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SEED YIELD AND QUALITY OF SOYBEAN (GLYCINE MAX (L.) MERRILL) GENOTYPES EXPOSED TO SUNLIGHT REFLECTORS AND HIGH TEMPERATURE

The Ohio State University

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SEED YIELD AND QUALITY OF SOYBEAN (Glycine max (L.) Merr) GENOTYPES EXPOSED TO SUNLIGHT REFLECTORS AND HIGH TEMPERATURE

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

Kahtan Khalaf Ali, B.S., M.S.

* * * * *

The Ohio State University

1983

Reading Committee:
Dr. P. R. Henderlong
Dr. D. L. Jeffers
Dr. S. K. St. Martin
Dr. C. A. Swanson

Approved By

Co-Advisers
Department of Agonomy
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VITA

Kahtan K. Ali

April 18, 1947 . . . . . . Born, Baghdad, Iraq

June, 1970 . . . . . . . B.Sc. (Field Crop) University of Baghdad, Iraq

November, 1970 . . . . . . Agronomist, Al-Dalmaj Agricultural Project, Kut, Iraq

May, 1972 . . . . . . . Managing Director, Al-Dalmaj Agricultural Project, Kut, Iraq

October, 1973 . . . . . . Graduate Research Associate, Department of Field Crop, University of Baghdad, Iraq

June, 1976 . . . . . . . M.Sc. (Field Crop) University of Baghdad, Iraq

September, 1976 . . . . . . Research Assistant, Oilseeds Section, General Body of Applied Agricultural Research, Baghdad, Iraq

1980-1983 . . . . . . . Graduate Research Associate (Ph.D) Dept. of Agronomy, The Ohio State University, Columbus, Ohio

FIELDS OF STUDY

Major Field: Agronomy

Minor Field: Plant Physiology, Plant Breeding

Studies in Crops and Seed Science: Professors P.R. Henderlong and M.B. McDonald.


Studies in Plant Physiology: Professors C.A. Swanson, M.L. Evans, and J. Wong.


Studies in Biochemistry: Professor J.F. Snell.

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INTRODUCTION

Temperature is an important factor influencing soybean (Glycine max (L.) Merr) growth, development and yield. Excessively high temperatures negatively affect photosynthesis and other physiological processes and reduce yield and seed quality. Photosynthesis and growth in C-3 species like soybean are most efficient at temperatures of less than about 28°C, whereas in C-4 species, like maize (Zea mays L.) optimum temperature is above 28°C.

In Iraq (30 - 36° Lat. N) and other arid zone countries, shrinkage of mature seed is considered to be a major problem facing development of this crop. Shrivelled seeds seem to be mostly related to high temperatures during reproductive stages, since persistent irrigation does not alleviate the problem.

Relatively little attention has been given to identification and selection of genotypes with tolerance to high temperature. This is because the source of germplasm and new cultivar development have occurred mostly in temperate zone countries of the world. Although it is difficult to separate the effect of high temperature on plant growth from other environmental factors, especially drought and high
light intensity, it appears from various studies that deve-
lopment of cultivars having good seed quality in high tem-
perature environments is feasible.

Accordingly, special effort has been made to identify
some genotypes whose seed development is tolerant to high
temperature. This study examines the effect of sunlight
reflectors and excessive high temperature during the repro-
ductive period on yield, yield components, seed shrinkage,
germination, vigor and chemical composition in greenhouse
and field-grown soybeans.
REVIEW OF LITERATURE

The effect of high temperature and light enrichment on some of the most important characteristics of soybeans will be discussed in the following review.

