AN ABSTRACT OF THE THESIS OF

Jyotendra Narain Singh for the Ph.D. in Horticulture
(Name) (Degree) (Major)

Date thesis is presented Feb. 21st 1964.

Title EFFECTS OF MODIFYING THE ENVIRONMENT ON FLOWERING, FRUITING, AND BIOCHEMICAL COMPOSITION OF THE SNAP BEAN (PHASEOLUS VULGARIS L.)

Abstract approved ______________
(Major Professor)

The effects of modifying air temperature, soil temperature, and soil moisture levels on flowering, fruiting, and chemical composition of Tendercrop snap beans were studied in experiments in the field and in the greenhouse during 1961, 1962, and 1963.

High maximum temperatures of 95-105° F. during bloom reduced the percent set and number and weight of pods of bean plants. Plants appeared to be most sensitive to temperatures at six to eight days after first bloom. Air temperatures in the field were increased 8-10° F. above controls by use of clear polyethylene plastic cages.

The carbohydrate content of leaves and stems of plants subjected to high temperatures was decreased with a greater relative reduction of starch than of other sugars. Air temperature appeared also to affect the protein metabolism since cystine was not detected in plants subjected to high temperature. Furthermore, threonine

was detected in plants exposed to high temperatures, but not in control plants.

Soil temperatures ranging from 55° to 90° F. had a pronounced effect on growth, flowering, and yield of snap beans, with best growth of plants and highest number of flowers and pods and weight of pods being obtained at soil temperatures of 75° to 80° F. Diurnal fluctuation of soil temperature had no advantage over comparable constant mean soil temperature for growth of plants. An exception was at fluctuating soil temperatures of 50-60° F. compared to constant temperature of 55° F. Soil temperature did not affect levels of total sugar and reducing sugar, but the starch content was decreased with an increase in soil temperature. Sucrose content of plants at fluctuating soil temperatures tended to be higher than in plants grown at comparable constant mean temperatures. Dry weight of shoots and roots and P and K content of plants increased with increased soil temperature. Magnesium content tended to decrease with an increase of soil temperature while Ca content of plants was variable.

Snap bean plants which received the highest amount and frequency of irrigation from planting to harvest had the highest dry weight of shoots, number of flowers, percent set, and yield of pods when compared to plants subjected to moisture stress, either before or after bloom, or during both periods.

On a dry weight basis, the carbohydrate content of leaves and stems of plants was highest when amount and frequency of irrigation was highest, but on the fresh weight basis, the carbohydrate content decreased with an increase in soil moisture. The stems and leaves of plants at the high moisture treatments contained highest levels of P and K while N and Mg levels of the same plants were lowest. A higher concentration of arginine was found in plants at high moisture levels than at low moisture levels. Tyrosine was detected in plants grown at the higher moisture, but not in plants subjected to moisture stress. Data suggest that soil moisture levels affected protein metabolism. Sucrose sprays had no significant effect on production of pods and carbohydrate content of bean plants.

When soil temperature and moisture levels were varied, significant correlation co-efficients were obtained between weight of plants and number of pods, and between weight of plants and weight of pods.

Data suggest that for highest yield, environmental factors should favor production of a large vigorous plant, with large photosynthetic capacity for bearing flowers and fruits.

Bean plants appear to be especially sensitive to adverse temperature and moisture conditions during the period of anthesis and early pod development. Although adverse effects of high temperature and of moisture stress on pollination and fertilization were not studied, *per se*, in the present investigations, these adverse conditions caused a lower production of pods, lower carbohydrates levels, and appeared also to affect protein metabolism in snap beans.

Further research is needed, especially to elucidate the adverse effects of high temperatures and moisture stress on biochemical processes and constituents of the snap bean and the significant relationship of these to growth, flowering, and fruiting.

EFFECTS OF MODIFYING THE ENVIRONMENT ON FLOWERING, FRUITING, AND BIOCHEMICAL COMPOSITION OF THE SNAP BEAN (*PHASEOLUS VULGARIS* L.)

by

JYOTENDRA NARAIN SINGH

A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

June 1964

APPROVED:

Associate Professor of Horticulture

In Charge of Major

Head of Department of Horticulture

Dean of Graduate School

Date thesis is presented Feb 21 St 1964

Typed by Marcia Holcombe

ACKNOWLEDGEMENTS

The author wishes to express his very sincere and deep appreciation to Dr. Harry J. Mack for his inspiring guidance, continuous encouragement, and invaluable assistance during the study and in the preparation of this thesis.

Acknowledgement is also made to Dr. S. B. Apple, Jr., and Dr. W. W. Chilcote for critical reading of the transcript.

Last, but not least, I am grateful to my family and friends in India, and at Corvallis; especially to Dr. S. K. Bhullor for inspiration and encouragement to accomplish this goal.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDIX TABLES

LIST OF FIGURES

EFFECTS OF MODIFYING THE ENVIRONMENT ON FLOWERING, FRUITING, AND BIOCHEMICAL COMPOSITION OF THE SNAP BEAN (PHASEOLUS VULGARIS, L.)

INTRODUCTION

The snap bean (*Phaseolus vulgaris*, L.) is grown commercially in large acreages in the United States, either for dry shell or green pod consumption. About 300 thousand acres of snap or green beans with a value of approximately 87 million dollars were grown for fresh market and processing in the United States in 1962.

Oregon is the leading state in production of beans for processing, having about 16,300 acres, with an estimated value to growers of approximately 13.4 million dollars in 1962. The Willamette Valley of western Oregon has good soils, an abundant water supply, and long, clear, relatively cool summer days and cool nights for the production of beans. Beans are grown for canning and freezing, and thus, the processing industry is dependent on high yields of high quality snap beans.

The problem of securing consistent satisfactory yields of beans is one of importance to the vegetable industry. Under certain conditions, and in practically all parts of the country, large numbers of bean blossoms fail to set fruits. Even in areas where climatic conditions are considered to be ideal, the abortion and dropping of bean flowers, as well as loss of the small pods, may be so great as to reduce yields materially. Moreover, there may be a "split set" of pods which mature at different times and become difficult to harvest at the proper stage of maturity. Losses in yield of pole beans in western Oregon due to blossom drop occur occasionally but losses in 1956 were reported to be severe. This loss was apparently related to a period of about 10 days of abnormally high maximum temperatures, beginning in mid-July.

Blossom drop or pod set of beans appears to be a complex problem. Research workers in other areas have suggested several factors that may influence blossom drop and pod set of bush and lima beans. These include high maximum temperature, low minimum temperature, lack of available soil moisture, low relative humidity, and poor pollen germination. Other associated factors which have been mentioned are the carbohydrate-nitrogen ratio, light intensity, wind, inadequate fertilization, insects, inadequate plant nutrition, and plant spacing. The effects of the environment and other factors on growth, development, flowering and fruiting have been reported in considerable detail for tomatoes and lima beans, but information is limited for snap beans.

The objective of this study was to investigate the effect of modifying the environment (air temperature, soil temperature, irrigation practices) on flowering and fruiting of snap beans in the field, as well as in the greenhouse. The effects of these modified environments on the biochemical composition of the plants were also studied.

REVIEW OF LITERATURE

Air Temperature

Effect on Flowering and Fruiting

The growth and development of plants is governed by environmental factors interacting with the genetic makeup of the plant. Environmental factors such as temperature, moisture, light, soil, etc., are interrelated in affecting plant growth, and it can hardly be said one is more important than the other. During the life cycle of the plant, any one of the factors may become limiting. Temperature is one of the most important environmental factors affecting the morphological and physiological developments of plants. The detrimental effect of high temperature and low humidity on loss of blossoms and fruits has been observed for many years.

Davis (18) studied the effects of temperature, humidity, soil moisture, leaf area and fertilizer on the behavior of white pea beans (*Phaseolus vulgaris*, L.) in the greenhouse and in the field. He found that maximum temperature influenced the set of pods more than any other factors, and that the percent set of pods could be predicted from maximum temperature. Minimum relative humidity and soil moisture exerted only a minor influence on the set of pods. He concluded that bean plants have a certain capacity for holding blossoms and pods, and after they reach that limit, the blossoms and pods fall off. Iwami (29), working in Japan with snap beans, reported that at high temperature percentage set of pods is generally decreased. This effect was widely distributed among varieties, which he classified into three different types, high temperature, medium, and low temperature types. Watanabe (66) confirmed the work of Iwami and further reported that the germination of pollen grains and growth of pollen tubes were favored under wet conditions and moderate temperatures, the optimum temperature being 20-25° C. and humidity 94-100 percent. Smith and Pryor (53) studied the effect of high temperature on three varieties of beans and calculated the correlation of maximum temperature of the day before bloom, maximum temperature for the day of bloom, and maximum temperature the day after bloom with percent set. Significant negative correlations were found between percent set and maximum temperature the day before, the day of, and the day after bloom in two varieties.

Thomson (59) noted that climatic factors greatly affect bean blossom abscission. He suggested that the abortion of the bean flowers was probably due to poor pollen germination and pollen tube growth as a result of excessively high temperatures, which also caused the drying of the stigma and the styles before fertilization of the ovule. Viglierchio and Went (63) studied the effect of temperature, light intensity, and photoperiod on growth, development, and flowering and fruiting behavior of bean plants under controlled conditions. They found that the temperature to which plants are exposed during the night period is the most critical factor governing the developmental process. Temperature affected the habit as well as the stem elongation of bean plants. The number of leaves increased with increasing night temperature. Low night temperatures decreased and delayed the onset of flower opening while low day temperatures delayed the onset but increased the number of opening flowers.

As early as 1911, Shaw and Sherwin (52) and Hendry in 1918 (26) reported that the yield of lima beans was poor at high temperature and low humidity. According to Cordner (17) abscission of flowers of the Henderson bush lima bean is associated with high air temperature and dry atmosphere. He stated that the detrimental effect of these conditions will depend upon the time of occurrence and the duration of the adverse weather. Andrews (2) found that different varieties of lima beans responded differently to dry conditions. He noted that under the same conditions, the Henderson bush outyielded the Fordhook variety. This difference appeared to be due to the larger, thicker leaves, greater chlorophyll content, longer palisade cells and more open stomates of the leaves of the Henderson variety. Lambeth (35) studied the effect of mean daily temperature and mean daily humidity on percent set of Tendergreen snap beans grown at different nitrogen levels. He found a significant correlation between the percent set of pods and mean daily temperature, but no significant correlation was found between pod set and the mean daily relative humidity. Rappaport and Carolus (46) studied the effect of constant and alternate cool and warm night temperature periods during selected phases in the growth of two lima bean varieties. There was a trend in decreasing pod weight as night temperatures were varied from 50° to 70° F., following pre-bloom temperatures of 50° to 70° F. The number of pods produced was not necessarily associated with pod weight, although a general reduction in pod number occurred with increased temperatures.

Temperature has a marked effect on fruit set in the tomato. Fruit set is usually poor when the temperature is either relatively low or relatively high. Smith (54) reported that flowering of tomatoes appeared to be correlated with temperature and humidity. He stated that high temperature caused abnormal elongation of the stigma and also resulted in destruction of the stigmatic surface before pollination could occur. Thus, flowers failed to become fertilized and soon abscissed. Pollen germination was poor at 100° F. and the optimum temperature for pollen germination was 85° F. Radspinner (45) found similar results and reported that blossom drop is greatly increased by hot, dry winds and low humidity as well as low soil moisture. A lag of approximately three days was found between the time the temperature exerts an effect and the time that the effect becomes visible. Moore and Thomas (42) noted that when the average maximum day temperature was above 90° F. and the average minimum night temperature was above 70° F., the fruit set was low. High light intensity accompanied by high temperature was harmful to fruit set.

One of the important discoveries in the study of fruit set in recent years was that of Went (70) who found that with the commercial tomato varieties, fruit set is possible only over a limited and experimentally determinable range of night temperature. For the varieties studied, the night temperature found to be optimum for fruit setting ranged from 57^{o} to 68^{o} F. When night temperatures were either higher or lower than this range, fruit setting was reduced or completely terminated. Went (69) has also shown that the tomato plant is thermoperiodic, that is, the growth is more rapid with fluctuating than with constant temperature. His extensive study of the tomato clearly demonstrated that temperature is a highly decisive growth factor and that optimal temperature for different physiological processes may change with the age of the plant. Cochran (15) working with peppers (*Capsicum annuum*) showed that by altering the temperature throughout the growth of the pepper plant, the fruit set varied from zero to 100 percent. At 100^{o} F., no blossoms set fruit, but as the temperature was reduced from 90^{o}-100^{o} to 70^{o}-80^{o} and to 60^{o}-70^{o} F., an increase in percentage of fruit set resulted. On the other hand, pepper plants grown at an average temperature of 55^{o} F. failed to develop flower buds. Cochran associated the dropping buds, blossoms, and immature fruits of pepper to an excessive water loss as a result of high temperature, low humidity, excessive transpiration and low soil moisture.

Effect on Biochemical Composition

The rate of every physiological and biochemical process occurring in plants is markedly influenced by temperature. The rate of reaction or rate of growth of the plant has been reported to increase two to ten-fold with each 10° C. rise in temperature. In 1920, Walster (65) reported that at high temperatures, barley leaves contained a much lower percentage of both total and reducing sugar and lower percentage of polysaccharides. These leaves also contained high percentages of phosphorus and nitrogen. The amount of active metabolic nitrogen constituents, such as amino acids, polypeptides, and similar water soluble proteins, was much higher at high temperatures. Tottingham (62) found in red clover (*Trifolium pratense*) and Buckwheat (*Polygonum fagophyrum*) higher contents of polysaccharides and crude protein at a 15° C. temperature than at 22° C. to 25° C. The nitrogen content of leaves and stems varied inversely with the polysaccharides content. Bushnell (13) grew potato plants at temperatures of 20°, 22°, 24°, 26° and 29° C. He found greater tuber formation at 20° than at 26° C. and there was no tuber formation at 29° C. He concluded that the reduction in carbohydrates by a high rate of respiration accounted for the failure to form tubers at the highest temperature. Went and Engelsberg (72) determined the sucrose content of the leaves, stem and roots of tomato plants held at temperatures of 8°, 17° and 26° C for 12 hours in darkness. There was a higher sucrose content in the roots of those plants held at 8^{o} than those held at 17^{o} C. Also, there was higher sucrose content in the roots and a slightly lower sucrose content in the leaves of those plants held at 17^{o} than those held at 26^{o} C. They noted that sucrose content of leaves was high after both cool (8^{o}) and warm (26^{o}) nights because growth was reduced at those temperatures. They interpreted their data to mean that the rate of sugar translocation in a tomato plant decreased as the temperature was raised from 8^{o} to 26^{o} C. Hewitt and Curtis (27) noted that the carbohydrate content of the roots, stems and leaves of bean plants grown at 10^{o}, 20^{o}, 30^{o}, and 40^{o} C., became progressively smaller with each 10^{o} C. rise in temperature. At all temperatures the final carbohydrate content was less than the initial content. The dry weight of the plants also decreased as the temperature increased. Loss in dry matter was associated with losses of carbohydrate content due to increased respiration at higher temperature.

Bonner (9) proposed the chemical cure of "climatic lesions" on the hypothesis that at certain climatic extremes, there may be inactivation of one or a few reactions contributing to growth and cause a shortage of one or a few essential metabolites. Shortage of metabolites could be overcome by supplying the substance from an external source. Galston and Hand (24) found a greater response in growth of peas to exogenous adenine at high temperatures. At the highest temperature (35^{o} C), the thermal inhibition of growth was overcome by the addition of relatively small quantities of adenine. They concluded that the capacity of the pea plant to produce sufficient adenine for growth was reduced at high temperatures. Langridge and Griffing (37) reported that eight out of 43 races of *Arabidopsis thaliana* showed a marked decrease in growth at 31.5^{o} C. Some of the races produced increased growth at high temperature with vitamin C, yeast extract, and nucleic acids. Ketellapper (32) recently indicated that in a number of cases the reduction in growth caused by unfavorable temperature can be prevented either partially or completely by applying chemically well defined substances to plants growing under unfavorable temperature conditions. Nicotinic acid stimulated the growth of tomato, a mixture of B vitamins stimulated cosmos and a mixture of ribosides stimulated the growth of eggplant when plants were grown at below optimum temperatures. The detrimental effect of high temperature on peas could be counteracted by sucrose, vitamin B, or a riboside mixture, depending on seed source and temperature. Vitamin C stimulated the growth of broad bean at the high temperature (30^{o} C).

Weintraub and Brown (67) found that the stem elongation of bean plants varied linearly with concentration of supplied sucrose up to 0.75 m. Glucose and maltose were approximately equal to sucrose in supporting growth, whereas fructose was somewhat inferior; lactose and galactose were much less satisfactory. Went and Carter (71) reported that tomato roots took up very little sugar, stems took up mainly through wounds and intact leaves absorbed through the whole surface. The applied sugar greatly increased the growth rate and life span of the tomato plants when applied in darkness, but the results of the experiments in light in greenhouse were not consistent. Sugar increased growth and flower production only when the plants were grown at a high temperature and at a low light intensity. Bohning, et. al. (8) found that leaf and stem elongation in tomato were directly proportional to concentration of supplied sucrose within certain limits (in the range of 0.00 to 0.4M). The optimum temperature for carbohydrate transport occurred at approximately 24° C.

