the first experiment was 73 cal/cm^2/hr while for the second experiment is 53/cm^2/hr.

Effect of sand mixtures on yield: Yields of the different growing medias of pure sand, 3 parts sand and 1 part peat moss, and 2 parts sand and 2 parts peat moss were 4,940.5, 3,846.1 and 3,730.6 kg per hectare respectively

(Table 13). Data in Fig. 13 show the productivity was highest in the pure sand medium. Table 14 and 15 present data on the number of pods per plant and the weight of seeds respectively. Statistical analysis of the data given in Table 17 show that linear affect of sand mixture on yield was significant at the 5 per cent level of probability. Plants that were grown in pure sand (4:0) yielded significantly more than those grown in sand and peat moss at ratio of 2:2 (Table 13). The remaining treatments were not significantly different.

Data in Table 13 show that the yield of soybean plants grown in pure sand (4:0) was 1094.4 kg/ha higher than 3:1 and 1209.9 kg/ha higher than 2:2. These differences in yield were due to the production of less seedless pods by plants grown in 4:0, because the number of pods per plants (Table 14) and weight of seeds (Table 15) were practically the same. Production of more seeds by plants grown in 4:0 also accounted for the heavier weight of empty pods (Table 20).

From these results, however, it should not be concluded exclusively that soybean plants will always perform best in the pure sand medium. Two factors in this experiment might have been involved in the reduction of the yield of soybean plants grown in the sand - peat moss mixtures. One may have been that the microrganisms in sand - peat moss mixtures were competing for nitrogen with

Table 21. Experiments I and II. The average daily and hourly (at noon) solar energy for each month throughout the Experiment I and II.

Month	$Cal/cm^2/day$	$Cal/cm^2/hr$
June	670.0	78.9
July	603.9	80.2
August	572.47	75.3
September	473.7	63.9
October	439.6	64.6
November	332.1	51.9
December	287.9	47.5
January	331.8	49.4

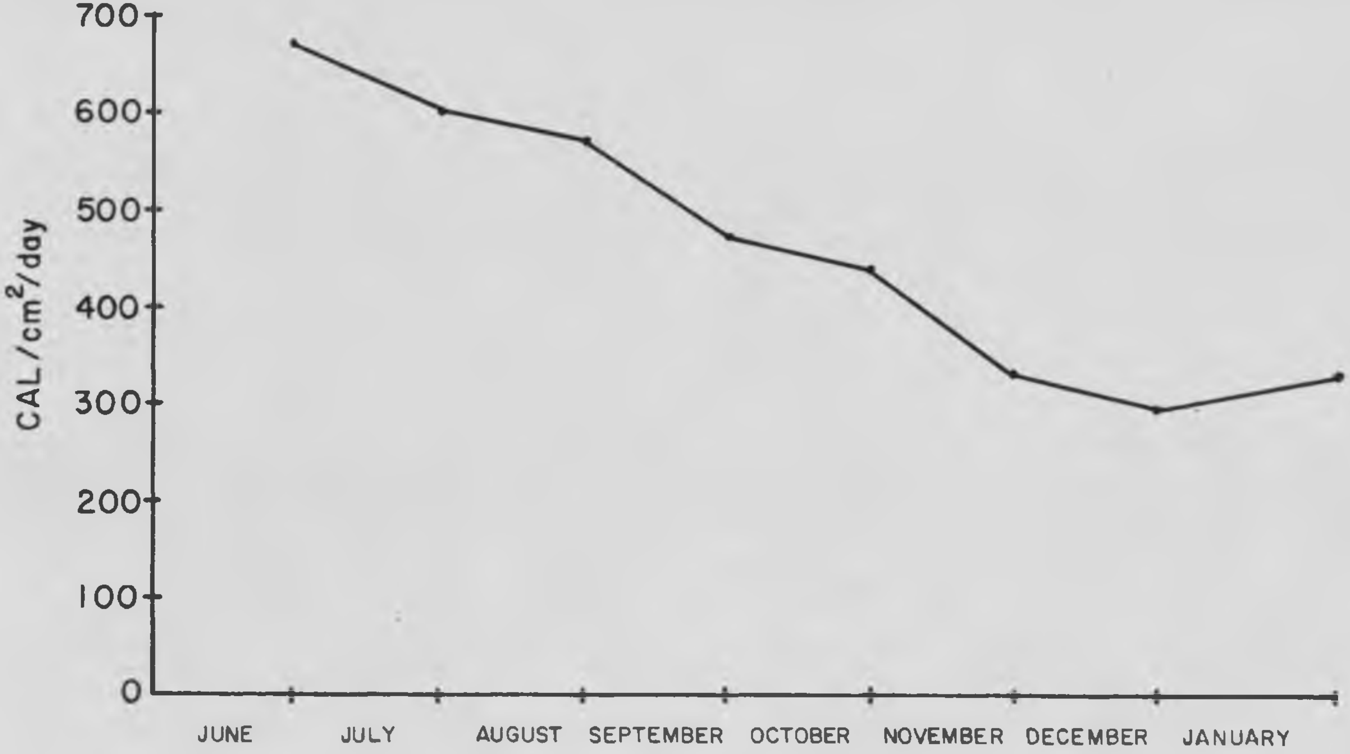


Figure 11. The average daily solar energy for each month throughout Experiments I and II.