Effect of High Temperature

Photosynthesis

Reduction in photosynthesis is a result of stresses in many environmental conditions. Although soybeans are commonly regarded as a warm-season crop, high temperature might be considered one of the basic environmental elements that reduces the rate of photosynthesis in soybean. However, the assimilation of carbon dioxide (CO$_2$) in soybean leaves is lower than that of many crops (El-Sharkawy and Hesketh, 1965), but it is much higher in sun-exposed leaves of spaced plants (Beuerlein and Pendelton, 1971). Jeffers and Shibles (1969) found that the optimum air temperature for net CO$_2$ assimilation in field-grown soybeans was 25 to 30°C. Hofstra and Hesketh (1969) measured the CO$_2$ assimilation over a range of temperatures from 15 to 50°C. They found that a temperature increase from 30 to 40°C resulted in approximately a 20 percent decrease in CO$_2$ assimilation by soybean canopies. Their data showed that the optimum temperature for net photosynthesis is 35°C, and the maximum rate in the absence of oxygen occurred at 40°C. They concluded that respiration in the light had a different sensitivity to temperature compared with respiration in the
dark. At the lower temperatures the rate of respiration in the light was higher than respiration in the dark, whereas at temperatures above 40°C the reverse was observed. The maximum rates of photosynthesis and photorespiration occurred at about the same temperature.

In some crops, photosynthesis rates may be limited by the size of the sink, but this might not be the case in soybean where the photosynthesis, per se, is the primary limiting process under unfavorable conditions. However, there are two views on this point as summarized by Thomas and Raper (1976). The first view, which is supported by a number of workers (Hardy and Havelka, 1975; Harper and Vigue, 1975; and Lawn and Brun, 1974), suggests that the rate of photosynthesis is the limiting factor for both yield and nitrogen fixation potentials. The second view as proposed by Sinclair and de Wit (1975), suggests that the photosynthetic activity of vegetative tissues, and ultimately yield of seed, is restricted by the inability of the soybean plant to accumulate nitrogen (from the soil or by symbiotic fixation) at rates similar to the demand generated by seed-fill.

The rate of photosynthesis varies with different stages of plant development. It is much higher during pod filling than during flowering, even under water stress, presumably due to increased demand at the later stage (Shibles et al., 1975). But the effect of temperature is always accompanied
by other environmental factors such as water stress and light. There is an abundance of evidence indicating that photosynthetic reduction is a function of water and heat stresses which are difficult to control independently. Stevenson and Shaw (1971) found that high water stress caused as much as a 7°C increase in soybean leaf temperature above that of unstressed leaves. Mann and Jaworski (1970) suggested that both heat (40-46°C) and shade stresses (63 percent of ambient) in their experiments may have acted through the same mechanism in reducing the supply of photosynthate.

**Nutrient Absorption and Translocation**

According to DeMooy et al. (1973), the general trend of nutrient uptake with temperature is that an optimum occurs. At low temperatures uptake and translocation to the top of the plant are reduced and above a certain critical temperature, the plant is damaged. Wallace (1957) studied the influence of soil temperature on cation uptake in soybeans. He concluded that potassium concentration of soybeans increased with temperatures up to 32°C, whereas magnesium and calcium uptake decreased as temperature increased from 12 to 32°C. The concentration of zinc increased from 17 to 30 ppm with a temperature change from 14 to 26°C. The greatest zinc uptake was observed at 30°C.

Paulsen and Rotimi (1968) studied the phosphorus-zinc interaction in two soybean cultivars and came to a similar
conclusion. More zinc uptake and better translocation to leaves occurred at 30°C than at 20°C. High phosphorus levels in the nutrient solution did not depress the zinc concentration of plants at low temperature as much as the higher temperature. According to a phytotron experiment conducted by Gukova in 1960 (cited by DeMooy et al., 1973), nitrogen concentration increased 20 percent in plant tissue and seeds of uninoculated plants when the soil temperature increased from 19 to 30°C. Accumulation of nitrogen from soil and from nitrogen fixation responded differently at high and low temperature. The optimum temperature for nitrogen absorption from soil was higher than that for nitrogen fixation.

Mederski and Wilson (1955) reported that the rate of manganese accumulation was enhanced by increasing the root zone temperature from 15 to 27°C. Ghazali and Cox (1981) also reported a decrease in the functional requirement of manganese with increasing temperature from 15.5 to 27.5°C.