Soil Temperature

Effect on Flowering and Fruiting

Reddick (47) noted in early work with beans grown in the greenhouse at soil temperatures of 15°, 22°, and 34° C. that soil temperature affected general vigor and yields. He concluded that root and foliage temperatures are readily separable as conditions influencing the growth of plants. Burkholder (12) reported that a soil temperature of 18° C., as compared to 26° C., decreased the yield of healthy bean plants. He suggested that the optimum soil temperature range for beans was 22° to 26° C. Allen (1) observed the effect of soil temperature on the growth and flowering of certain ornamental greenhouse crops, greenhouse stocks, calendulas, snapdragons, fuscias, and found that at soil temperatures of 52°, 60°, and 72° F., there were differences in time of flowering as well as number of flowers. He stated that part of the effect of high temperature in the greenhouse bench was to hasten nitrification in the soil.

Riethmann (48) reported an increased shoot growth of tomatoes with increasing root temperature in the range of approximately 10° to 25° C. and that stem growth and fruit set largely depended on root temperature. Went (69) used the term "thermoperiodicity" to include all effects of temperature differentials between light and dark periods on the flowering, fruiting, and plant growth. Fruiting of tomatoes as well as shoot growth and root growth was significantly increased by lowering the air, and presumably to some extent, the soil temperature, during the dark hours. Went concluded from his limited data that under his experimental conditions, which provided good aeration and abundant nutrient supply to the roots, shoot growth was not materially increased or decreased by root temperature varying from 15.5° to 32.5° C. Recently, Martin and Wilcox (40) found in tomato a growth increase (as expressed by dry weight) between 56° and 58° and 58° and 70° F., but not between 58° and 60° F. The root growth at 56° F. was slower than at the higher soil temperatures. Also, at 56° F., there was almost no secondary root growth, whereas at 58° F. and above, profuse secondary root growth was observed.

Effect on Biochemical Composition

Apparently very little work has been done on the effect of soil temperature on the biochemical composition of plants. Shanks and Laurie (51) observed effects of soil temperatures on rooted cuttings of Better Times roses at soil temperatures of 56°, 60°, 68° and 72° F. They found the percentage of glucose and sucrose in the tops did not show any correlation with temperature. In roots, the same was true except starch was lower at 60° F. and greater amount was present up to 72° F. Benedict (5) found that the dry weight of flowers, leaves, and stems of guayule plants increased with increased soil temperature up to 80-85° F. and then decreased with further increases in soil temperature. Low soil temperature seemed to favor the accumulation of carbohydrate reserves. The percentage of free sugars, levulins, and inulins dropped rapidly as the soil temperature was increased to 65° F., but no further change occurred as the soil temperature increased to 95° F. Sullivan and Sprague (56) found that in rye grass, reducing sugar showed little response to soil temperature, but there was a reduction of reserve carbohydrate with rising temperature.

Apple and Butts (3) reported a greater response of beans to phosphate application at a soil temperature of 63° than at 82° F., but stated that other factors not under their control, such as light intensity, might have affected their results. They noted that uptake of P increased as the soil temperature increased.

Several workers have studied the effect of soil temperature on chemical composition of tomato plants. Cannell, et. al. (14) determined the growth of tomato plants at four soil temperatures, 54°, 68°, 82°, and 96° F., in combination with two soil moisture levels and three phosphorus levels. They found a curvilinear relationship between yield and temperature. The contents of Ca, K, P, N, Cu, Fe, Mn and Zn were significantly affected by temperature, and for all elements but Mn, the effects were curvilinear. Highest yield was found at 68° F. Lingle and Davis (38) found increased shoot growth with increasing root temperature in the range of approximately 10 to 25° C. Absorption of all the mineral constituents determined increased as soil temperature increased from 50-55° to 70-75° F. Concentration of P and K increased over the entire range of temperature studied, while Na and Ca concentration were lower at 80-85° than at 70-75° F. Mg concentration had apparently stabilized at a point below the highest temperature. Locascio and Warren (39) found that soil temperature had a marked effect on both the growth of tomato plants and response to P. Dry weights of tomato plants were much less at a soil temperature of 55° than at 70° or 85° F. There was no significant difference between the growth at 70° and 85° F. Martin and Wilcox (40) recently reported that uptake of nutrient in tomato increased with the increase of temperature from 56° F. to 58° F., but the difference was not great enough to have any practical importance. However, Ca composition was not directly affected by temperature. Theron (57) noted a significant increase in total nitrogen content as well as nitrate content with increase in soil temperature. Also, the increases in percentage of K in both corn and turnips were found to be associated with an increase in soil temperature.

Soil Moisture

Effect on Flowering and Fruiting

Kattan and Fleming (31) reported that irrigation during the period from planting to blooming had little effect on the yield and number of pods per plant of snap beans, provided soil moisture was adequately supplied throughout the rest of the growing season, and provided soil moisture content was high at planting time. Moisture stress during the period of pod development and harvest was most detrimental to yield, size, and quality of pods. According to Binkley (6), irrigation increased the yield of garden beans 20-30 percent. The fluctuation of the soil moisture during the blooming period increased the rate of abscission of flowers and young pods. Lambeth (36) found that wilting lima bean plants for six hours during blooming reduced the percentage flowers setting pods from 30 percent to less than 5 percent. He concluded from his study that pod set was markedly lowered at soil moisture levels exceeding field capacity or at soil moisture levels approaching the wilting co-efficient. The reduction in pod set was due to failure of pollen grains to germinate and grow after germination. Microscopic examination showed that under moisture stress, water was withdrawn from the floral buds, causing their desiccation and abscission. Less stigmatic fluid was produced under high temperature and low soil moisture. Gabelman and Williams (23) reported that soil moisture levels low enough from planting to anthesis to induce plant stunting without wilting, reduced the yield of beans even though the available moisture in the soil following anthesis was kept above 50 percent. The reduction in yield was due to the production of fewer flowers and smaller pods containing a higher percentage of aborted ovules. Even in the experiment in which there was little difference in plant size prior to blooming, the yield was reduced due to abscission of flower buds. The reason for abscission was not clear. Ayers, et al. (4) obtained best growth and yields of pods from bean plants grown in soils in which moisture was maintained at a low tension. The number of pods, number of seeds per pod, and weight of beans per plot was higher in the low tension treatment.

Cochran (16) associated the dropping of buds, blossoms, and immature fruits of peppers with unfavorable water supply to the plant or to excessive water loss as a result of high temperature, low humidity, excessive transpiration, or low soil moisture.

Effect on Biochemical Composition

Many papers report that specific changes in composition and metabolism take place in plants under water stress conditions. The data do not show clearly, however, how water deficits influence these shifts in metabolism, and reports on the biochemical composition of tissue under moisture deficits are frequently conflicting.

Wadleigh and Ayers (64) found that increased soil moisture tension tended to increase nitrogen and decrease starch in the leaves of beans. Starch reserves of bean leaves showed marked depletion as the soil dried out, but was still above the wilting percentage. Soil moisture tension had no effect on percentage of reducing sugars, whereas increasing salt concentration was associated with a definite decrease in percentage of these sugars in stems. There was a pronounced buildup of starch immediately following irrigation. Janes (30) found (on the fresh weight basis) that the average contents of ascorbic acid, carotene, reducing sugar, total sugar, acid hydrolyzable carbohydrates, acid insoluble residue, ash, Ca, Na, P, N, S, Fe, and Mn were highest in the beans grown without irrigation, intermediate in those grown with light irrigation and lowest in those grown with heavy irrigation. However, when the results were expressed on a dry weight basis, most of the differences became smaller or disappeared. The beans from the light irrigation plots had the lowest sugar content on a dry weight basis. He stated that the greatest difference was one of hydration.

Woodhams and Kozlowski (74) studied the effect of different degrees of moisture stress on the carbohydrate reserves and growth of beans and tomato plants. Reducing the moisture content of the soil brought about definite changes in the carbohydrate content of plants. They found a reduced starch content (dry weight basis) of stem, leaves, and roots after bean plants had been allowed to wilt for some time. During the period of gradual loss of water, the plants exhibited a decrease in both forms of sugars and starch which took place before the appearance of first signs of wilting. When the plants were irrigated, there was a rapid and marked increase in starch, but no corresponding increase in reducing sugar and non-reducing sugar.

Gates and Bonner (25) reported that the amount of both DNA and RNA per leaf decreased under water deficits, although they were similar on a dry weight basis in the water deficient and control treatments of tomatoes. The decrease in nucleic acid per leaf was intimately related to the slower growth rate per leaf. They attempted to verify whether this decrease was due to decreased synthesis in response to water deficits. Their results show that the rate of P_{32} incorporation into nucleic acid under moisture deficits remained unchanged with respect to the control. This indicated that the decrease in net production of nucleic acid under a water deficit was probably due to accelerated destruction rather than decreased synthesis. Since protein synthesis is related to RNA, the effects of moisture deficits on nucleic acid will reduce the rate of protein synthesis.

Petrie and Wood (44) did a series of studies on the nitrogen metabolism of plants (Lolium multiflorum) in relation to several environmental factors and noted that the net formation of protein from amino acid decreased as moisture deficits increased. The result of one of the experiments indicated that there was a considerable change in the ratio of the amounts of one amino acid (cystine) to that of the others as the water content decreased. The amount of cystine did not continuously increase, but may have actually decreased as the amount of other amino acid increased.

The results of different experiments on the uptake of nutrient elements in relation to moisture levels is conflicting. Emmert (20) found that tomato plants grown under relatively low moisture conditions were higher in leaf N and K and lower in P than in more moist conditions. The effect on soil phosphate nutrition was less consistent than N and K. Janes (30) in beans found a high content of P in plants limited in growth by low soil moisture supply, whereas Emmert (20) in tomato, and Thomas, *et*. *al*. (58) noted low content of phosphate. Emmert and Thomas also noted that Mg was relatively high in plants growing under restricted soil moisture supply. Since entry of Ca and K into plants tends to vary reciprocally, it could be inferred that the characteristically low K content of plants with inadequate soil moisture supply would be accompanied by a relatively high content of Ca. Miller and Duley (41) with corn, and Janes (30) with beans, found virtually no effect of soil moisture supply on Ca content of their experimental plants. It is evident, therefore, that the status of other constituents in the soil has an effect on Ca availability under varying soil moisture contents. Cannell (14) recently observed in tomato plants that Ca, Mg, K, N, Mn, and Zn were increased with decreasing soil moisture content. Microelements Fe, Mn, Zn, and Cu consistently increased with decreased soil moisture.

MATERIALS AND METHODS

Eight experiments in the field and in the greenhouse were conducted to study the effects of modifying the environment on flowering, fruiting, and biochemical composition of snap beans. The following arrangement will be used in reference to the eight experiments: (1) Air temperature effects -- field and greenhouse -- Experiments No. 1, 2, 3, 4. (2) Soil temperature effects -- greenhouse -- Experiments No. 5, 6. (3) Soil moisture effects -- field -- Experiments No. 7, 8.

Tendercrop, a bush type snap bean, was used in all experiments. Percent set of blossoms (pod set) was evaluated by tagging individual blossoms before or at anthesis and then counting pods on individual plants at harvest. Harvest was by hand on a once-over basis. Certain data were analyzed statistically by analysis of variance.

Field Experiments -- All field experiments were conducted at the Oregon State University Vegetable Research Farm near Corvallis where the soil type is a Chehalis silt loam. Seeding of beans was by conventional planters in rows three feet apart. Approximately 400 to 500 pounds 8-24-8 fertilizer per acre was banded at planting time. Plants were thinned so that there was a uniform stand in each experiment. Weed control and insect control were according to general practice. Unless moisture variables were studied, plots were irrigated by overhead rotary sprinklers with sufficient water at eight to ten day intervals to insure an adequate moisture supply. The amount and frequency of water applied in the irrigation experiments is reported in those experiments.

Greenhouse Experiments -- Beans were planted in Chehalis soil in two-gallon cans. One teaspoon of 8-24-8 fertilizer had been mixed with the soil prior to planting. After emergence plants were thinned leaving uniform numbers of plants per can. Plants were watered periodically to maintain adequate moisture levels.

Effects of Air Temperatures on Bean Plants

Experiment No. 1 -- A preliminary field experiment was conducted in 1961 to study the effect of modifying the temperature on yield of snap beans.

Tendercrop snap bean seed was planted in the field on May 18 in eight-foot plots. Three kinds of cages, made of black polyethylene plastic, near-clear polyethylene plastic with perforations, and white cloth, were used to raise the air temperatures. The plants at about full bloom were kept enclosed under the cages for approximately 50 hours continuously from July 11 to July 13. Of course, light intensities were affected as well as temperature. Two additional treatments included a control and a spray treatment on July 10 of two percent sugar (sucrose). A sugar solution was sprayed on plants in an attempt to increase the carbohydrate content of plant and to evaluate the subsequent effect on the yield. The plots were harvested on July 25, and yield was recorded as pounds per plot as well as grams per plant.

Experiment No. 2 -- A field experiment in 1962 was designed to study the effects of high air temperature and moisture levels on flowering, fruiting, and carbohydrate content of bean plants.

Tendercrop bush beans were planted on May 29, and after emergence, plants were thinned to a spacing of nine inches in the row to facilitate counting of blossoms. Plots were 11 feet long.

The experiment included three moisture levels and seven temperature treatments. Moisture levels were as follows:

M1 -- Normal irrigation early, moisture stress during bloom, irrigate after the major flowering period; three irrigations -- approximately 4.5 inches of water.

M2 -- No irrigation until bloom, then irrigate for remainder of the season; three irrigations -- approximately 5.0 inches of water.

M3 -- Normal irrigation throughout, every seven to ten days; six irrigations -- approximately 9.5 inches of water.

At each moisture level, seven temperature treatments were replicated four times. These treatments included a check treatment and the use of plastic cages at zero, two, four, six, eight, and ten days after first bloom. The cages of 11 ft. x 3 ft. were covered with polyethylene plastic which had been perforated to allow ventilation. Plastic cages covered the plants for a 40 hour period. The temperatures outside and inside plastic cages in moisture treatment M3 were recorded continuously by thermographs. Temperatures inside and outside the plastic cages in other moisture treatments were checked periodically. In all cases the temperature inside the plastic cages was 8-10^{o} F. higher than outside. Light intensity under plastic cages was 75 to 80 percent of controls. Carbohydrate content and fresh weight of the plants were determined on two plant samples from each treatment. The first sample was taken before plants were covered with the plastic cage, and the second after the plastic cage was removed. Samples from check plots were also taken at the time when plastic cages were removed. At harvesting, number and weight of pods per plant and the weight of plants were determined.

Experiment No. 3 -- In 1963 an experiment was conducted in the field to further study the effect of high temperature and sugar sprays on flowering, fruiting, and biochemical composition of bean plants.

Tendercrop snap beans were planted in the field on June 11. The experiment included the four following treatments, replicated five times, in a randomized block design: (1) control, (2) plants covered with plastic cages for 75 hours, (3) plants covered with plastic cages for 75 hours plus two four-percent sugar sprays, and (4) sugar sprays. A sugar solution was sprayed on bean plants to attempt to offset the adverse effect of high temperatures by increasing the carbohydrate content of plants. Polyethylene (near-clear) plastic cages previously mentioned in Experiment No. 2 were used, and plants were covered at eight days after first bloom. Plant samples for carbohydrate analysis were taken at the time plastic cages were removed on August 10. Thirty-five plants per plot were harvested for yield, and number and weight of pods per plot and per plant were determined.

Experiment No. 4 -- The objective of this experiment in 1963 was to study the effect of high temperature in the greenhouse on flowering, fruiting, and biochemical composition of beans.

On July 12, beans were planted in cans that were kept outside adjacent to the greenhouses. After emergence, the plants were thinned leaving two plants per can. At first bloom and at full bloom, certain plants were transferred to two greenhouses in which the maximum temperatures were maintained at approximately 100° F. and 110° F. The plants in each stage of bloom were exposed to these high temperatures in the greenhouse for five days and then returned to an area outside the greenhouses. Two plant samples from each treatment were taken (the first before exposing plants to high temperature, and the second after removing plants from high temperature) for analysis of carbohydrate content and free amino acids. Plants were harvested on September 6th and the number and weight of pods per plant were recorded. Also, percent set was determined.

Effects of Soil Temperatures on Bean Plants

Experiment No. 5 -- The purpose of this experiment in the greenhouse in 1961-62 was to study the effects of soil temperatures on growth, flowering, and fruiting of bean plants.

Tendercrop snap beans were planted on December 15, 1961, and were germinated at 75° F. After emergence, the cans with seedlings were transferred to water bath temperature tanks in which temperatures were maintained at 60°, 65°, 70°, and 75° F. ± 1° F. The cans were immersed in water to such a depth that the soil level in each can was below the level of water. The water baths were equipped with thermostatically controlled refrigeration and heating units, and continuous operating immersion pumps, for maintaining uniform temperatures throughout each tank. The water baths were covered except for openings in the cover in which the containers were inserted. Peat moss was used as an insulating material over the soil surface of each container to lessen heat exchange between the soil and the atmosphere. The soil moisture content in the cans was maintained near the predetermined field capacity by weighing daily. To determine fresh and dry weight and mineral composition of plants, five plant samples were taken at weekly intervals after transferring the cans to tanks. Only one plant remained in each can for flower and pod counts. The pods were harvested on February 14, 1962, and the number of pods and weight of pods per plant were recorded. After harvesting, the roots of plants were removed by slowly washing the roots free from the soil and dry weight of roots was determined. The design of the experiment was completely randomized with 11 replications. Correlation coefficients between root weight and number of pods, and dry weight of shoots and number of pods were calculated.

Experiment No. 6 -- This experiment was similar to Experiment No. 5 in 1962, except that a wider range of soil temperatures was included. Furthermore, both constant and fluctuating soil temperatures were maintained.