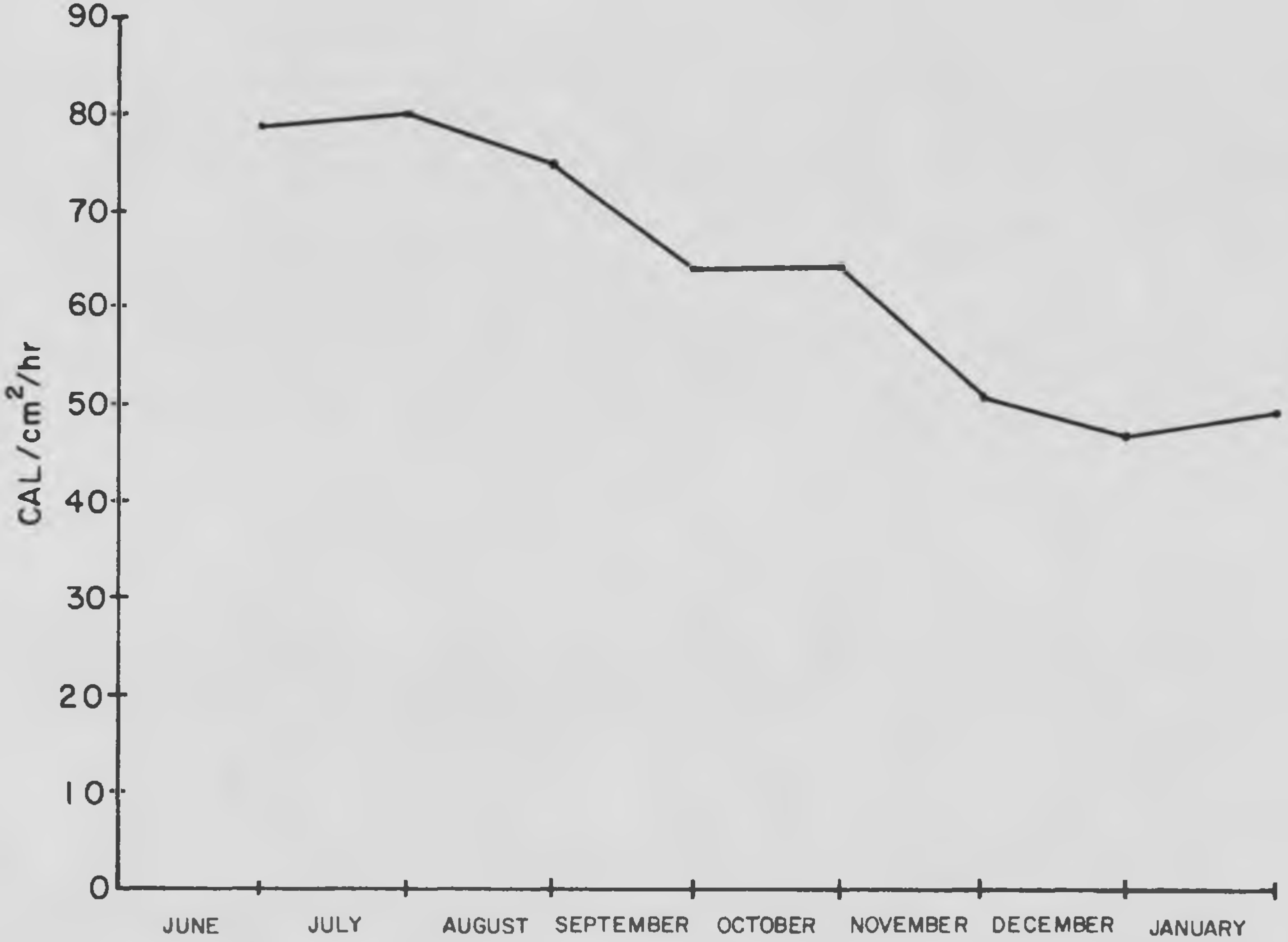


Figure 12. The average hourly solar energy for each month throughout the Experiments I and II.