The effect of temperature on translocation of photosynthetic products in soybean is uncertain. Mortimer (1961) and Whitte (1964) reported increased translocation of photosynthetic product with increased temperature up to 30°C in sugar beet (Beta vulgaris L.) petioles and Pteridium, respectively. On the contrary, Hsia et al. (1963) showed an increase in translocation in wheat (Triticum aestivum L.) as
temperature decreased. In general, the optimum temperature for translocation of carbohydrates in bean (*Phaseolus vulgaris* L.) leaves is usually in the range of 20 to 25°C (Swanson and Bohning, 1951). Data obtained by Thorne (1982) revealed that temperatures (15, 25, or 35°C) and oxygen treatments (0, 21, or 10 percent O\(_2\)) over a short period of time influenced photosynthate uptake in intact pods of field-grown 'Amsoy 71' soybeans by affecting processes only within the seed. Pod walls were only a minor sink for incoming photosynthate and were not affected by temperature or oxygen treatments.

**Nodulation and Nitrogen Fixation**

Nodulation and nitrogen fixation in soybean are greatly affected by soil temperature. Whigham and Minor (1978), in their review of environmental stress, stated that *Rhizobium japonicum* growth is limited by temperatures in excess of 33°C and consequently nitrogen fixation is reduced. However, it seems that nodulation and nitrogen fixation are more sensitive to high temperature than low temperature. Apprison et al. (1954) reported that the maximum nitrogen fixation in soybean root nodules was obtained at 25°C. At 15 and 30°C the nitrogen fixation was only 20 and 40 percent of the maximum, respectively. But Ahmad (1978), by using the acetylene reduction technique, found the optimum temperature for nitrogen fixation was 31°C. Differences between *Rhizobium japonicum* strains were observed in rates
of nitrogen fixation at temperatures of 28, 34 or 40°C (Munevar and Wollum, 1981).

Kuo and Boersma (1971), in studying nitrogen fixation at different temperatures, obtained the highest nitrogen concentration in plants grown at about 24°C. The nitrogen concentration was very low at 38°C. Munevar and Wollum (1981) studied the effect of high root temperature with three *Rhizobium* strains on nodulation, nitrogen fixation and growth of 'Lee' soybean. They found that increasing root temperatures from 28 to 40°C had a detrimental effect on nodule numbers, specific nitrogenase activity, nitrogen concentration and dry weight of inoculated plants. The 40°C treatment prevented nodulation by the three strains used and also severely restricted growth of plants supplied with combined nitrogen. They observed that a 38°C treatment prevents nodule initiation but did not completely prevent growth of nodules already formed before exposing the plants to high root temperature.

Legume plants such as soybean depending on nitrogen fixation have a lower optimum temperature for their growth than those to which nitrogen fertilizer is added (Munevar and Wollum, 1981). In general, effective nitrogen fixation is restricted to a relatively narrow root temperature range in such plants. The effect of high temperature on nitrogen fixation in soybean may be masked by nitrogen absorption from soil. Whigham and Minor (1978) stated that the optimum
temperature for nitrogen absorption from soil is higher than that for nitrogen fixation. Thus plant growth may not always show the effects of temperature-related reduction of nitrogen fixation.

It seems that the translocation rate of carbohydrates and other compounds to nodules has a direct effect on nitrogen fixation. Any reduction in translocation rate might affect nitrogen fixation because the latter requires an adequate supply of recently manufactured photosynthate. Lawrie and Wheeler (1973) studied the supply of photosynthetic assimilates to nodules of Pisum sativum in relation to the fixation of nitrogen. A correlation was found between the accumulation of labeled photosynthates in nodules and the rate of acetylene reduction during the entire growth cycle of pea plants in nitrogen-free culture.

**Flowering and Maturity**

In addition to day length, temperature has an effect on flowering and maturity. Steinberg and Carner (1936) observed that increasing temperatures hastened flowering of soybean up to an optimum temperature of 28°C, above which flowering was delayed. Whigham and Minor (1978) stated that temperature below 24°C will normally delay flowering by 2 or 3 days for each decrement of 0.5°C. Flower initiation is accelerated, however, when temperature increases from 15 to 32°C, whereas temperatures above 40°C have an adverse effect. Thomas and Raper (1976, 1978) noticed more rapid
flower appearance with increased day/night temperature from 22/18 to 30/26°C. Van Schaik and Probst (1958) also found a similar effect when temperature rose from 15.5 to 32.5°C.