Tendercrop bush beans were planted in cans on March 21 and were germinated at 70° F. After emergence, cans with seedlings were transferred to respective water bath temperature tanks. Constant soil temperatures used were 55°, 60°, 65°, 70°, 75°, 80°, 85°, and 90° F. Fluctuating soil temperatures of 50-60°, 60-70°, 70-80°, and 80-90° F. were also used. Soil temperatures during the day were higher by 10° F. than night temperatures, and were attained by daily transfer of cans at 7:00 A.M. and 7:00 P.M.

The design of the experiment was completely randomized with ten replications.

One sample at full bloom was taken to determine the dry weight, height, and number of internodes of plants. At the same time, plant samples were also taken for determination of carbohydrate content on a fresh weight basis and mineral composition on a dry weight basis. One plant per can remained for yield determinations later. Because of attempting to harvest pods at comparable stages of maturity, the dates of harvesting were different for soil temperature treatments. At harvest, the number and weight of pods per plant and dry weight of shoots and roots were determined. Data were subjected to analysis of variance. Also, correlation coefficients between root weight and number of pods and shoot weight and number of pods were calculated.

Effects of Moisture Treatments on Bean Plants

Experiment No. 7 -- The objective of this field experiment in 1962 was to study the effect of soil moisture levels on flowering, fruiting, and biochemical composition of beans. The seed was planted on June 11 and plants were thinned to a stand of one plant per foot to facilitate the counting of blossoms. Rows were spaced three feet apart and plots were 20 feet in length. Plot irrigations were used for application of irrigation water (49). The experiment included the six moisture treatments listed below with four replications in a randomized block design.

Moisture levels	Number of irrigations	Inches of water applied
M1 -- To be irrigated to field capacity when moisture tension value is below 2.5 bar.	3	6.8
M2 -- Maintain same tension value as in M1, but on a more frequent schedule (also entire profile may not be irrigated up to field capacity).	3	5.2
M3 -- To be irrigated to field capacity when moisture tension value is below 1.0 bar.	5	9.0
M4 -- Maintain same tension value as in M3, but on a more frequent schedule (also entire profile may not be irrigated up to field capacity).	6	8.1
M5 -- No irrigation until bloom, then irrigate every other day.	14	10.9
M6 -- Irrigated weekly until bloom, then every other day.	18	17.1

All plots received an irrigation of approximately 1.0 inch just after planting, in addition to that listed above. Rainfall for the period of June 11 to August 16 was approximately 0.6 inch.

Gypsum stakes were installed in each moisture plot in order to record progress of moisture use and to determine when to irrigate. Soil moisture tension values are not included here.

Blossoms of plants in moisture treatments M1, M3, and M6 were counted. Two plant samples, on August 4 and August 18, from the three treatments were taken for chemical analysis. Carbohydrate content was determined on the fresh weight basis on both the samples, but the mineral content was determined on dry weight basis on only one sample. The pods of all six treatments were harvested by hand and yield per plant in grams as well as the weight of plants were recorded. The pods were counted and their sieve size and grades were determined. The correlation coefficients between weight of plants and number of pods, and weight of plants and weight of pods, were calculated.

Experiment No. 8 -- This irrigation experiment in 1963 was similar to Experiment No. 7 with a slight modification in the M5 moisture treatment as follows: Until bloom, to be irrigated to field capacity when moisture tension below 2,5 bar, beginning at early bloom, irrigate every other day.

Moisture level	Number of irrigations	Inches of water applied
M1	2	4.1
M2	3	3.0
M3	5	9.2
M4	7	7.5
M5	11	8.9
M6	14	11.5

In addition to amounts of water applied above, all plots received approximately 0.8 inch of irrigation water after planting; rainfall for May 31 to August 15 was approximately 1.5 inches.

The seeds of Tendercrop snap beans were planted on May 31 and 400 pounds per acre of 8-24-8 was banded at the time of planting. Prior to planting, 30 pounds of nitrogen (ammonium sulfate) was broadcast and disked in.

One plant sample was taken on August 1 to determine moisture content and chemical composition. Carbohydrate content was determined on fresh and on dry plant material. Free amino acids were determined by paper chromatography. The pods were harvested on August 16 and the weight of pods and number of pods were recorded on an individual plant basis. Correlation coefficients between weight of plants and weight and number of pods were calculated.

Chemical Analysis

Carbohydrates -- As soon as possible after sampling, plants were washed with water and then air dried. The plants were segregated into leaves, stems, and pods, if present. Plant material was chopped into small pieces and extraction was done in 80 percent ethyl alcohol in a Waring blender. The alcohol soluble portions were used for determination of reducing sugar, sucrose, and total sugar. The alcohol insoluble portions were used for starch determination. An aqueous extract was prepared by evaporating the alcohol, adding water and clarifying with neutral lead acetate. (28) The titration method of Somogyi (55) was used for the reducing sugar determination. Total sugar and sucrose were determined with the same procedure as reducing sugar, except the sugar solution was hydrolyzed by concentrated hydrochloric acid into reducing sugar and determined by the same procedure. Acid was used for hydrolysis of sucrose rather than invertase because the completion of hydrolysis by invertase was attained very slowly in the bean plant extract. Sucrose was calculated by amount of total sugars, minus the amount of reducing sugar, multiplied by 0.95.

Starch was determined on the residue by the method described in A.O.A.C. (28) using hydrochloric acid as the hydrolytic agent. All the determinations were made in duplicate.

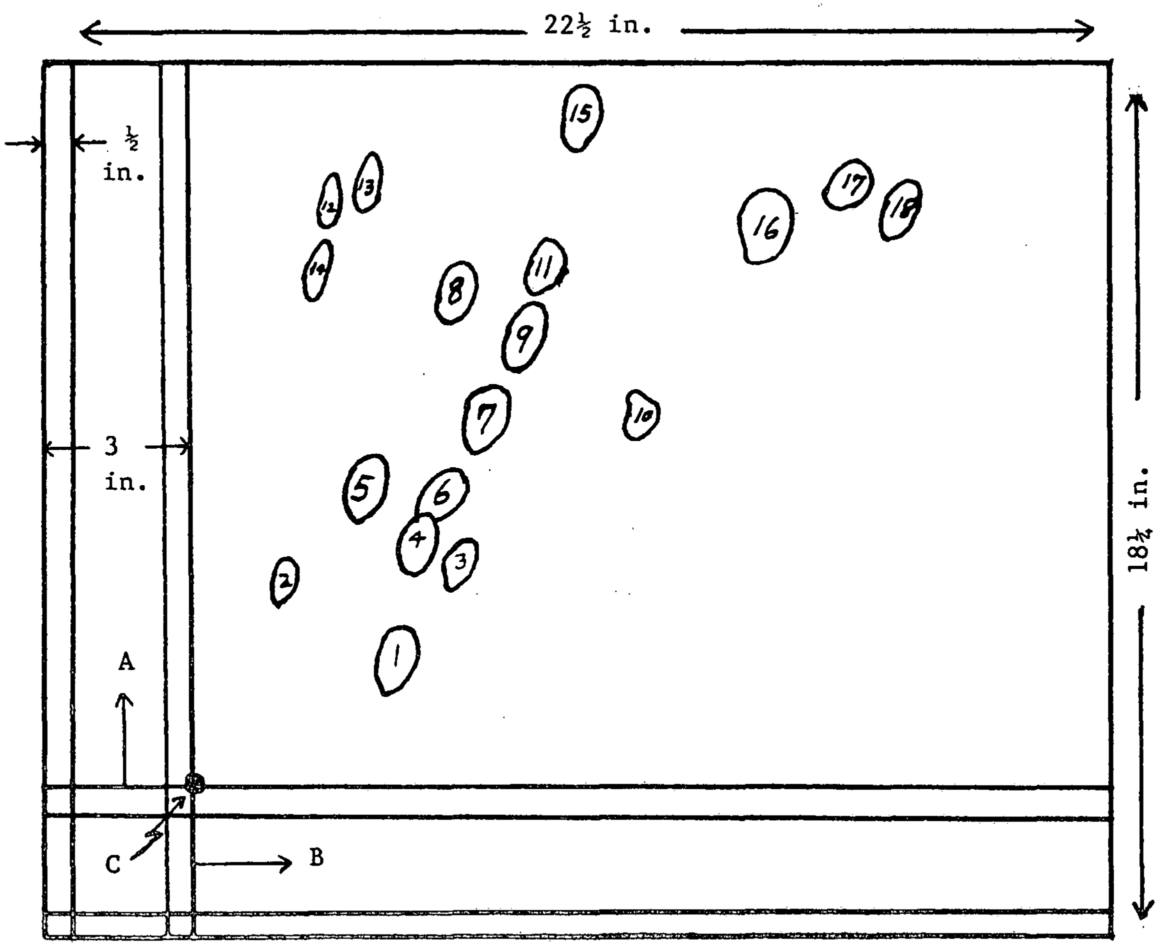
In Experiment No. 8, the carbohydrate content was determined also on a dry weight basis. The material was dried in an oven at approximately 70° C., then extracted with 80 percent ethyl alcohol in a soxhlet extraction apparatus for 15 hours to yield alcohol soluble and insoluble portions.

Mineral Composition -- The samples taken from certain experiments were analyzed for N, P, K, Ca, and Mg. Phosphorus was determined colorimetrically by the molybdenum blue method of Fiske and Subbarow (21), K and Ca with the flame photometer (11), Mg by the thiazole yellow procedure of Drosdoff and Nearpass (19), and the N was determined by the Kjeldahl method (28).

Paper Chromatography of Amino Acids -- The 100 ml alcohol extract of samples was reduced to 5 ml by evaporating under reduced pressure at 50° C. Amino acids which were adsorbed on a Dowex 50W-X4 column prior to removal of organic acids and other interfering elements, were eluted by three to four washings with 20 ml. 3N NH_4OH solution. The combined elutes were then evaporated under a ventilated hood until no odor of ammonia could be detected. The concentrated solutions were diluted to 5 ml. by adding 0.1N HCl.

Amino acids were separated by two-dimensional paper chromatography following the general procedures outlined by Block, et. al. (7). A 150 microliter aliquot of the extract was spotted on one corner of a 18 x 22 inch sheet of Whatman #1 filter paper, which was then suspended in a chromatography cabinet. After sealing, 100 ml. of N-butanol: acetic acid: water (250:60:250) was added for saturation of the chamber. The first solvent used was freshly prepared N-butanol-acetic acid: water (250:60:250), 100 ml. of solution was put into the trough. After 20 hours, the paper was removed and dried. After thorough drying in a ventilated hood, the paper was replaced in the cabinet and developed in the second dimension with phenol:water (4:1); 100 ml. of phenol-water was added in the chamber for saturation of the cabinet. After 12 hours saturation, 90 ml. of phenol-water solvent was added to each trough and then the chromatogram was developed for 20-22 hours.

The papers were dried in a ventilated hood, the spots were detected by spraying the papers with 0.5 percent ninhydrin in 95 percent alcohol, and then were heated in an oven at 70-75°C. for 15-20 minutes. All spots were purple except proline (yellow) and asparagine (brown). Identity of the specific amino acids on the chromatograph was determined by comparing with a chromatograph of known amino acids (Figure 1).



1. Aspartic acid
2. Cystine
3. Glutamic acid
4. Serine
5. Asparagine
6. Glycine
7. Threonine
8. Glutamine
9. Alpha-analine
10. Tyrosine
11. Beta-analine
12. Lysine
13. Arginine
14. Histidine
15. Proline
16. Valine/Methionine
17. Phenylalanine
18. Leucine

Figure 1. Two dimensional paper chromatogram of known amino acids. A - Phenol:water; B - N-Butanol:water:acetic acid; C - Original spot.

RESULTS AND DISCUSSION

Effects of Air Temperature on Flowering, Fruiting, and Biochemical Composition of Bean Plants

The results of a preliminary experiment conducted in the field in 1961 are shown in Table 1. The treatments in which the plants were covered with black plastic cages and perforated clear plastic cages produced significantly lower pod weights than the control. There was no significant difference among other treatments. Yield of the white cloth treatment, although less than the control, was not significantly different. The temperatures inside the black plastic cage and perforated clear plastic cage were much higher than for the control, although they were not recorded. The results of this experiment indicate that high temperature, combined with lower light intensity, reduced the yield of snap beans. Analysis of variance for Experiment No. 1 is given in the Appendix Table 1.

Table 1. The effect of modified environment and sugar spray on weight of pods of snap beans in the field. Experiment 1, 1961.

Treatment	Weight of pods
Control	58.8
White cloth	55.7
Black plastic	28.9
Perforated clear plastic	28.0
Sugar spray	65.0
L.S.D. -- 0.05	21.2
0.01	30.2

Weights in all experiments are expressed in grams per plant.

Results of Experiment No. 2, summarized in Tables 2, 3, and 4, show the effects of plastic cages (increased air temperatures) and moisture levels on weight of plants, and weight and number of pods. There was no significant difference among the treatments in plant weights, but there were significant differences in weight and number of pods per plant (Table No. 2). The plants covered with plastic cages at four, six, and eight days after first bloom had significantly lower weights of pods than the control. Plants covered with plastic eight days after first bloom produced significiantly fewer number of pods than the control (Table 2). The analysis of variance for the effect of plastic cages and moisture levels on weight of plants and weight and number of pods is shown in Appendix Table 2.

Tables 3 and 4 show the effect of soil moisture levels on weight of plants, number of flowers and pods, and weight of pods. Table 3 summarizes results of the three moisture levels when all seven plastic treatments were combined, whereas Table 4 is the summary of only the control or check plots of each moisture level. The M3 moisture level (normal irrigation) had significantly higher weights of plants (Table 3) and pods and number of pods than either the M1 moisture level (normal irrigation early, moisture stress during bloom, then irrigate after major flowering period) or the M2 moisture level (no irrigation until bloom, then irrigate for remainder of season). The M2 moisture level was intermediate in weights of plants and pods.

Table 2. The effect of plastic cages on weight of plants and weight and number of pods per plant in the field. (Three moisture levels combined). Experiment 2, 1962.

Plastic cage Treatment	Weight of Plants	Weight of Pods	Number of Pods
Check (no plastic)	134.9	83.8	21.8
At first bloom	162.7	89.4	23.3
First bloom + 2 days	169.9	85.2	22.5
" " + 4 days	158.3	70.6	20.6
" " + 6 days	141.4	75.6	19.6
" " + 8 days	150.3	68.4	16.9
" " + 10 days	138.6	81.1	19.1
L.S.D. -- .05	N.S.	12.4	3.5
.01	N.S.	16.4	4.6

Table 3. The effect of soil moisture levels on weight of plants, weight and number of pods per plant in the field. (Plastic cage treatments combined) Expt. 2, 1962.

Moisture Level	Weights (grams)		Number of Pods
	Plants	Pods	
M1	104.1	48.5	14.7
M2	143.9	80.8	19.2
M3	204.1	108.3	27.6
L.S.D. --			
.05	16.4	8.1	2.2
.01	21.7	10.8	3.0

When only control treatments with no plastic covering were compared (Table 4), there was a significant difference among the moisture levels in number of flowers, percent set, and number of pods. The number of flowers and percent set of pods were highest at the M3 moisture level. There was little difference in percent set of pods between M1 and M2. The analysis of variance tables for the data above are shown in Appendix Tables 2 and 3.

In Tables 2, 3, and 4, main effects were compared. In Table 5, data are of the individual plastic treatments at each of three moisture levels with each value in the table based on the mean of forty plants. Data were not analyzed statistically.

*****

Table 4. The effect of soil moisture levels on weight of plants and pods, number of flowers, percent set, and number of pods per plant. Experiment 2, 1962.

	(Check plots - no plastic cages)				
Moisture Level	Weight (grams) Plants	Pods	Number of Flowers	Percent set of pods	Number of Pods
M1	87.4	50.0	49.0	30.0	14.0
M2	130.8	89.4	61.2	33.7	21.0
M3	186.6	112.2	72.5	42.3	31.0
L.S.D. --					
.05	----	----	9.4	5.9	6.1
.01	----	----	13.3	8.3	8.6

----- Not analyzed statistically.

Table 5. The effect of plastic cages and moisture levels on weight of plants and number and weight of pods per plant in the field. Experiment 2, 1962.

Moisture Level	Plastic cage Treatments	Weights (grams) Plants	Pods	Number of Pods
M1	Check (no plastic)	87.4	49.9	14.0
	At first bloom	100.4	43.6	13.2
	First bloom + 2 days	142.7	67.5	13.9
	" " + 4 days	99.2	42.5	16.0
	" " + 6 days	116.9	54.4	18.0
	" " + 8 days	95.9	42.5	12.7
	" " + 10 days	83.2	39.2	10.7
M2	Check (no plastic)	130.7	89.4	20.6
	At first bloom	173.0	105.6	26.8
	First bloom + 2 days	138.0	70.2	16.3
	" " + 4 days	143.0	68.9	16.7
	" " + 6 days	137.6	75.9	18.1
	" " + 8 days	143.5	74.4	16.3
	" " + 10 days	142.2	81.4	20.0
M3	Check (no plastic)	186.6	112.2	30.8
	At first bloom	211.2	119.0	30.0
	First bloom + 2 days	225.8	118.1	32.4
	" " + 4 days	232.9	100.6	29.1
	" " + 6 days	170.1	96.7	22.8
	" " + 8 days	211.5	88.5	21.7
	" " + 10 days	190.5	102.9	26.7

Mean value based on forty plants.