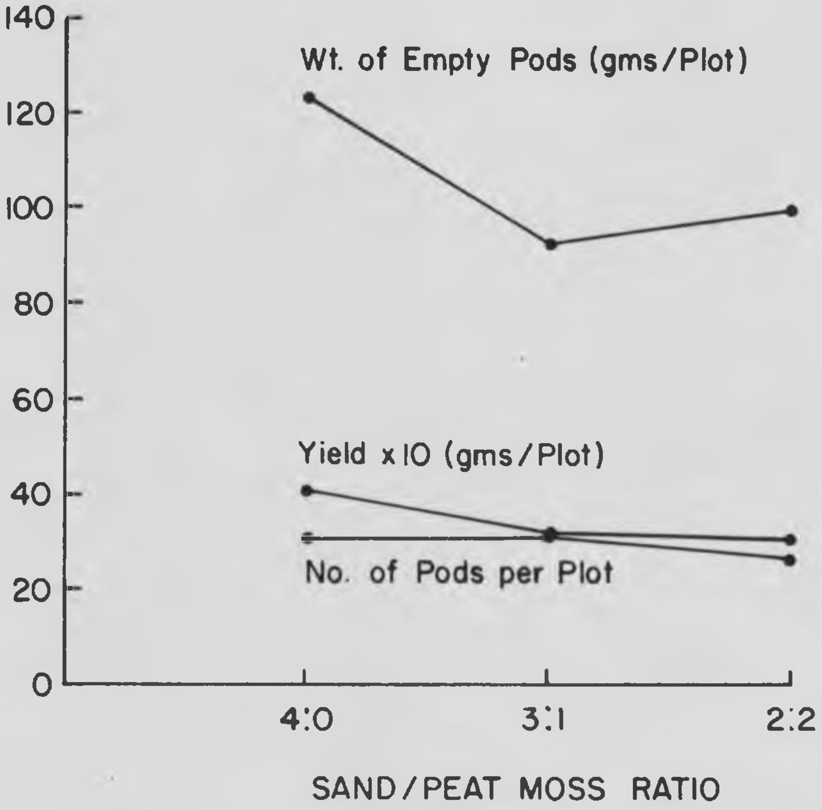


Figure 13. Experiment II. The seed yields (gms/plot), weight of empty pods (gms/plot), and number of pods per plant of Kino soybeans grown in pure sand (4:0), 3 parts sand and 1 part peat moss (3:1), 2 parts sand and 2 parts peat moss (2:2).

the plants and that the C/N ratio was rather high during the growing season. The second factor could have been the absorption of bromine by peat moss during the fumigation with methyl bromide. During this experiment, slight bromine toxicity symptoms showed up among soybean plants, and such toxicity was rather intensive among other crops that were growing in the same environment. Subsequent analysis of the sand - peat moss mixtures by Methyl Bromide Detector tubes (manufactured by UNICO) indicated the considerable absorption of bromine by peat moss (42). When air containing Methyl Bromide is drawn through the tube, its content (silica gel and a reactive chemical) turns reddish orange color, with total length of the discoloration being proportional to the air concentration.

The total amount of water used in this experiment was 408 gallons, which is 17 per cent of the total amount of water used in the Experiment I.

SUMMARY AND CONCLUSION

Two experiments were conducted concerning the growth of Kino soybeans in an enclosed environment of a plastic greenhouse. The first experiment started on June 11, 1966 and the second on October 4 of the same year. In the first experiment, an attempt was made to study the effect of the environment and plant population on growth development and yield of the soybean plants.

Results of the experiment showed that soybeans perform very well under high humidity (80%), high carbon dioxide concentration (800 ppm), in a polyethylene plastic greenhouse. The seed yield increased as plant density was increased. The yield was 3208, 4868, and 5782, and 6555 kilograms per hectare, corresponding to the plant populations of 247,097, 494,194, 988,388 and 1,729,679 per hectare respectively. The number of pods per plant increased, but plant height decreased at lower plant densities. High humidity prevented shedding of the flowers and dehiscences of pods.

In the second experiment an attempt was made to study the response of the soybean plants to three levels of carbon dioxide concentrations (300, 1200, 2400 ppm) and three different mixtures of sand and peat moss (4:0, 3:1, 2:2).

Results of this experiment indicated that the soybean plants performed best under 1200 ppm carbon dioxide and in pure sand. The yield obtained under 1200 ppm carbon dioxide concentration was 5037 kilograms per hectare which was a 45 per cent increase over the yield of plants grown in 300 ppm carbon dioxide concentration. High concentration of carbon dioxide (1200 ppm) apparently increased the yield by increasing the number of pods per plant.

The yield of the soybean plants grown in a pure sand was 4940 kg/ha which was 1209 kg/ha increase over plants grown in sand and peat moss at a ratio of 2:2.

A maximum yield of 9636 kg/ha (Table 7 Rep. 2 density of 1,729,679 plants/ha) of soybeans in this experiment was a good indication of favorable and suitable environmental conditions. Reiser (57) won the Illinois five-acre soybean yield contest in 1966 by obtaining an average of 5560 kg/ha. In 1964 the record was 4942 kg/ha.

The yield and productivity of any crop are a function of its genetic potential, environment, physiological factors and their interactions. The yield obtained in this experiment was a good indication of adaptability of the soybean plant to the environmental conditions of the experiment.

The length of time for emergence, flowering and maturing was normal when compared with varieties of soybeans grown in the field.

From the performance of the soybean plants observed in the first and second experiments, it can be deduced that this crop is apparently well adapted to high humidity and responds effectively and efficiently to high levels of plant population, carbon dioxide, light and temperature. Data obtained from these studies indicate that there is a good possibility of growing vegetables and other crops with a high level of protein in many arid coasts of the world using closed environments such as the ones described and used in the experiments reported in this thesis.

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