Cultivars from different maturity groups tend to respond differently to varied temperatures. Thomas and Raper (1978) cited that an increase in night temperature for certain cultivars of soybean decreased the time to flowering, but as the plants mature an increase in day temperature decreased seed yield. Martineau et al. (1979b) suggest that early maturing genotypes tend to have relatively greater heat tolerance (membrane thermostability) than later maturity genotypes. At a constant 14-hour day length, Major et al. (1975) showed that the later cultivars flowered after the early cultivars, but there were no apparent differences in sensitivity to temperature. There was little difference among genotypes in sensitivity to seasonal temperature or day length during the period of flowering to physiological maturity.

High temperature seems to shorten the seed filling period in soybean. Egli and Wardlaw (1980) found that the time to the end of filling period (physiological maturity) was not affected by day/night temperatures of 24/19, 27/22 or 30/25°C but occurred 3 days earlier at 33/28°C. They suggested that the shorter filling period at 33/28°C may be one mechanism by which yields are reduced by high temperature. Hesketh et al. (1973) reported that number of
days between flowering and the first brown pod was not affected by temperatures ranging from 22 to 30°C. According to Peters et al. (1971) high temperatures up to 30°C were associated with earlier senescence and maturity; hence, the grain filling period was shortened.

From the previous review, it appears that the pod-filling period is the critical stage in soybean development. Plants at this stage are more sensitive to heat stress which shortens the pod-filling period, and reduces dry matter accumulation, hence a reduction in seed yield.

**Plant Height**

It has been found that temperature greatly influences soybean growth; hence, the final plant height is also affected. Thomas and Raper (1978) showed that the main stem length was increased by increasing either day or night temperature. The average length of the main stems increased gradually from 35 to 105 cm when increasing the day temperatures from 14 to 30°C, while the effect of increasing night temperature from 10 to 25°C provided less than 20cm difference in length. Van Schaik and Probst (1958) also reported an increase in the final plant height with increasing temperature from 15.5 to 32°C. Plants of the determinate cultivar 'Midwest' reached their final height sooner and remained shorter than those of the indeterminate cultivar 'Clark' with most temperature and photoperiod regimes.
Overholt (1974) studied the effect of temperature and seed size on soybean growth at 30-day intervals. He found that cultivars planted 16 May produced significantly taller plants over all seed sizes than did the cultivars planted at 16 April, which was due to warmer temperatures during the vegetative phase for the May planting encouraging faster emergence and plant growth. Shibles and Weber (1965) studied the characteristics of 'Wayne' soybean under different temperatures. They measured the plant heights at flowering time and found the tallest plants (147cm) under the 33/28°C (day/night) regime.

Yield and Yield Components

The effect of temperature on soybean yields is often underestimated despite reports of a significant relationship between yield and growing season temperatures (Martineau et al., 1979a). Runge and Odell (1960), in a statistical evaluation of the effect of weather on soybean yields at Urbana, Illinois, reported that soybean yields were slightly lower than average when temperatures were above average during July and August. On the other hand, temperatures above average during June and September resulted in a small increase in yield. They concluded that temperatures during the middle part of the growing season (at Urbana, Illinois) are too high for maximum soybean yields. At Brawley, California where daily maximum temperatures are above 38°C for June through September, Green (1961) showed that the
cultivar 'Lee' makes excellent growth and produces good seed yield and quality.

Peters et al. (1971) grew maize, wheat, and soybean under controlled night air temperatures (19 to 30°C). Their findings indicated that soybeans were relatively insensitive to high night temperature, whereas wheat and maize yields were greatly reduced by increasing night temperatures up to 30°C. For soybean, temperatures at night exceeded 30°C before any noticeable reduction in grain yield was experienced.