In moisture level M1, the weight of plants of all treatments, except plants covered ten days after first bloom, was higher than the control. The weights of pods of the plants covered at first bloom and at four, eight, and ten days after first bloom were lower than the control. Also, the number of pods of plants covered at first bloom and eight and ten days after first bloom were lower than the control. The weight of pods of plants covered two days after first bloom was high, but there was no difference in number of pods compared to control. In moisture levels M2 and M3, the weights of plants of all plastic treatments were higher than the control. In moisture level M2, the weight and number of pods of all treatments except plants covered at first bloom was lower than the control. There was a marked reduction of weight and number of pods of plants covered from six, eight, and ten days after first bloom in moisture level M3. The weight of pods of plants covered at first bloom and two days after first bloom and number of pods of plants covered at first bloom were higher than for control plants. Generally, the weight and number of pods of plants covered eight and ten days after first bloom under all three moistures were less in comparison to control treatments. The temperature records during the time the plants were covered with plastic, shown in Appendix Table 4, indicates that the temperature inside the plastic cages of plants covered eight and ten days after first bloom was higher than other plastic cage treatments with mean maximum temperatures averaging 107° F.

Generally, total sugar, reducing sugar, sucrose, and starch tended to be lower in leaves and stems of plants covered with plastic than in control plants, as shown by data in Tables 6, 7, and 8.

In moisture level M1 (Table 6), the total sugar and sucrose in leaves tended to increase with the maturity of the plants, but starch content tended to decrease. Reducing sugar of leaves and stems showed no definite relationship with maturity. In moisture levels M2 (Table 7) and M3 (Table 8), there was no consistent relationship between maturity of plants and carbohydrate content.

Generally, the carbohydrate content of plants in moisture level M1 was higher than in M2 and M3 moisture levels. The difference was more pronounced in the leaves than in the stems. There was very little difference in carbohydrate content of plants of the M2 and M3 moisture levels.

Table 6. The effect of plastic cages (air temperature) on carbohydrate content of bean plants. Percent fresh weight basis. Ml moisture level. Experiment 2, 1962.

Plastic cages Days after first bloom	Sample	Total sugar Leaf	Total sugar Stem	Reducing sugar Leaf	Reducing sugar Stem	Sucrose Leaf	Sucrose Stem	Starch Leaf	Starch Stem
0	A	0.88	----	0.29	0.91	0.56	----	4.18	2.87
	B	0.68	1.15	0.25	0.95	0.31	0.19	3.07	2.88
	C	0.67	1.09	0.26	0.90	0.39	0.18	3.23	3.00
2	A	0.71	1.50	0.20	0.77	0.48	0.69	3.93	3.19
	B	0.80	1.30	0.24	0.89	0.52	0.38	3.29	2.68
	C	0.72	1.27	0.23	0.87	0.47	0.38	3.51	2.58
4	A	0.96	1.56	0.28	0.91	0.64	0.61	4.18	2.88
	B	0.78	1.15	0.28	0.82	0.47	0.31	3.12	3.20
	C	0.72	1.27	0.34	0.80	0.35	0.44	3.62	3.17
6	A	0.96	1.66	0.22	0.90	0.69	0.72	3.37	3.53
	B	0.76	1.44	0.26	0.98	0.47	0.43	----	----
	C	0.79	1.13	0.20	0.81	0.56	0.30	----	----
8	A	1.00	1.69	0.25	0.95	0.70	0.70	3.01	3.20
	B	0.95	1.47	0.28	1.07	0.63	0.28	2.59	3.32
	C	0.93	1.31	0.25	0.93	0.64	0.36	3.07	3.50
10	A	----	1.16	----	0.95	----	0.20	----	3.65
	B	1.06	1.15	0.52	0.94	0.51	0.20	2.28	3.20
	C	1.15	1.69	0.46	0.78	0.65	0.67	2.90	3.80

(A) Sample taken before plastic cages kept on plants.
(B) Sample taken just after plastic cages were removed.
(C) Sample taken from control at the same time when (B) was taken.

--- Some values are missing because of inadequate sample.

Table 7. The effect of plastic cages (air temperature) on carbohydrate content of bean plants. Percent fresh weight basis. M2 moisture level. Experiment 2, 1962.

Plastic cages Days after first bloom	Sample	Total Sugar		Reducing sugar		Sucrose		Starch	
		Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
0	A	0.75	1.44	0.18	0.95	0.53	0.46	3.52	3.42
	B	0.56	1.32	0.25	0.88	0.29	0.52	2.83	2.60
	C	0.50	1.28	0.24	0.72	0.27	0.53	3.11	2.32
2	A	0.71	1.45	0.20	0.77	0.49	0.64	3.69	2.97
	B	0.67	1.23	0.18	0.88	0.47	0.32	3.08	2.55
	C	0.55	1.07	0.17	0.72	0.35	0.32	3.06	2.50
4	A	0.75	1.48	0.18	0.90	0.53	0.55	3.16	2.36
	B	0.62	1.07	0.26	0.73	0.34	0.31	2.51	2.58
	C	0.68	1.01	0.23	0.75	0.42	0.24	2.77	2.79
6	A	0.88	1.44	0.22	0.91	0.62	0.50	----	2.86
	B	0.44	0.85	0.23	0.64	0.19	0.20	----	----
	C	0.54	1.05	0.18	0.85	0.34	0.19	3.34	2.47
8	A	0.82	1.34	0.23	0.75	0.55	0.56	2.80	2.55
	B	0.50	0.90	0.24	0.62	0.24	0.27	1.75	2.64
	C	0.80	0.93	0.40	0.78	0.37	0.14	2.53	2.68
10	A	0.94	1.53	0.30	0.85	0.60	0.63	3.00	2.68
	B	0.59	0.94	0.28	0.80	0.29	0.13	1.81	2.38
	C	0.75	0.77	0.27	0.70	0.45	0.09	2.27	2.47

(A) Sample taken before plastic cages kept on plants.
(B) Sample taken just after plastic cages were removed.
(C) Sample taken from control at the same time when (B) was taken.

---- Some values are missing because of inadequate sample.

Table 8. The effect of plastic cages (air temperature) on carbohydrate content of bean plants. Percent fresh weight basis. M3 moisture level. Experiment 2, 1962.

Plastic cages Days after first bloom	Sample	Total Sugar Leaf	Total Sugar Stem	Reducing Sugar Leaf	Reducing Sugar Stem	Sucrose Leaf	Sucrose Stem	Starch Leaf	Starch Stem
0	A	0.74	1.28	0.22	0.89	0.49	0.37	3.00	2.28
	B	0.59	1.12	0.25	0.75	0.32	0.35	2.56	2.46
	C	0.58	1.06	0.20	1.07	0.36	0.33	2.96	2.17
2	A	0.63	1.39	0.16	0.78	0.44	0.57	2.32	2.76
	B	0.54	1.13	0.16	0.81	0.36	0.30	2.79	2.20
	C	0.69	1.00	0.21	0.75	0.45	0.24	2.69	2.47
4	A	0.82	1.36	0.21	0.79	0.57	0.54	3.30	2.62
	B	0.57	1.11	0.25	0.89	0.30	0.21	2.49	2.36
	C	0.55	1.08	0.19	0.81	0.34	0.25	2.93	2.55
6	A	0.91	1.37	0.23	0.85	0.64	0.49	3.13	3.16
	B	0.97	0.93	0.15	0.72	0.77	0.19	2.11	2.40
	C	0.56	0.86	0.15	0.72	0.49	0.13	2.44	2.56
8	A	0.79	1.29	0.17	0.72	0.59	0.53	3.08	2.58
	B	0.41	0.80	0.19	0.67	0.20	0.12	1.90	2.44
	C	0.55	1.02	0.22	0.82	0.39	0.18	2.27	2.86
10	A	0.88	1.49	0.18	0.96	0.66	0.50	2.41	2.77
	B	0.65	1.13	0.38	0.94	0.26	0.17	1.79	2.20
	C	0.80	1.06	0.29	0.92	0.48	0.13	2.78	2.73

(A) Sample taken before plastic cages kept on.
(B) Sample taken just after plastic cages were removed.
(C) Sample taken from control at the same time when (B) was taken.

The results of Experiment No. 3 are summarized in Tables 9 and 10. There was a significant difference among the treatments in weight and number of pods per plant at the five percent level. The plants which were enclosed in plastic cages produced less weight and fewer number of pods than the control. The analysis of variance for weight and number of pods is shown in Appendix Table 5.

Table No. 10 shows that use of plastic cages reduced total sugar, reducing sugar, sucrose, and starch of plants.

The temperature record during this experiment, shown in Appendix Table 6, indicates that maximum temperatures under plastic cages were 6 to 7^{o} F. higher than the control treatment. However, these temperatures were not high enough to significantly reduce weight and number of pods, although carbohydrate levels were lowered.

Table 9. The effect of plastic cages and sugar spray on weight and number of pods per plant. Experiment 3, 1963.

Treatment	Wt. of Pods in gms.	No. of Pods
Control	120.5	17.3
Plastic cage	110.5	15.7
Sugar spray + Plastic cage	113.3	16.2
Sugar spray	138.1	19.3
L.S.D. -- .05	17.4	2.4
.01	24.5	3.4

Plastic cage on Aug. 7 at 9:00 A.M. to Aug. 10 at 11:30 A.M.

Table 10. The effect of plastic cages and sugar spray on carbohydrate content of plants. (leaf) Percent fresh weight basis. Experiment 3, 1963.

Treatment	Total Sugar	Reducing Sugar	Sucrose	Starch
Control	1.10	0.47	0.60	4.51
Plastic cage	0.89	0.42	0.44	2.05
Sugar spray + Plastic cage	0.90	0.42	0.45	2.29
Sugar spray	0.99	0.36	0.60	4.38

Effects on flowering, fruiting, and carbohydrate contents of bean plants subjected to high temperature in the greenhouse during bloom in Experiment 4 are shown in Table 11. There was a significant difference among the treatments in percent set of pods and number of pods per plant. The differences in number of flowers and weight of pods were not significant. The percent set of pods was significantly lower in the plants exposed to high temperature, (mean maximum 107° F.) for a five-day period, beginning two days after first bloom. The number of pods of plants exposed to medium temperature (mean maximum 103° F.) and high temperature (mean maximum 107° F.) two days after first bloom, and at high temperature (mean maximum 100° F.) six days after first bloom, was significantly lower than the control. Temperatures during these periods are shown in Appendix Table 7. There was very little difference in temperature of the medium and high levels. The analysis of variance for number of flowers, percent set of pods, number and weight of pods is shown in Appendix Table 8. Data in Table 12 show that the carbohydrate contents of leaves and stems of plants exposed to medium and high temperatures were similar and were always less than in control plants. The decrease of starch at medium and high temperatures in the leaves was greater than in stems. The total sugar, reducing sugar, and sucrose content of the stems were higher than in leaves, but the difference in starch content of leaves and stems were not consistent.

Table 11. The effect of temperature on number of flowers, percent set, number and weight of pods per plant in the greenhouse. Experiment 4, 1963.

Stage of Bloom	Treatment	No. of Flowers	Percent Set of Pods	No. of Pods	Weight of Pods (gms.)
2 days after 1st bloom	Control	23.1	49.9	11.2	32.8
	Med. temp.	20.0	44.9	8.2	32.1
	High temp.	23.8	32.1	7.7	26.4
6 days after 1st bloom	Med. temp.	22.0	49.2	10.6	38.7
	High temp.	18.7	44.9	8.3	26.1
L.S.D. -- .05		N.S.	11.0	2.3	N.S.
.01		N.S.	14.7	3.00	N.S.

Table 12. The effect of temperature on carbohydrate content of bean plants in the greenhouse. Percent fresh weight basis. Experiment 4, 1963.

Stage of Bloom	Treat. ment	Total Sugar		Reducing Sugar		Sucrose		Starch	
		Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
2 days after first bloom	Con- trol	0.64	0.85	0.19	0.49	0.42	0.33	2.32	1.81
	Med. temp.	0.51	0.66	0.13	0.33	0.36	0.31	1.49	1.43
	High temp.	0.52	0.67	0.14	0.26	0.35	0.38	1.51	1.53
6 days after first bloom	Con- trol	0.39	0.78	0.13	0.48	0.24	0.28	2.23	1.86
	Med. temp.	0.24	0.42	0.08	0.28	0.15	0.13	1.28	1.42
	High temp.	0.20	0.46	0.07	0.25	0.12	0.19	1.20	1.48

The paper chromatographic maps of free amino acids in leaf extracts of plants in these treatments are shown in Figures 2 and 3. In the control plants, 11 free amino acids were detected and were: aspartic acid, cystine, serine, glutamic acid, asparagine, glutamine, alpha alanine, gamma aminobutyric acid, valine/methionine, phenylalanine, and leucine. In plants at medium and high temperatures, no cystine was detected, but there was a trace of threonine. There appeared to be no difference in concentration of the amino acids based on color intensity.

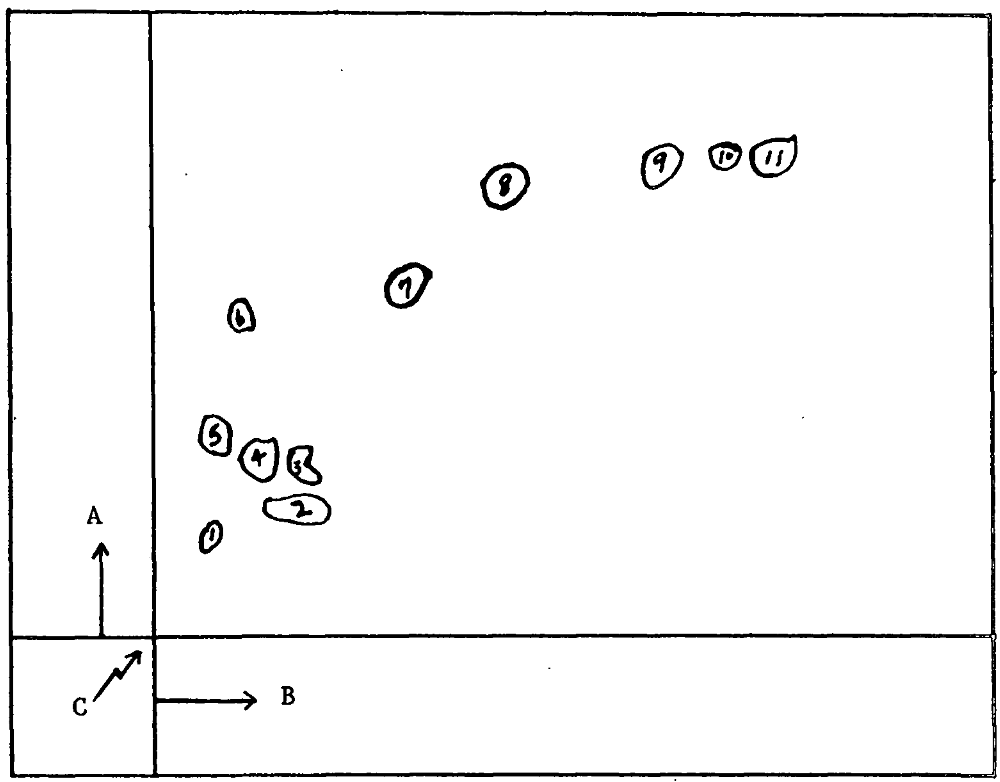


Figure 2. Amino acids in leaf extract of bean plants grown outside greenhouse at normal temperature. Expt. 4. 1963. Control plants.
A - Phenol:water; B - N-Butanol:acetic acid:water; C - Original spot.

1. Cystine
2. Aspartic acid
3. Glutamic acid
4. Serine
5. Asparagine
6. Glutamine
7. Alpha-alanine
8. Gamma-aminobutyric acid
9. Valine/Methionine
10. Phenylalanine
11. Leucine

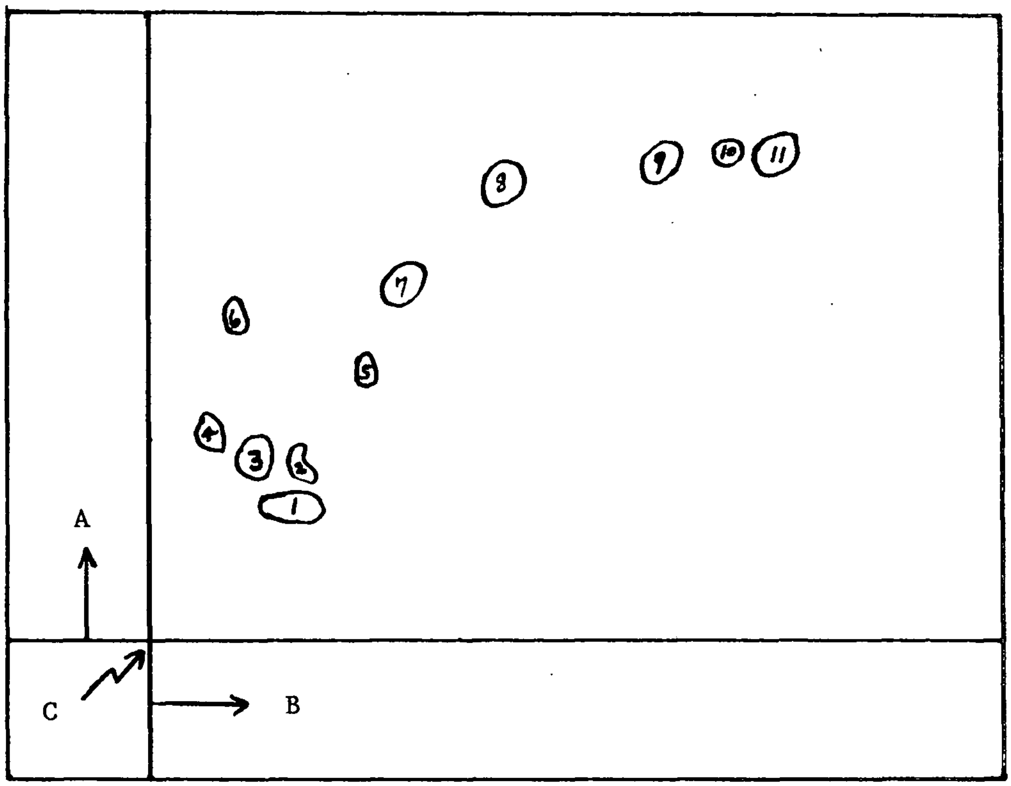


Figure 3. Amino acids in leaf extract of bean plants exposed to high temperature in greenhouse. Expt. 4. 1963. A - Phenol:water; B - N-Butanol:water:acetic acid; C - Original spot.

1. Aspartic acid
2. Glutamic acid
3. Serine
4. Asparagine
5. Threonine
6. Glutamine
7. Alpha-alanine
8. Gamma-aminobutyric acid
9. Valine/Methionine
10. Phenylalanine
11. Leucine

Exposure of bean plants to high temperatures in the field, as well as in the greenhouse, reduced the percent set and yield of pods. These results are in agreement with investigators who have reported that high temperatures, and in some cases low temperatures, at blooming time have a deleterious effect on fruit set and yield of various crops such as tomatoes, peppers, lima beans, and snap beans.

Several workers have indicated the failure of pollen germination at high temperature (29, 66). In the present studies on snap beans, the effects of high temperatures on pollination and fertilization were not investigated.

A better understanding of the specific manner by which temperature affects pod set and chemical composition of bean plants may be gained by a consideration of the effects of temperature on various processes in the plant, such as respiration, photosynthesis and biochemical metabolism of the plants. Suboptimal temperatures may reduce certain chemical reactions that are contributing to growth, whereas supra-optimal temperatures may permit the incidence and accelerate the rate of destruction reactions.

Deficiency of carbohydrates may be a limiting factor in growth at temperatures above the optimum. In most cases all forms of sugars decreased at high temperatures, even though number of pods was not reduced significantly in Experiment 3. Hewitt and Curtis (27) reported that carbohydrate content of the roots, stems and leaves of bean plants exposed to the high temperature became progressively smaller with each increase of 10^{o} C. and at all temperatures, the final carbohydrate content was less than the initial contents. At a temperature higher than optimum, they were rapidly dissipated without serving as reserves.

Results of carbohydrate analysis of Experiment 2 were variable, possibly because of limited sampling. Furthermore, time of exposure of plants to high temperature was for only a few hours in Experiment 2, but was for a longer period in Experiments 3 and 4. In some treatments in Experiment 2, the weight of the plants increased because of use of plastic cages shortly after first bloom. This increase in temperature benefited the growth of plant because at that time the temperature prevalent was lower than normal. Plastic cages not only increased temperature, but also reduced light intensity approximately 15 to 20 percent. However, under the normally high light intensities found in Experiments 2 and 3, this magnitude of reduction may not have affected plant metabolism. This interception of light, of course, was considerable under black plastic cages used in Experiment 1. Reduction in production of pods was no doubt a combination of both high temperature and reduced light intensity. There appeared to be deficiencies in chlorophyll content in the leaf extract of bean plants with control plants having more chlorophyll than the plants exposed to high temperature. No differences in leaf sizes due to high temperatures were observed on bean plants although Bushnell (13) found reduction in potato leaf size at high temperatures. High temperature combined with high rate of transpiration would, no doubt, develop a diffusion pressure deficit within the leaves sufficiently high to inhibit photosynthesis and account for low reserves of photosynthetic products. Although growth may not be visibly affected by increase in temperature, there may nevertheless be an impairment of biochemical activities.

The absence of cystine, and the presence of threonine at high temperature in contrast to the control, indicate that high temperature may also affect the protein metabolism of plants. It is probable that at high temperature, there may be a hydrolytic breaking of the cystine bridge.

Furthermore, from results of this study, one could speculate that at high temperature, certain enzymes might be inactivated, thereby altering metabolic processes. High temperature may also have some effect on hormonal mechanisms of flowering.

Further research is needed to gain a greater understanding of the biochemical aspects of response of plants to above and below normal temperatures.

Effects of Soil Temperature on Flowering, Fruiting, and Biochemical Composition of Bean Plants

The effects of soil temperature on number of flowers, number and weight of pods, and weight of roots and shoots are shown in Table 13 (Experiment 5). There were significant differences among the soil temperature treatments with the above components being increased as soil temperature was increased from 60° to 75° F. There was no significant difference between 65° and 70° F. in any of the components studied. Plants grown at 75° F. were significantly higher in all the components studied than plants grown at 60°, 65°, and 70° F. Significant correlation coefficients between dry weight of shoots and number of pods ($r = 0.711$) and between dry weight of roots and number of pods ($r = 0.717$) were obtained. The analysis of variance for number of flowers and pods, weight of pods, and dry weight of roots and shoots are shown in Appendix Tables 9 and 10.

Table 14 shows the effects of soil temperatures on dry weight and mineral composition of bean plants taken at weekly intervals. The dry weight of plants at each sampling date increased with an increase of soil temperature. Generally, the P content also was increased as soil temperature was increased. The percentage P content of the first sample, taken one week after transferring cans to temperature tanks, was the highest with a general decrease in later samplings. The K content of the plants of the first two samples was higher than of plants of later samples. There was a tendency for increase of P as the soil temperature increased, but there appeared to be no difference between 60° and 65° and between 70° and 75° F. The Ca and Mg contents of the plants were variable and did not follow any definite pattern related to soil temperature. The Ca content at harvest time was highest. Table 15 shows the effect of soil temperatures on mineral composition of root, shoot, and pods of bean plants at harvest. The P, K, Ca, and Mg content of the roots at different temperatures were variable and did not follow any definite pattern. Calcium contents of roots at 75° F. were much higher than at any other temperature. The Mg content tended to decrease with the increase of soil temperature.

The P, Ca, and K of shoots at harvest tended to increase with the increase of temperature, except at 65° F., where the K content was the highest. Magnesium content of the shoot decreased with an increase of temperature.

Calcium and Mg content of pods tended to decrease with the increase of temperature. The P and K contents in pods were variable, and were higher than in roots and shoots.

Table 13. The effect of soil temperature on number of flowers and pods, weight of pods, and dry weight of roots and shoots per plant in the greenhouse. Experiment 5, 1961.

Soil Temperature (°F)	Number of Flowers	Number of Pods	Weight of Pods	Dr. wt. of roots (at harvest)	Dry wt. of shoots (at harvest)
60	7.7	2.6	8.4	0.48	1.36
65	11.3	4.4	14.2	0.64	1.74
70	11.8	4.9	15.7	0.65	2.08
75	15.1	6.4	20.9	0.82	2.64
L.S.D. --					
.05	1.9	0.9	2.4	0.15	0.65
.01	2.5	1.2	3.2	0.22	0.92

Table 14. The effect of soil temperature on dry weight and mineral composition of shoots. Percentage dry weight basis. Experiment 5, 1961.

Sample Number	Soil Temper-ature (°F)	Dry Wt/ Plant	P	K	Ca	Mg
1	60	0.13	0.49	2.30	1.26	0.63
	65	0.12	0.52	2.76	1.20	0.59
	70	0.14	0.50	2.88	1.54	0.70
	75	0.13	0.56	3.02	1.31	0.69
2	60	0.25	0.15	2.30	1.87	0.77
	65	0.26	0.08	2.01	1.81	0.94
	70	0.27	0.33	2.78	1.91	0.77
	75	0.30	0.47	2.89	1.95	0.70
3	60	0.46	0.19	1.31	1.39	0.76
	65	0.51	0.24	1.56	1.47	0.78
	70	0.65	0.26	1.91	1.77	0.80
	75	0.63	0.30	2.00	1.80	0.89
4	60	0.73	0.18	1.35	1.57	0.85
	65	0.80	0.22	1.55	1.57	0.82
	70	0.87	0.32	2.08	2.09	0.91
	75	0.92	0.32	2.23	2.04	0.85
5	60	1.22	0.14	1.26	1.36	0.72
	65	1.31	0.19	1.91	1.51	0.75
	70	1.70	0.20	2.18	1.73	0.82
	75	1.86	0.27	2.30	1.75	0.65
Harvest	60	1.36	0.13	0.85	2.35	0.77
	65	1.74	0.22	1.03	2.35	0.63
	70	2.08	0.22	0.85	2.35	0.57
	75	2.64	0.24	0.94	2.59	0.59

Samples were taken at 1, 2, 3, 4, 5, and 6 weeks after transferring the cans to respective temperature tanks.

Table 15. The effect of soil temperature on mineral composition of roots, shoots, and pods of bean plants at harvest. Percent dry weight basis. Experiment 5, 1961.

Soil Temperature(^{o}F)	P	K	Ca	Mg
		Roots		
60	0.17	0.94	0.60	0.88
65	0.20	1.10	1.56	0.75
70	0.18	1.03	0.68	0.46
75	0.19	1.30	1.12	0.59
		Shoots		
60	0.13	0.85	2.35	0.77
65	0.22	1.03	2.35	0.63
70	0.22	0.85	2.35	0.57
75	0.24	0.94	2.59	0.59
		Pods		
60	0.23	1.64	0.89	0.30
65	0.27	1.78	0.56	0.27
70	0.24	1.68	0.50	0.22
75	0.24	1.55	0.60	0.23

The effects of constant and fluctuating soil temperatures on number of flowers, number and weight of pods, and dry weight of shoots and roots are shown in Table 16 (Experiment 6). There were significant differences among the soil temperature treatments for the above components. Generally these components increased with an increase of soil temperature from 55° to 85° F. There were no significant differences in number of flowers among constant temperatures ranging from 60° to 85° F., except at 80° F. where plants had fewer number of flowers than plants grown at 65°, 70°, and 75° F. The number of pods per plant was higher at 75° and 85° F. than at other constant soil temperatures. The weight of pods at 75° F. was highest, while the weights of pods at 55°, 60°, and 50-60° F. were lowest. The difference in pod weight among the other treatments was not pronounced. The weights of roots and shoots of plants at 75° and 80° F. were greater than other treatments. It is not clear why growth of certain plants at 80° F. was poor from the beginning of the experiment; the poor growth at 80° F. is reflected in the lower weights produced. Plants at fluctuating temperatures, except at 50-60° F., produced about the same weights and number of pods, number of flowers, etc., as the plants at corresponding mean constant temperatures. Optimum growth and highest yield of pods were obtained at 70° to 85° F. soil temperature. Soil temperatures of 55° to 60° F. were too low for best growth and a soil temperature of 90° F. appeared to be

Table 16. The effect of constant and fluctuating soil temperatures on number of flowers and pods, weight of pods, and dry weight of shoots and roots per plant at harvest. Experiment 6, 1962.

Soil Temper-ature (°F)	Number of Flowers	No. of Pods	Weight in grams Pods (Fresh)	Root (dry)	Shoot (dry)
55	1.50	1.30	2.87	0.29	0.98
60	10.70	4.00	14.59	0.84	2.29
65	13.30	5.80	19.42	1.40	3.75
70	11.30	6.50	25.35	1.50	4.36
75	12.90	8.50	37.74	2.23	7.19
80	8.60	5.60	23.81	2.09	5.60
85	10.60	8.90	28.85	2.75	7.14
90	9.00	6.30	21.18	1.74	5.10
50-60	8.40	3.60	12.09	0.70	2.07
60-70	14.80	5.20	23.08	1.35	3.81
70-80	11.10	6.80	26.33	1.94	6.50
80-90	7.90	5.50	22.90	2.00	7.07
L.S.D. --					
.05	3.14	1.94	7.23	0.35	1.33
.01	4.18	2.58	9.60	0.46	1.77

(A) Temperature of 90 F. is not included in statistical analysis because of inadequate number of observations.

(B) The first temperature indicates the night temperature, and the second one indicates the day temperature of the water bath temperature tanks.

higher than optimum. Growth of plants is shown in Figure 4.

Table 17 shows the effect of constant and fluctuating soil temperature on dry weight and height of plants at blooming time. The dry weights and height of plants grown at 55°, 60°, 50-60° F. were significantly lower than other treatments, with little difference among other treatments. There could have been a greater number of internodes present at 55° and 60° F. than indicated in Table 17. However, with the scale of measurement used, they were not detected, if present.

The analysis of variance for number of flowers and pods, weight of pods, dry weight of shoots and roots are shown in Appendix Table 11, and for height of plants in Appendix Table 12. Significant correlation coefficients between dry weight of shoots and number of pods ($r = 0.638$) and between dry weight of roots and number of pods ($r = 0.705$) were obtained. Therefore, the association between dry weight of roots and number of pods was greater than between weight of shoot and number of pods.

Data in Table 18 show that there was very little difference among soil temperature treatments in total sugar, reducing sugar and sucrose content of bean plants. However, plants grown at 75°, 80°, and 85° tended to be higher in total sugar, and reducing sugar. Plants grown at fluctuating temperatures of 50-60°, 60-70°, and 70-80° F. contained higher sucrose content than other treatments.

Figure 4. Growth of snap beans as influenced by soil temperature in Experiment 6.

Table 17. The effect of constant and fluctuating soil temperature on dry weight, weight and number of internodes per plant at blooming time. Experiment 6, 1962.

Soil Temperature (°F)	Dry Weight in gms.	Height in cms.	Number of Internodes
55	0.79	7.66	2
60	1.45	12.70	3
65	2.36	19.70	4
70	2.31	20.00	4
75	2.77	23.00	4
80	2.15	17.70	4
85	2.47	24.70	4
90	2.07	21.10	4
50-60	----	8.20	2
60-70	2.38	20.00	4
70-80	2.77	24.20	4
80-90	2.41	23.60	4
L.S.D. --			
.05	0.63	3.27	-
.01	0.84	4.35	-

Table 18. The effect of constant and fluctuating soil temperature on carbohydrate contents of bean plants. Percent fresh weight basis (whole plant). Experiment 6, 1962.

Soil Temper-ature (°F)	Total Sugar	Reducing Sugar	Sucrose	Starch
55	1.07	0.66	0.38	7.57
60	0.89	0.67	0.21	7.32
65	0.95	0.70	0.24	5.93
70	1.03	0.71	0.30	5.76
75	1.22	0.84	0.36	4.96
80	1.26	0.88	0.36	4.41
85	1.20	0.71	0.37	----
90	1.07	0.70	0.35	4.00
50-60	1.06	0.61	0.43	6.78
60-70	1.08	0.68	0.38	5.86
70-80	1.22	0.78	0.41	4.90
80-90	1.05	0.74	0.29	4.60

The starch content of bean plants was lower as there was an increase in temperature. This trend occurred at both constant and fluctuating temperatures. The growth of plants at 55° and 60° F. was very poor even though starch content was high.

Table 19 shows the effect of constant and fluctuating soil temperatures on the mineral composition of bean plants. Phosphorus and K contents of plants at both sampling times increased with increase of soil temperature. Plants grown at 50-60° F. had comparatively lower levels of P and K. There was no difference among treatments in N and Ca content of plants. Nitrogen content of plants grown at 50-60° F. of the first sample was higher than at other soil temperatures. The N content of plants at 55° F. and Ca content of plants at 60° F. of the second sample were higher than at other soil temperatures. Magnesium content of both samples tended to decrease with an increase in soil temperatures. Nitrogen, P, and K content of the first sample taken at full bloom were higher than in plants of the second sample taken at harvest. The Mg content in the first sample was lower than in the second sample. There was no difference in Ca content in these two samples.

Table 20 shows the effect of soil temperature on mineral composition of roots of bean plants. Phosphorus and K content of the plant increased with an increase of soil temperature and followed the same pattern of composition as the shoots. Calcium content of roots was not affected by soil temperature while Mg

Table 19. The effect of constant and fluctuating soil temperature on mineral composition of shoots of bean plants. Percent dry weight basis. Experiment 6, 1962.

	Soil Temperature (°F)	N	P	K	Ca	Mg
Sample I						
at full	55	2.71	0.11	0.76	1.32	0.53
bloom	60	2.19	0.11	0.70	1.45	0.55
	65	2.03	0.17	0.84	1.45	0.48
	70	2.29	0.20	0.99	1.45	0.48
	75	2.77	0.23	1.08	1.45	0.44
	80	2.91	0.22	1.03	1.32	0.37
	85	2.78	0.24	1.43	1.38	0.41
	90	2.48	0.23	1.43	1.32	0.41
	50-60	3.12	0.06	0.46	0.88	0.25
	60-70	2.07	0.20	0.90	1.52	0.53
	70-80	2.51	0.20	1.11	1.67	0.51
	80-90	2.95	0.27	0.98	1.52	0.43
Sample II						
at	55	2.40	0.05	0.46	1.58	1.07
harvest	60	1.58	0.14	0.38	2.16	0.75
	65	1.86	0.16	0.34	1.52	0.70
	70	1.84	0.15	0.34	1.32	0.72
	75	1.75	0.15	0.30	1.01	0.72
	80	1.70	0.17	0.38	1.12	0.34
	85	1.89	0.20	0.51	1.07	0.32
	90	1.94	0.25	0.67	1.12	0.21
	50-60	1.63	0.09	0.38	1.58	0.92
	60-70	1.72	0.15	0.34	1.52	0.72
	70-80	1.43	0.14	0.38	0.82	0.75
	80-90	1.60	0.20	0.43	1.07	0.61

Table 20. The effect of constant and fluctuating temperatures on mineral composition of roots of bean plants. Percent dry weight basis. Experiment 6, 1962.