In 1926, Boswell reported that high temperature has a depressing effect on growth and yield of garden peas (Pisum sativum). He observed a decrease in yield when average air temperature during day rose from 17.3 to 20.6°C. His data indicated that most of the loss in yield was occasioned through the setting of fewer pods per plant. Similar findings were obtained by Stanfield et al. (1966), who studied the effect of day/night temperature from 7/4 to 32/24°C on growth and development of peas in controlled-environment cabinets. They concluded that pea yield decreased as temperature increased above 16/10°C, due mainly to the reduction in number of pods per plant.

Because seed yield is a product of factors influencing yield components, it is important to consider effects upon number of pods, number of seeds per pod, and seed size. Mann and Jaworski (1970) suggested that high temperature (40
to 46°C) was responsible for severe pod abortion. Hesketh et al. (1973) noticed that number of pods per plant increased slightly (from 74 to 80 pods) with increasing air temperature from 21 to 30°C in controlled environments in a phytotron. Similarly, Thomas and Raper (1978) found that plants grown at high day temperatures (26 and 30°C) produced a large number of pods over the whole range of night temperatures compared to 14, 18 or 22°C day temperatures. In contrast, Van Schaik and Probst (1958) reported that mean day temperatures between 16 and 32°C under controlled conditions of temperatures and photoperiods had no effect on average number of pods set per node. When the temperature rose above 40°C, the pod set was reduced by 57 to 71 percent and the number of seeds per plant was reduced by 59 to 63 percent (Mann and Jaworski, 1970). In peas, Stanfield et al. (1966) noted that the number of pods per plant decreased markedly as the temperature increased up to 32/24°C. This was attributed mainly to a decrease in the number of pod pairs per plant, and partly to a decrease in the number of nodes which produced pods.

Temperature also influences seed size (weight per seed) of soybean. Hesketh et al. (1973) found that seed size increased about 40 percent in response to increasing mean air temperature between 21 and 27°C above which weight per seed declined. Egli and Wardlaw (1980) reported that the seeds produced at a low temperature (18/13°C) and at a high
temperature (33/28°C) were significantly smaller (24 percent) than seeds produced at intermediate temperatures. They concluded that reduction in seed size at low temperature can be attributed to a lower seed growth rate while the reduction in size at high temperature was caused by more rapid leaf senescence and a shorter filling period. Thus, reduction in duration of seed growth at high temperature is one mechanism by which temperatures affect seed size and consequently reduce yield.

Mederski (1983) reported that comparisons of day and night temperatures in the range of 17/12 (day/night) to 30/25°C show that day temperatures of about 25 to 30°C in combination with night temperatures of 15 to 20°C were optimum for total seed production and maximum number of pods and seeds. Temperatures of 30/25 or 17/12 decreased seed yield about 30 percent.

**Seed Quality**

Kriton and Penner (1977) defined seed quality as the chemical composition of the seed and its ability to germinate and produce a vigorous, healthy seedling. Green and Pinnell (1968) at Colombia, Missouri studied the effect of planting and maturity dates on soybean seed quality. They reported that hot and dry weather during the maturation period are unfavorable and may be detrimental to soybean seed quality. They associated reduced seed quality as measured in laboratory germination tests, field emergence
counts, and visual ratings with such conditions. Cartter and Hartwig (1962) also reported that very high temperatures under dry conditions may arrest seed maturation, resulting in green, shrivelled seeds. Hesketh et al. (1973) reported that maximum weight per seed was found at 27°C; those seeds developed at 30°C were shrivelled.

Green (1961) showed that seed quality is adversely affected by high temperatures (over 40°C) during seed development. Siddique and Goodwin (1980) studied maturation temperature influences on seed quality of some snap bean (Phaseolus vulgaris L.) genotypes. Their results revealed that all the bean genotypes studied produced better quality seed at low maturation temperatures (18/13 and 21/16). With an increase in temperatures (24/19, 27/22, 30/25, and 33/28°C) seed quality, as assessed by seedling evaluation declined in the white seeded beans. They concluded that, generally, the colored seeded genotypes, unlike the white seeded genotypes, tolerated a wide range of maturation temperatures.