Sample at Harvest	Soil Temperature (°F)	P	K	Ca	Mg
	55	0.13	0.34	0.50	0.48
	60	0.07	0.12	0.63	0.33
	65	0.11	0.38	0.56	0.85
	70	0.13	0.34	0.63	0.77
	75	0.17	0.30	0.50	0.98
	80	0.18	0.55	0.75	0.65
	85	0.13	0.73	0.50	0.67
	90	0.22	1.34	0.50	0.57
	50-60	0.07	0.12	0.50	0.33
	60-70	0.09	0.08	0.95	0.18
	70-80	0.20	0.51	0.56	0.46
	80-90	0.20	0.51	0.56	0.41

content of the roots increased as soil temperature increased from 55° F to 75°F and then decreased. Plants grown at 75° F. soil temperature had the highest Mg content. Mineral composition was similar for constant and comparable fluctuating temperatures. However, in the case of magnesium content, plants at fluctuating temperatures appeared to contain less Mg than at constant temperatures.

Growth and development of plants generally can be considered to be affected by both air and the soil temperatures. In the present study, soil temperatures were varied with air temperatures being essentially the same for all plants. The results of these experiments show that the best growth of plants and highest yields of pods were obtained at soil temperatures ranging from 70 to 85° F. Number of flowers and pods, dry weights of roots, and height of plants were related to the best growth, vigor, and size of plants (shoots) in the soil temperature range of 70 to 85° F. Growth of plants at 55°, 60°, and 50-60° F. was reduced markedly. Significant correlations were obtained between weight of plants and number of pods. These results are in agreement with those of Burkholder (12) who found that the optimum range of soil temperatures for beans was 72° to 79° F.

Soil temperatures may be directly or indirectly affecting growth processes of plants through effects on mineralization of soil organic matter, uptake of water and nutrients, and biochemical composition of plants. Kramer (33, 34) concluded that the principal cause of decreased water absorption by plants at low temperature was due to decreased permeability of the root membranes and increased viscosity of water resulting in increased resistance to water movement across the living cells of roots.

There was a higher content of P, K, and Ca in plants at the higher soil temperatures; Mg content tended to decrease with increased temperature. Thompson (60) and Thompson and Black (61) reported that temperature has considerable influence on mineralization of P over a wide temperature range. They expressed the opinion that the amount of P mineralized was significant in relation to the P requirement of plants. Apple and Butts (3) reported higher dry weights and P content of pole beans at soil temperatures of 82° F., than at 63° F. Wort (75) found in wheat that the root temperatures regulated the rate of nitrate or ammonia assimilation in the roots and respiration of carbohydrate in the roots and tops and was more or less independent of air temperature.

The increased mineral content of bean plants may, therefore, be attributed to an increased solubility of nutrients in the soil at higher temperatures or to increased respiratory activity of roots. Respiratory energy is expended to absorb ions against a concentration gradient and it can be reasonably assumed that the respiratory activity of root tissue would be materially reduced at the low temperature of 55° to 60° F. in these experiments. Another factor to be considered in explanation of response to soil temperatures is the favorable effect of warmer soils on the rate and extent of root growth. At higher soil temperatures, a greater root area would be provided for the absorption of water and nutrients. The dry weights of roots at soil temperatures of 75 to 85° F. were comparatively higher than other treatments.

In these experiments the carbohydrate content of tops was affected by soil temperature with starch content being decreased as the soil temperature increased. Reducing sugar, total sugar, and sucrose showed little response to temperature, but sucrose content of plants at fluctuating temperature was higher than at a comparable constant mean temperature. The increase in sucrose content may be due to increased translocation of sucrose from root to the top at fluctuating temperature. Went (70) related the thermoperiodicity behavior of tomato to increased translocation of sugar. Shanks and Laurie (51) found that the percentage of glucose and sucrose in tops did not show any correlation with soil temperature. Sullivan and Sprague (56) found little response of reducing sugar to soil temperature, but there was a reduction of reserve carbohydrates with rising soil temperature. It appears possible that an increase of polysaccharides observed in bean plants exposed to low soil temperature may bear some relation to disturbed equilibrium in the hydrolysis of these compounds. There are other possibilities, however, which should not be overlooked. One of these is the possible difference in net temperature coefficients for the synthesis of polysaccharides and of protein of the plant. More plausible than above is the possibility of limitation of polysaccharides storage due to consumption of sugars by increased respiration at the highest temperatures. In this case tissue would be expected to become richer in N which was not the case in present experiments, except at a soil temperature of 55° F. where plants had a high N content.

In summary, results from Experiments 5 and 6 where soil temperatures varied from 55° to 90° F. and air temperature was essentially the same at all soil temperatures, growth, pod set and percentage of various constituents in the top varied with change in soil temperature. To obtain a more complete and realistic picture of the influences of soil temperature on plant growth in further studies, the air temperature should also be varied simultaneously with the soil temperature.

Effects of Soil Moisture on Flowering, Fruiting, and Biochemical Composition of Bean Plants

The effects of soil moisture treatments on weights of plants, number of flowers, percent set, and number and weight of pods in 1962 are shown in Table 21. There was a significant difference among moisture treatments in all the components studied. Moisture treatments M4 and M6 had significantly higher weights of plants and pods and number of pods than other moisture treatments. There was no significant difference among M1, M2, M3 and M5 in plant weight and number of pods except M5 which had significantly fewer number of pods. There was no difference between plants of M1 and M3 in weight of pods. The weight of pods at M1 and M3 were lower than at M4 and M6. Weight of pods from plants in moisture treatments M2 and M5 were significantly lower than other treatments.

For number of flowers and percent set of pods, only three moisture treatments, M1, M3 and M6, were compared. The number of flowers and percent set of pods increased with an increase in frequency and amount of irrigation. Plants at the M6 level had significantly higher number of flowers and percent set of pods than at M1 and M3. There was no significant difference in number of flowers and percent set of pods of plants at the M1 and M3 moisture levels. Analysis of variance for these data is shown in Appendix Tables 13 and 14.

Significant correlations between fresh weight of plants and number of pods (r = 0.643) and between fresh weight of plants and weight of pods (r = 0.599) were obtained.

In Table 22 are shown the effects of moisture treatments on carbohydrate content of bean plants. In both samplings, total sugars, reducing sugar, and sucrose content of stems and leaves, on a fresh weight basis, tended to decrease as the number of irrigations and amount of water increased. The starch content in leaves and stems in the second sample decreased with an increase of moisture level. The total sugars, reducing sugar, and sucrose in the pods increased with an increase in soil moisture levels, but the starch content of the pods decreased.

The effect of soil moisture treatments on mineral composition of bean plants is shown in Table 23. In leaves and stems N content decreased with an increase in number of irrigations and amount of water applied. Phosphorus content of leaves and stems and K content of stems increased with an increase of moisture level. The K content of leaves did not follow any definite pattern in relation to irrigation treatments. Calcium content of leaves increased with the increase of moisture level, but the Ca content of stems decreased with increased moisture level. The Mg content of leaves decreased with increased moisture level while the Mg content of stems was variable. Plants in the M1 and M3 moisture treatments had higher Mg contents, than those of the M6 moisture

Table 21. The effect of soil moisture treatment on weight of plants, number of flowers, and percent set, number and weight of pods per plant. Experiment 7, 1962.

Treat-ment	Weight of Plants (gms)	Number of Flowers	% Set of Pods	No. of Pods	Weight of Pods (gms)
M1	167.7	94.5	42.7	40.0	202.5
M2	220.1	-----	----	35.0	147.8
M3	211.2	108.5	38.4	40.0	201.7
M4	292.9	----	----	52.5	274.7
M5	199.9	----	----	22.2	90.1
M6	287.4	119.0	49.3	56.7	288.0
L.S.D. --					
.05	51.0	17.1	4.4	8.1	55.1
.01	70.7	25.9	6.7	11.3	76.3

Table 22. The effect of soil moisture treatment on carbohydrate content of bean plants. (Percent fresh weight basis). Experiment 7, 1962.

Treat-ment	Total Sugar			Reducing Sugar			Sucrose			Starch		
	Leaf	Stem	Pod	Leaf	Stem	Pod	Leaf	Stem	Pod	Leaf	Stem	Pod
					First Sample							
M1	0.96	1.76		0.33	1.42		0.59	0.32				
M3	0.79	1.71		0.32	1.43		0.45	0.26				
M6	0.63	1.66		0.23	1.33		0.37	0.28				
					Second Sample							
M1	0.57	1.21	2.49	0.29	1.08	2.43	0.26	0.12	0.05	3.16	3.93	1.39
M3	0.32	1.15	2.66	0.21	1.05	2.60	0.10	0.09	0.05	3.17	3.56	1.34
M6	0.32	1.16	2.71	0.21	1.13	2.60	0.11	0.03	0.10	2.64	3.32	1.27

Table 23. The effect of soil moisture treatment on mineral composition of bean plants. (Percent dry weight basis). Experiment 7, 1962.

Treat-ment	N	P	K	Ca	Mg
			Leaf		
M1	4.08	0.208	1.32	2.84	0.800
M3	4.12	0.208	1.95	2.78	0.750
M6	3.83	0.240	1.70	3.01	0.656
			Stem		
M1	2.17	0.150	1.51	0.51	0.296
M3	2.14	0.163	1.95	0.47	0.308
M6	1.88	0.180	2.31	0.27	0.246
M			Pods		
M1	3.32	0.250	2.15	0.30	0.260
M3	3.41	0.230	2.42	0.28	0.246
M6	3.22	0.290	2.53	0.38	0.236

treatment. There was very little difference in mineral composition of stems and leaves of plants in the M1 and M3 moisture treatments. The N and Mg contents of pods decreased while the P and K contents of pods increased with an increase of moisture levels. The Ca content of pods did not follow any definite pattern associated with moisture treatments.

The effects of soil moisture treatments on weight of plants, number of flowers, percent set of pods, and number and weight of pods in 1963 are shown in Table 24. There was a significant difference among the treatments in weight of plants, and number, percent set, and weight of pods.

The M6 moisture treatment had the highest weights of plant and pods, and also the highest number of pods. Moisture treatment M3 did not differ significantly from M6 in plant weights and number and weight of pods. Although the M5 moisture treatment had lower plant weights and fewer number of pods than M3 and M6 moisture treatments, it produced a higher weight of pods than the M3 moisture treatment. In 1963, the M5 moisture treatment showed relatively better results than in 1962 because of different scheduling of irrigation. Plants of moisture treatment M1 had higher weights and number and weight of pods than plants of the M2 and M4 moisture treatments.

The difference in number of flowers among plants of M1,

Table 24. The effect of soil moisture treatment on weight of plants, number of flowers, and percent set, number, and weight of pods per plant. Experiment 8, 1963.

Treat-ment	Weight of Plants (grams)	Number of Flowers	% Set of Pods	No. of Pods	Weight of pods (grams)
M1	54.6	39.4	45.7	18.7	68.7
M2	37.1	----	----	12.5	43.4
M3	75.6	45.7	50.2	23.4	86.1
M4	46.0	----	----	16.7	66.8
M5	62.5	----	----	21.9	92.1
M6	91.2	49.7	57.1	28.6	109.2
L.S.D. --					
.05	19.3	N.S.	7.6	6.2	22.0
.01	26.8	N.S.	11.5	8.6	30.4

M3, and M6 moisture treatments was not significant although number of flowers increased with an increase of moisture level. The percent set of pods was increased at higher moisture levels, but the differences between M1 and M3 and between M3 and M6 moisture treatments were not significant. Plants at the M6 moisture level had a significantly higher percentage of pod set than plants at the M1 moisture level.

The percent moisture content of stems and leaves of plants of the M6 moisture treatment was higher than in plants of M1 and M3. There was no difference in moisture contents of plants at M1 and M3.

Significant correlation coefficients between weight of plants and number of pods ($r = 0.856$) and between weight of plants and weight of pods ($r = 0.816$) were obtained. The analysis of variance for weight of plants, number and weight of pods is given in Appendix Table 15, and for percent set of pods and number of flowers in Appendix Table 16.

In Table 25 the effects of soil moisture treatments on carbohydrate content of bean plants are presented. Results of this experiment in 1963 are in agreement with 1962 results. There was a reduction of total sugar, reducing sugar, sucrose, and starch (on a fresh weight basis) as the moisture level increased. There was little difference in these components between plants of M1 and M3 moisture levels. Stems had higher total sugar, reducing

Table 25. The effect of soil moisture treatments on carbohydrate content of bean plants. (Percent fresh weight basis). Experiment 8, 1963.

Treat-ment	Total Sugar		Reducing Sugar		Sucrose		Starch	
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
M1	0.68	1.27	0.16	0.88	0.49	0.36	5.72	4.05
M3	0.66	1.29	0.14	0.85	0.49	0.41	4.21	3.90
M6	0.62	1.00	0.11	0.65	0.48	0.32	4.49	3.61

Table 26. The effect of soil moisture treatments on carbohydrate content of bean plants. (Percent dry weight basis). Experiment 8, 1963.

Treat-ment	Total Sugar		Reducing Sugar		Sucrose		Starch	
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
M1	7.30	6.02	0.73	2.25	6.24	3.58	10.99	15.41
M3	8.42	5.99	0.95	2.49	7.00	3.31	13.91	16.27
M6	8.18	6.66	1.02	2.77	6.95	3.69	13.86	17.07

sugar, and lower sucrose and starch content than leaves.

Table 26 shows the effect of soil moisture treatments on carbohydrate content of bean leaves and stem on a dry weight basis. Total sugar, reducing sugar, sucrose, and starch increased on dry weight basis with an increase of moisture level. Leaves had a higher content of total sugar and sucrose, and less reducing sugar and starch than stems. The total sugar of stems of plants at M3 was about the same as M1, but sucrose content of stems of M3 was less than M1. The starch content of leaves of the M6 and M3 moisture treatments was very high in comparison to the M1 treatment. In most cases these sugars were higher in plants at M6 than in plants at M1 and M3 moisture levels.

The chromatographic maps of free amino acids in plants of different moisture levels are shown in Figures 6, 7, and 8. The following free amino acids were detected in plants of the M6 moisture treatment: aspartic acid, cystine, serine, glutamic acid, asparagine, glutamine, alpha-alanine, arginine, gamma aminobutyric acid, valine or methionine, phenylalanine, leucine and tyrosine. Tyrosine was not detected in plants of M1 and M3 moisture treatments. On the basis of color intensity, a difference in concentration of arginine was found, M1 plants had very little arginine in comparison to M6 plants, with plants of the M3 moisture level being intermediate.

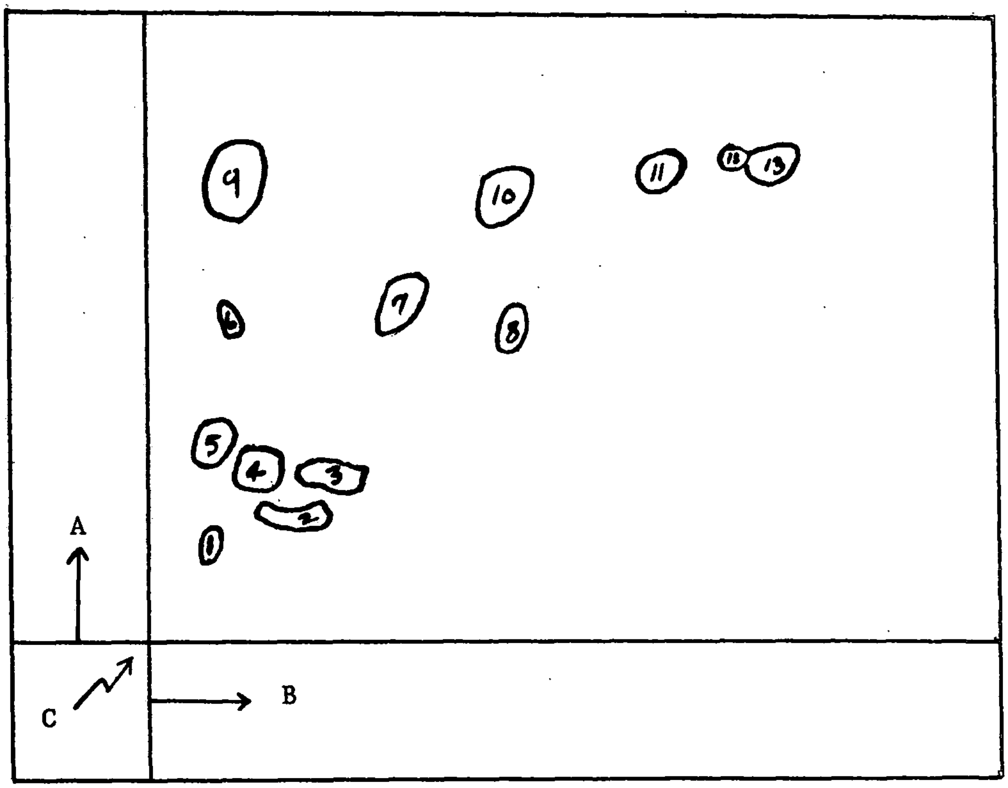


Figure 5. Amino acids in leaf extract of bean plants of moisture level M6. Expt. 8. 1963.
A - Phenol:water; B - N-Butanol:water: acetic acid;
C - Original spot.

1. Cystine
2. Aspartic acid
3. Glutamic acid
4. Serine
5. Asparagine
6. Glutamine
7. Alpha-alanine
8. Tyrosine
9. Arginine
10. Gamma-aminobutyric acid
11. Valine/Methionine
12. Phenylalanine
13. Leucine

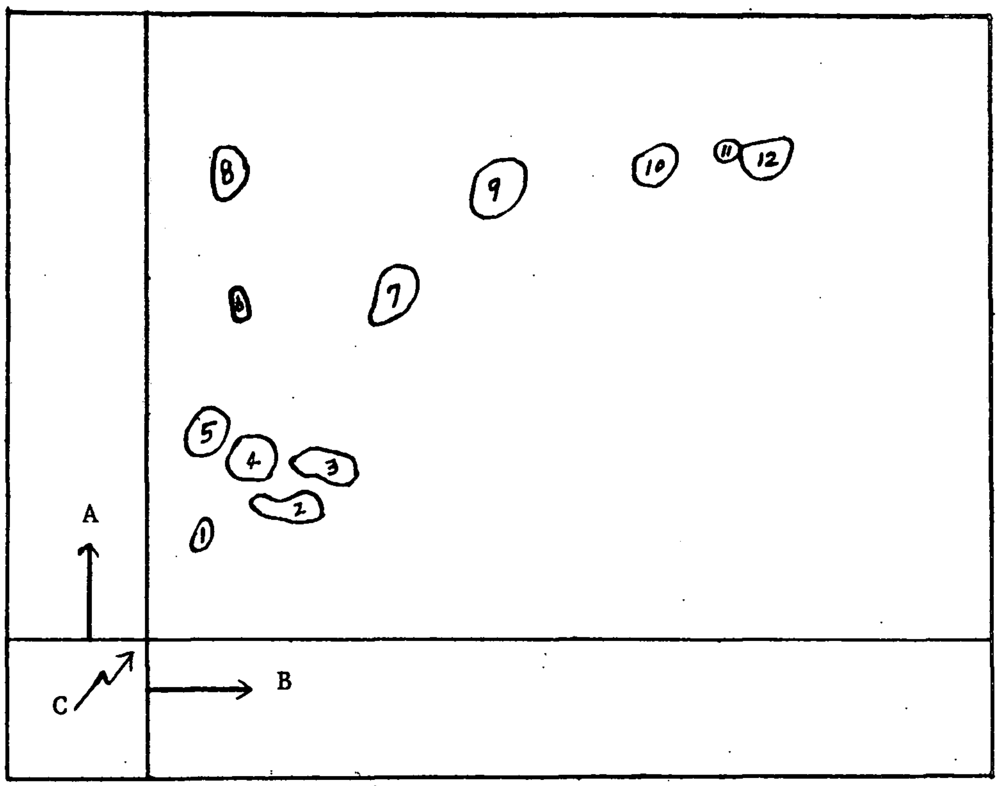


Figure 6. Amino acids in leaf extract of bean plants of moisture level M3. Expt. 8. 1963. A - Phenol:water; B - N-Butanol:water:acetic acid; C - Original spot.

1. Cystine
2. Aspartic acid
3. Glutamic acid
4. Serine
5. Asparagine
6. Glutamine
7. Alpha-alanine
8. Gamma-amino butyric acid
9. Arginine
10. Valine/Methionine
11. Phenylalanine
12. Leucine

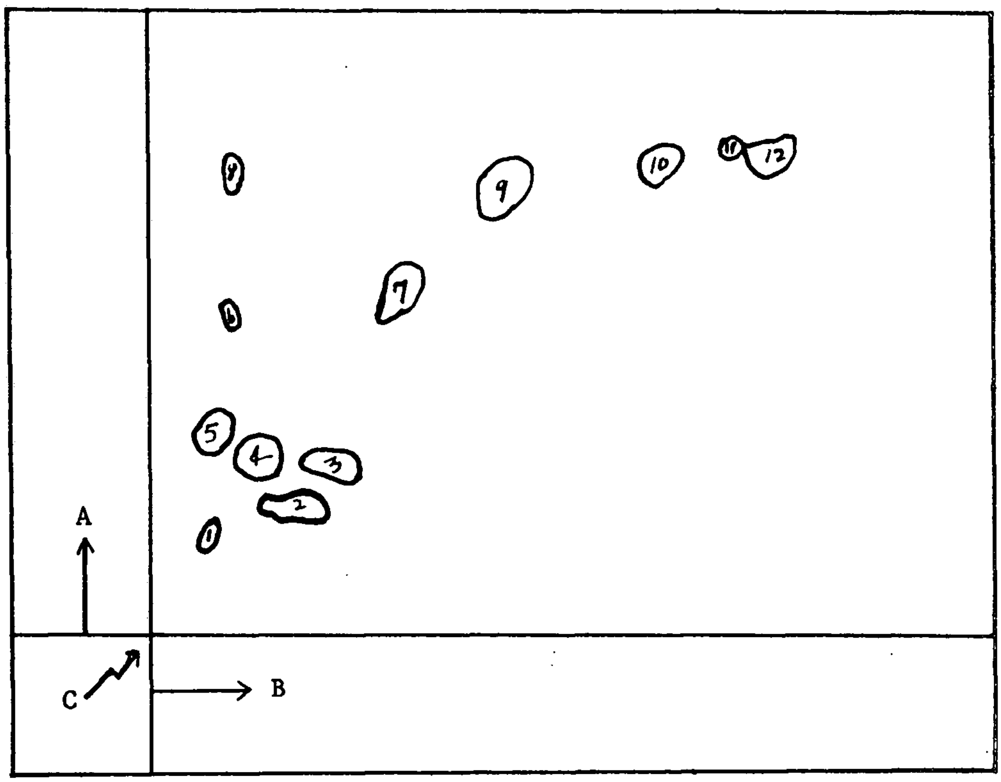


Figure 7. Amino acids in leaf extract of bean plants of moisture level M1. Expt. 8. 1963.
A - Phenol:water; B - N-Butanol:water: acetic acid;
C - Original spot.

1. Cystine
2. Aspartic acid
3. Glutamic acid
4. Serine
5. Asparagine
6. Glutamine
7. Alpha-alanine
8. Arginine
9. Gamma-aminobutyric acid
10. Valine/Methionine
11. Phenyl-alanine
12. Leucine

Plants grown at the highest moisture level, M6, produced the highest weight of plants and pods, number of flowers and pods, and percent set of pods. Under conditions of moisture stress (M1 and M2) the plants were stunted in growth and reduction in yield was due to reduced percent set of pods, as well as fewer flowers being produced per plant. These results are in agreement with those of Binkley (6), Lambeth (36), and Gabelman and Williams (23), who found that soil moisture deficiencies greatly affect fruit set. The results do not agree with the work of Kattan and Fleming (31) who found that irrigation during the period from planting to bloom had little effect on the yield of snap beans if the soil was moist at planting time, even though lack of irrigation during the period produced stunted growth of plants. Moisture treatment M2 of Experiment 2, and M5 of Experiment 7, which were not irrigated prior to bloom, but then irrigated until harvest, produced fewer pods and less weight of pods than plants receiving adequate irrigation throughout the season. Weights of plants from these treatments were also markedly reduced. Number of flowers and number and weight of pods was usually related to the size of the plants at various moisture levels. A significant correlation was found between plant size (dry weight) and number of pods.

The question may be raised as to the way in which water stress reduced plant growth and number and percent set of pods.

Williams (73) found little evidence that severe moisture stress upset pollination or fertilization of snap beans. He concluded that moisture stress affected fruiting behavior through abscission of floral buds and pods containing retarded, but fertilized, ovules. This aspect of moisture stress was not investigated in the present study.

The results indicate that the plants grown at high moisture levels had less carbohydrate content on fresh weight basis, but on a dry weight basis, the carbohydrate contents of plants at high moisture levels was highest. These data suggest that carbohydrate metabolism may be altered as a result of decreasing soil moisture content before the onset of wilting. Reduced carbohydrate levels may have limited normal fertilization and/or development of small pods. Wadleigh and Ayers (64) showed that starch reserves of bean leaves were depleted as soil dried out, and before soil moisture content reached the wilting percentage. Under moisture stress, increased conversion of starch to sugar frequently occurs and nitrogen metabolism often is disturbed. Also, a starch hydrolysis may take place due to amylolytic activity. Brix (10) reported a decreased rate of photosynthesis and respiration with increasing water stress in tomatoes, but with Loblolly pines subjected to water stress, rate of photosynthesis was decreased and rate of respiration was increased. Schneider and Childers (5) found that when the moisture content of soil in which apple trees were grown approached the wilting percentage, there was a corresponding decrease in the rate of apparent photosynthesis in the leaves and an increase in the rate of respiration. Gates and Bonner (25) noted an increased rate of destruction of RNA at high moisture stress. Paper chromatographic analysis of free amino acids of plants indicated that at the high moisture level, there was a higher concentration of arginine than at the lower moisture levels (M1 and M3). Furthermore, tyrosine was present in plants grown at M6 but was not detected in plants at M1 and M3. Evidently water stress may also have an effect on protein synthesis since there appears to be a change in the ratio of the amounts of certain amino acids. Petrie and Wood (44) found a considerable change in cystine in relation to other amino acids as the water content decreased. Under conditions of stress, inhibitory to growth, certain phases of protein synthesis may become limiting. However, the total quantity of protein may give little or no information on the quality of proteins or the prevalence of types essential for growth. Mothes (43) showed a relationship between water content and proteolysis. Proteolytic enzymes are activated by reduced sulfhydral groups and their activation may be enhanced because of oxygen deficiency resulting from stomatal closure. Many of the biochemical effects of water stress must be exerted through changes in activity of enzyme systems, but very little is known about this.

The results of the mineral composition of bean plants at different moisture levels agree with those of Emmert (20) who found that tomato plants grown under relatively low moisture conditions were higher in leaf N and K and lower in P than at high moisture levels. Williams (73) concluded that moisture stress lowered the nutritional status of bean plants to a sub-optimal level where supplies of nutrients were not sufficient to satisfy the demands of all developing seeds.

Effects of Sucrose Spray on Flowering, Fruiting, and Carbohydrate Content of Bean Plants

Bean plants sprayed with a sucrose solution yielded higher than control plants, but the difference was not statistically significant. (Table 1).

In Experiment 3, the weights of pods of the plants sprayed with sugar were significantly higher than the control. Furthermore, the number of pods of plants in this treatment was higher than for plants placed under plastic cages or for control plants, but the difference between the control and sugar spray treatments was not significant, (Table 9). The sucrose and starch contents of control plants and plants sprayed with sugar were about the same. It is not clear why sucrose did not increase carbohydrate levels in plants. Perhaps other forms of sugars might have been more effective.

Although the difference in weight and number of pods was not significant from the control, there was a marked reduction of starch and sugars in snap beans from use of plastic cages in the present study. Sugar sprays did not offset the decreased effects of high temperatures. For sprays to be effective in overcoming detrimental effects of high temperature, the sensitive reaction should be known, and at the same time, substances used should penetrate the plant tissues and be metabolized.

Ketallapper (32) reported that in a number of cases, the reduction in growth caused by unfavorable temperature can be prevented, either partially or completely by applying chemically well defined substances to plants growing under such unfavorable temperature conditions.

SUMMARY AND CONCLUSIONS

The effects of modifying air temperatures, soil temperatures and soil moisture levels, on flowering, fruiting, and biochemical composition of Tendercrop snap beans were studied in experiments in the field and in the greenhouse during 1961, 1962, and 1963.

High maximum temperatures of 90^{o}-105^{o} F. during bloom reduced the percent set and number and weight of pods of bean plants. Plants appeared to be most sensitive to temperatures at six to eight days after first bloom. Air temperatures in the field were increased 8^{o}-10^{o} F. above controls by use of clear polyethylene plastic cages.

The carbohydrate content of leaves and stems of plants subjected to high temperatures was decreased with a greater relative reduction of starch than of sugars. Air temperature appeared also to affect the protein metabolism since cystine was not detected in plants subjected to high temperature. Furthermore, threonine was detected in plants exposed to high temperatures, but not in control plants.

Soil temperatures ranging from 55^{o} to 90^{o} F. had a pronounced effect on growth, flowering, and yield of snap beans with best growth of plants and highest number of flowers and pods and weight of pods being obtained at soil temperatures of 75^{o} to 80^{o} F.

Diurnal fluctuation of soil temperature had no advantage over comparable constant mean soil temperature for growth of plants. An exception was at fluctuating soil temperatures of 50-60^{o} F. compared to a constant temperature of 55^{o} F. Soil temperatures did not affect levels of total sugar and reducing sugar, but the starch content was decreased with an increase in soil temperature. Sucrose content of plants at fluctuating soil temperatures tended to be higher than in plants grown at comparable constant mean temperatures. Dry weight of shoots and roots and P and K content of plants increased with increased soil temperatures. Magnesium content tended to decrease with an increase of soil temperature while calcium content of plants was variable.

Snap bean plants which received the highest amount and frequency of irrigation from planting to harvest had the highest dry weight of shoots, number of flowers, percent set, and yield of pods when compared to plants subjected to moisture stress, either before or after bloom, or during both periods.

On a dry weight basis, the carbohydrate content of leaves and stems of plants was highest when amount and frequency of irrigation was highest, but on the fresh weight basis, the carbohydrate content decreased with an increase in soil moisture. The stems and leaves of plants at the high moisture treatments contained highest levels of P and K, while N and Mg levels of the same plants were lowest. A higher concentration of arginine was found in plants at high moisture levels than at low moisture levels. Tyrosine was detected in plants grown at the high moisture level, but not in plants subjected to moisture stress. Data suggest that soil moisture levels affected protein metabolism. Sucrose sprays had no significant effect on production of pods and carbohydrate content of bean plants.

When soil temperature and moisture levels were varied, significant correlation coefficients were obtained between weight of plants and number of pods, and between weight of plants and weight of pods. The data suggest that for highest yield, environmental factors should favor production of a large, vigorous plant, with large photosynthetic capacity for bearing flowers and fruits.

Bean plants appear to be especially sensitive to adverse temperature and moisture conditions during the period of anthesis and early pod development. Although adverse effects of high temperature and of moisture stress on pollination and fertilization were not studied, *per se*, in the present investigation, these adverse conditions caused a lower production of pods, lower carbohydrate levels, and appeared also to affect protein metabolism in snap beans.

Further research is needed, especially to elucidate the adverse effects of high temperatures and moisture stress on biochemical processes and constituents of the snap bean and the significant relationship of these to growth, flowering, and fruiting.

BIBLIOGRAPHY

1. Allen, R. C. The effect of soil temperature on the growth and flowering of certain greenhouse crops. Proceedings of the American Society for Horticultural Science 32: 635-637. 1934.

2. Andrews, F. S. Physiological factors associated with the fruiting of the bush lima bean. Proceedings of the American Society for Horticultural Science 33: 473-476. 1935.

3. Apple, S. B., Jr., and J. S. Butts. Soil temperature studies. I. The effect of soil temperature and phosphorus on growth and phosphorus uptake by pole beans. Proceedings of the American Society for Horticultural Science 61: 325-332. 1953.

4. Ayers, A. D., et. al. The interrelationship of salt concentration and soil moisture content upon the growth of beans. Journal of the American Society of Agronomy 35: 796-810. 1943.

5. Benedict, H. M. The effect of soil temperature on guayule plants. Plant Physiology 25: 377-388. 1950.

6. Binkley, A. M. The amount of blossom and pod drop on six varieties of garden beans. Proceedings of the American Society for Horticultural Science 29: 489-494. 1932.

7. Block, R. J., E. L. Durrum, and C. Zweig. Paper chromatography and paper-electrophoresis. New York, Academic Press, 1958. 710 p.

8. Bohning, R. H., et. al. Effect of temperature and sucrose on growth and translocation in tomato. American Journal of Botany 40: 150-153. 1953.

9. Bonner, J. The chemical cure of climatic lesions. Engineering & Science 20: 28-30. 1957.

10. Brix, Holger. The effect of water stress on the rates of photosynthesis and respiration in tomato plants and Loblolly pine seedlings. Physiologia Plantarum 15: 10-20. 1962.

11. Brown, J. C., C. G. Pattern, M. E. Gardner, and R. K. Jackson. A line operated photomultiplier unit for measuring special emissions in flame analysis. Proceedings of the American Society for Horticultural Science 59: 337-342. 1952.

12. Burkholder, W. H. The effect of two soil temperatures on the yield and water relations of healthy and diseased bean plants. Ecology 1: 113-123. 1920.

13. Bushnell, J. The relation of temperature to growth and respiration of potato plant. St. Paul, 1925. 29 p. (Minnesota Agricultural Experiment Station. Technical Bulletin 34.)

14. Cannel, H. Glen. Yield and nutrient composition of tomatoes in relation to soil temperature, moisture, and phosphorus level. Soil Science Society of America Proceedings 27: 560-565. 1963.

15. Cochran, H. L. Factors affecting flowering and fruit setting in the pepper. Proceedings of the American Society for Horticultural Science 28: 434-437. 1932.

16. Cochran, H. L. Some factors influencing growth of fruit setting in pepper. Ithaca, 1936. 39 pp. New York (Cornell) Agricultural Experiment Station Memoir 190.

17. Cordner, H. B. External and internal factors affecting blossom drop and set of pods in lima bean. Proceedings of the American Society for Horticultural Science 30: 571-576. 1933.

18. Davis, D. F. The effect of some environmental factors on set of pods and yield of white pea beans. Journal of Agricultural Research 70: 237-249. 1945.

19. Drosdoff, Mathew, and D. C. Nearpass. Quantitative microdetermination of magnesium in plant tissue and soil extracts. Analytical Chemistry 20: 673-674. 1948.

20. Emmert, E. M. Effects of drought on the nutrient levels in the tomato plant. Soil Science 41: 67-70. 1936.

21. Fiske, C. H., and Y. Subbarow. The colorimetric determination of phosphorus. Journal of Biological Chemistry 66: 375-400. 1925.

22. Foster, A. C., and E. C. Tatman. Influence of certain environmental conditions on congestion of starch in tomato plant stems. Journal of Agricultural Research 56: 869-882. 1938.

23. Gabelman, W. H., and D. D. F. Williams. Developmental studies with irrigated snap beans. Madison, 1960. 49 p. (Wisconsin Agricultural Experiment Station Research Bulletin 221.)

24. Galston, A. W., and M. E. Hand. Adenine as a growth factor for etiolated peas and its relation to the thermal inactivation of growth. Archives of Biochemistry 22: 434-443. 1949.

25. Gates, C. T., and J. Bonner. The response of the young tomato plant to a brief period of water shortage. IV. Effects of water stress on the ribonucleic acid metabolism of tomato leaves. Plant Physiology 34: 49-55. 1959.

26. Hendry, G. W. Bean culture in California. Berkeley, 1918. p. 288-397. (California Agricultural Experiment Station Bulletin 294.)

27. Hewitt, S. P., and O. F. Curtis. The effect of temperature on loss of dry matter and carbohydrate from leaves by respiration and translocation. American Journal of Botany 35: 746-755. 1948.

28. Horwitz, William, ed. Official methods of analysis of the Association of Official Agricultural Chemists. Washington, D. C., 1955. 1008 pp.

29. Iwami, N. Ecological studies on beans. I. Set of pod in different varieties in relation to temperature. Journal of the Horticultural Association of Japan 19: 68-75. 1950.

30. Janes, B. E. The effect of varying amounts of irrigation on the composition of two varieties of snap beans. Proceedings of the American Society for Horticultural Science 51: 457-462. 1948.

31. Kattan, A. A., and J. W. Fleming. Effect of irrigation at specific stages of development on yield, quality, growth, and composition of snap beans. Proceedings of the American Society for Horticultural Science 68: 329-342. 1956.

32. Ketellapper, H. J. Temperature-induced chemical defects in higher plants. Plant Physiology 38: 175-179. 1963.

33. Kramer, P. J. Soil moisture in relation to plant growth. Botanical Review 10: 525-559. 1944.

34. Kramer, P. J. Root resistance as a cause of decreased water absorption by plants at low temperature. Plant Physiology 15: 63-79. 1940.

35. Lambeth, V. N. Some factors influencing pod set and yield of lima bean. Columbia, 1950. 60 pp. (Missouri Agricultural Experiment Station Research Bulletin 466.)

36. Lambeth, V. N. Studies in moisture relationship and irrigation of vegetables. Columbia, 1956. 55 p. (Missouri Agricultural Experiment Station Bulletin 605.)

37. Langridge, J., and B. Griffing. A study of the high temperature lesions in <u>Arabidopsis thaliana</u>. Australian Journal of Biological Science 12: 117-135. 1959.

38. Lingle, J. C., and R. M. Davis. The influence of soil temperature and phosphorus fertilization on growth and mineral absorption of tomato seedlings. Proceedings of the American Society for Horticultural Science 73: 312-322. 1959.

39. Locascio, S. J., and G. F. Warren. Interaction of soil temperature and phosphorus on growth of tomatoes. Proceedings of the American Society for Horticultural Science 75: 601-610. 1960.

40. Martin, C. George, and Gerald E. Wilcox. Critical soil temperature for tomato plant growth. Proceedings of the Soil Science Society of America. 27: 565. 1963.

41. Miller, M. F., and F. L. Duley. The effect of varying moisture supply upon the development and composition of the maize plant at different periods of growth. Columbia, 1925. 36 p. (Missouri Agricultural Experiment Station Research Bulletin 76.)

42. Moore, E. L., and W. O. Thomas. Some effects of shading and parachlorophenoxy acetic acid on fruit fullness of tomatoes. Proceedings of the American Society for Horticultural Science. 60: 289-294. 1952.

43. Mothes, K. Der Einfluss des Wasserzustandes auf Fermentprozesse und Stoffumsatz. In: Handbuch der Pflanzenphysiologie. Vol. 3. Springer Verlag, Berlin, Germany. 1956. p. 656-664.

44. Petrie, A. H. K., and J. G. Wood. Studies on the nitrogen metabolism of plants. III. On the effect of water content on the relationship between protein and amino acids. Annals of Botany 2: 887-98. 1938.

45. Radspinner, W. A. Effects of certain physiological factors on blossom drop and yield of tomatoes. Proceedings of the American Society for Horticultural Science 19: 71-75. 1923.

46. Rappaport, I., and R. L. Carolus. Effect of night temperature at different stages of development on reproduction in the lima bean. Proceedings of the American Society for Horticultural Science 67: 421-428. 1956.

47. Reddick, Doland. Effect of soil temperature on the growth of bean plants and on their susceptibility to a root parasite. American Journal of Botany 4: 513-519. 1917.

48. Riethmann, O. Der Einfluss der Bodentemperatur auf das Wachstum und Reiferzeit der Tomaten. Bericht der Schweizerischen Botanischen Gesellschaft. 42: 152-168. 1933.

49. Riley, J. P., and J. W. Wolfe. A field plot sprinkler irrigator. Corvallis, 1958. 9 p. (Oregon Agricultural Experiment Station. Miscellaneous Paper 57.)

50. Schneider, G. W., and N. P. Childers. Influence of soil moisture on photosynthesis respiration and transpiration of apple leaves. Plant Physiology 16: 565-583. 1941.

51. Shanks, J. B. and Alex Laurie. Rose root studies. Some effects of soil temperature. Proceedings of the American Society for Horticultural Science 54: 495-499. 1949.

52. Shaw, G. W., and M. E. Sherwin. Production of the lima bean. Berkeley, 1911. p. 201-247. (California Agricultural Experiment Station Bulletin 224)

53. Smith, Francis L., and Richard H. Pryor. Effects of maximum temperature and age on flowering and seed production in three bean varieties. Hilgardia 33: 669-689. 1962.

54. Smith, Ora. Relationship of temperature to anthesis and blossom drop of the tomato, together with a histological study of the pistil. Journal of Agricultural Research 44: 183-190. 1932.

55. Somoygi, M. A new reagent for the determination of sugars. Journal of Biological Chemistry 160: 61-68. 1945.

56. Sullivan, J. T., and V. G. Sprague. The effect of temperature on the growth and composition of the stubble and root of perennial ryegrass. Plant Physiology 24: 706-719. 1949.

57. Theron, A. A. Some effects of soil temperature on the growth and chemical composition of plants. Ph.D. Thesis. Ithaca. (Cornell University, 1958. Abstracted in Dissertation Abstracts 18: 753-754. 1958.)

58. Thomas, W., et. al. Nitrogen, phosphorus, and potassium nutrition of tomatoes at different levels of fertilizer application and of irrigation. Proceedings of the American Society for Horticultural Science 42: 535-544. 1943.

59. Thomson, H. J. Effect of temperature, humidity, and wind velocity on blossom drop of garden beans. Goodwell, 1937. p. 7-16. (Oklahoma Panhandle Agricultural Experiment Station. Bulletin 62.)

60. Thompson, L. M. The mineralization of organic phosphorus, nitrogen, and carbon in virgin and cultivated soils. Iowa State College Journal of Science 25: 369-370. 1951.

61. Thompson, L. M., and C. A. Black. The effect of temperature on the mineralization of soil organic phosphorus. Soil Science Society of America Proceedings 12: 323-326. 1948.

62. Tottingham, W. E. Temperature effects in plant metabolism. Journal of Agricultural Research 25: 13-30. 1923.

63. Viglierchio, D. R., and F. W. Went. Plant growth under controlled conditions. IX. Growth and fruiting of the Kentucky Wonder bean (Phaseolus vulgaris). American Journal of Botany 44: 449-453. 1957.

64. Wadleigh, C. H., and A. D. Ayers. Growth and biochemical composition of bean plants as conditioned by soil moisture tension and salt concentration. Plant Physiology 20: 106-132. 1945.

65. Walster, H. L. Formatic effect of high and low temperature upon growth of barley, a chemical correlation. Botanical Gazette 69: 97-126. 1920.

66. Watanabe, H. Studies on unfruitfulness of the bean. II. Influence of temperature on the flower bud differentiation and blooming. Journal of the Horticultural Association of Japan. 22: 172-176. 1953.

67. Weintraub, R. L., and J. W. Brown. Translocation of exogenous growth regulators in the bean seedling. Plant Physiology 25: 140-149. 1950.

68. Went, F. W. The experimental control of plant growth. Waltham, Massachusetts, 1957. 393 p. (Chronica Botanica, Vol. 17.)

69. Went, F. W. Plant growth under controlled conditions. II. Thermoperiodicity in growth and fruiting of tomato plants. American Journal of Botany 31: 135-150. 1944.

70. Went, F. W. Plant growth under controlled conditions. V. The relation between age, light variety, and thermoperiodicity of tomatoes. American Journal of Botany 32: 469-479. 1945.

71. Went, F. W. and M. Carter. Growth response of tomato plants to applied sucrose. American Journal of Botany 35: 95-106. 1948.

72. Went, F. W., and Engelsberg. Plant growth under controlled conditions. VII. Sucrose content of the tomato plant. Archives of Biochemistry 9: 187-199. 1946.

73. Williams, D. D. F. Influence of soil moisture level on flower abscission, ovule abortion and seed development in the snap bean. Ph.D. Thesis. Madison. The University of Wisconsin. 1962. 64 pp. (Xerograph).

74. Woodhams, D. H., and Theodore T. Kozlowski. Effect of soil moisture stress on carbohydrate development and growth in plants. American Journal of Botany 41: 316-320. 1954.

75. Wort, D. J. Soil temperature and growth of Marquis wheat. Plant Physiology 15: 335-343. 1940.

APPENDIX

Appendix Table 1. Analysis of variance for the effect of modified environment and sugar spray on weight of pods of snap beans in the field. Experiment 1, 1961.

Sources of Variation	DF	MS	F
Total	14		
Treatment	4	920.20	6.73**
Error	10	136.66	

** Significant at 1 percent level.

Appendix Table 2. Analysis of variance for the effects of plastic cages and moisture levels on weight of plants, and weight and number of pods in the field. (Three moisture levels combined.) Experiment 2, 1962.

		Mean Squares		
Sources of Variation	DF	Weight of plant	Weight of pods	Number of pods
Total	83			
Moisture	2	70840.35	25074.56**	1193.86**
Treatment	6	2027.81	735.01**	58.31**
Moist Tr.	12	1191.43	502.93*	48.68**
Error	63	954.31	233.88	18.63

Appendix Table 3. Analysis of variance for the effect of soil moisture levels on number of flowers, percent set, and number of pods in check plots in the field. Experiment 2, 1962.

		Mean Squares		
Sources of Variation	DF	No. of Flowers	% Set of pods	Number of pods
Total	11			
Moisture	2	552.58**	159.29**	292.00**
Error	9	36.86	14.38	15.33

* Significant at 5 percent level.
** Significant at 1 percent level.

Appendix Table 4. Air temperatures (^{o}F) of control and plastic cage treatments. M3 moisture level. (Regular irrigation). Experiment 2, 1962.

Treatments	Date July	No Plastic Min	No Plastic Max	Plastic Min	Plastic Max
Plastic at first bloom	15	44	84	46	106
Plastic 2 days after 1st bloom	17	48	87	50	105
Plastic 4 days after 1st bloom	19	44	93	46	106
Plastic 6 days after 1st bloom	21	51	96	56	104
Plastic 8 days after 1st bloom	23	52	100	56	107
Plastic 10 days after 1st bloom	25	52	97	54	107
Average		48	93	51	106

Air temperature under the plant canopy at 2-3 inches above the ground level.

Appendix Table 5. Analysis of variance for the effects of plastic cages and sugar sprays on weight and number of pods in the field. Experiment 3, 1963.

Sources of Variation	DF	Mean Squares: Weight of Pods	Mean Squares: Number of Pods
Total	19		
Treatments	3	771.77*	12.486*
Replications	4	458.13	6.367
Error	12	159.08	3.050

Appendix Table 6. Air temperatures (°F) of control and plastic cage treatments in the field. Experiment 3, 1963.

Date	Control		Plastic cage	
	Min	Max	Min	Max
Aug 7	--	84	--	90
Aug 8	54	90	57	96
Aug 9	60	87	64	95
Aug 10	60	--	64	--
Average	58	87	62	94

Appendix Table 7. Air temperatures of various treatments. Experiment 4, 1963.

Stage of Bloom	Date Aug. 1963	Check outside (greenhouse)		Medium (greenhouse)		High (greenhouse)	
		Min	Max	Min	Max	Min	Max
I							
2 days	22	--	98	--	100	--	100
after	23	58	76	62	100	60	110
1st	24	50	72	68	96	60	100
bloom	25	51	80	70	110	70	110
	26	52	85	70	110	68	115
Mean		53	82	67	103	65	107
II							
6 days	27	55	86	60	96	60	110
after	28	58	86	54	100	60	110
first	29	59	98	60	94	59	100
bloom	30	59	90	60	98	60	90
	31	58	85	58	98	64	90
Mean		58	89	58	97	61	100

Appendix Table 8. Analysis of variance for the effect of temperature on number of flowers, percent set of pods, number and weight of pods. Experiment 4, 1963.

		Mean Squares			
Sources of Variation	DF	No. of flowers	% Set of pods	No. of pods	Wt. of pods
Total	59				
Treatment	4	42.35	615.03*	29.85**	324.46
Error	55	40.49	184.72	7.75	163.35

Appendix Table 9. The analysis of variance for the effect of soil temperature on number of flowers, pods, and weight of pods in the greenhouse. Experiment 5, 1961.

		Mean Squares		
Sources of Variation	DF	No. of Flowers	Number of pods	Weight of pods
Total	43			
Treatments	3	99.90**	25.96**	290.14**
Error	40	5.03	1.11	9.02

Appendix Table 10. The analysis of variance for the effect of soil temperature on dry weight of shoots and roots in the greenhouse. Experiment 5, 1961.

		Mean Squares	
Sources of Variation	DF	Dry wt. of root	Dry wt. of shoot
Total	19		
Treatment	3	0.0965**	1.475**
Error	16	0.0129	0.272

Appendix Table 11. Analysis of variance for the effect of constant and fluctuating soil temperature on number of flowers, pods, weight of pods, dry weight of shoot and root. Experiment 6, 1962.

		Mean Squares					
Sources of Variation	DF	Number of Flowers	Number of Pods	Weight of Pods	Dry wt. of root (at harvest)	Dry wt. of shoot (at harvest)	Dry wt. of shoot (at full bloom)
Total	109						
Treatment	10	143.59**	46.81**	853.37**	5.39**	50.11**	3.40**
Error	99	12.64	4.82	66.72	0.15	2.72	0.52

Appendix Table 12. Analysis of variance for the effect of constant and fluctuating soil temperature on weight of plants. Experiment 6, 1962.

Sources of Variation	DF	Mean Squares
Total	119	
Treatment	11	352.49**
Error	108	13.72

Appendix Table 13. Analysis of variance for the effect of soil moisture treatments on weight of plants, and number and weight of pods. Experiment 7, 1962.

Sources of Variation	DF	Mean Squares Weight/ Plants	Number of Pods	Weight of Pods
Total	23			
Treatment	5	10029.86**	615.47**	22511.45**
Replication	3	1323.50	17.15	548.83
Error	15	1148.72	29.58	1338.78

Appendix Table 14. Analysis of variance for the effect of soil moisture treatments on number of flowers and percent set of pods. Experiment 7, 1962.

Sources of Variation	DF	Mean Squares No. of Flowers	% Set of pods
Total	11		
Treatment	2	604.35**	147.89**
Replication	3	218.00	6.22
Error	6	97.66	6.57

Appendix Table 15. Analysis of variance for the effect of soil moisture treatments on weight of plant, number and weight of pods. Experiment 8, 1963.

Sources of Variation	DF	Mean Squares Weight/ Plant	 Number of pods	 Weight of pods
Total	23			
Treatment	5	1573.31**	125.41**	2116.49**
Replication	3	703.20*	80.35*	1575.27*
Error	15	165.41	17.14	212.89

Appendix Table 16. Analysis of variance for the effect of soil moisture treatments on number of flowers and percent set of pods. Experiment 8, 1963.

Sources of Variation	DF	Mean Squares No. of Flowers	 % Set of pods
Total	11		
Treatment	2	107.93	130.45*
Replication	3	32.46	202.77**
Error	6	79.19	19.29

Appendix Table 17. Effects of two moisture levels on air temperatures in Experiment 7, 1962.

	M1		M6	
Date	Min	Max	Min	Max
July 28	50	100	50	92
" 29	48	98	*48	82
" 30	50	98	51	86
" 31	50	92	*51	80
Aug. 1	50	84	52	76
" 2	48	90	*49	83
" 3	59	78	59	75
" 4	52	78	*53	72
" 5	54	86	55	80
" 6	55	69	*55	68
" 7	*58	64	57	66
" 8	52	76	*52	73
" 9	50	84	50	81
" 10	48	84	*49	87
" 11	48	87	48	86
" 12	58	82	*57	79
" 13	51	85	51	82
" 14	48	92	*46	90
" 15	50	94	49	91
" 16	58	85	*58	86
" 17	48	82	50	78
Ave.	52	85	52	80

* Date Irrigated.

Temperatures under the plant canopy approximately 3 inches above the ground level.

Appendix Table 18. Effects of two moisture levels on air temperatures in Experiment 8, 1963.

Date	M3		M6	
	Min	Max	Min	Max
Aug. 1	46	79	46	78
2	47	91	*48	83
3	55	80	55	75
4	53	88	*53	84
5	50	90	50	84
6	52	92	*52	83
7	54	93	54	88
8	52	98	*53	91
9	*62	78	61	86
10	60	86	*60	84
11	58	90	58	87
12	56	77	*56	75
13	59	80	59	75
14	48	85	*49	79
Average	54	86	54	82

* Date irrigated.
Temperatures under the plant canopy approximately 3 inches above the ground.