Oil and Protein Concentration

Temperature is one of the basic elements of the environment that influences the oil concentration and composition in the seed. Oil percentage in mature seed is affected by temperature during certain periods of seed development. Howell and Cartter (1958) studied the correlations between oil percentage and temperature for 10-day periods
from 50 days before maturity until maturity for groups of northern and southern cultivars grown at several locations. They found that temperatures during the period 20 to 40 days before maturity exerted a greater effect on oil level, with the highest correlation coefficient values, than temperatures during post-maturity. They stated that under controlled conditions plants at a temperature of 29°C produced seeds with oil percentage 2 to 3 percentage higher than plants exposed to 22°C. Cartter and Hartwig (1962), however, reported that when temperatures were raised to 32.2°C, there was a seed yield and oil concentration reduction, indicating that the optimum temperature had been exceeded. On the contrary, oil concentration remained fairly constant near 18-19 percent and independent of change in yield and soil temperatures between 11 and 31°C under field conditions (Mack and Ivarson, 1972).

There is some evidence that oil components of soybean are influenced by temperature, also. Collins and Howell (1957) determined linolenic and linoleic acids in soybean oil produced under varied temperatures. They found that the concentration of both acids was negatively correlated with daily maximum temperature during seed development. Linolenic acid was more closely correlated negatively with temperature than was linoleic acid.

Protein concentration in soybean seeds is usually inversely related to oil concentration (Howell and Cartter,
1958). Mack and Ivarson (1972), however, reported that protein concentration was fairly steady at low moisture over the wide range in soil temperature from 11 to 31°C. At a medium and high soil moisture, protein concentration increased from about 41 to 45 percent from the cool soil (11.2°C) to the warm soil (31.2°C), respectively. However, under normal growing conditions in the field, high temperature is usually accompanied by high light intensity and low soil moisture.

Effect of Light on Yield and Yield Components

The level of light saturation for photosynthesis in soybean leaves depends on the light intensity of the environment in which plants are grown (Whigham and Minor, 1978). Shaw and Weber (1967) observed that light interception occurred predominantly at the periphery of the canopy, indicating that many of the lower leaves as not receive adequate radiation.

To study the influence of light on soybean yield, many attempts have been made to manipulate canopy architecture or the supply of light. Johnston et al. (1969) used reflective plastic and supplemental light to provide a light-rich environment for soybean plants. They found that plants under such conditions produced more seeds per plant, pods per plant, seeds per pod, and higher yield than those grown under normal light conditions, but seed size and protein content were decreased.
Parks et al. (1974) studied the effect of light on soybean yield using aluminum reflectors on each side of plants in a skip-row pattern. They concluded that the effect of reflectors alone caused an increase in soybean yield up to 22.5 bu/acre. However, soybean yield is most affected by light enhancement during a short period of time, namely the pod filling period. Schou et al. (1978), who used aluminum reflectors and black boards, found that plants with light enrichment treatment during the late flowering to mid-pod formation period produced up to 48 percent more pods per plant than controls. Earlier and later treatments caused smaller differences. They also observed that light had different effects on pod position. Light increased number of pods in upper, middle and lower segments by 21, 17, and 167 percent, respectively. Individual seed weight and number of seeds per pod were not affected. The differential effects of light on pod position might be due to the fact that the top leaves of the soybean canopy had a higher light saturation intensity and a higher rate of photosynthesis than those lower in the canopy.

However, there is some evidence that reflectors may affect air temperature and the plant temperature within the treated rows. Schou et al. (1978) reported that air temperature within treated and untreated rows did not vary significantly probably due to turbulence. Nevertheless, plant temperatures taken on a specific day showed that
plants in front of reflectors were $0.8 \pm 0.36^\circ C$ warmer than controls, and plants in front of black boards were $2.2 \pm 0.45^\circ C$ warmer than controls. Barndas et al. (1976), through a series of papers describing reflectant treatment (celite 209) effect on the radiation balance, found that near solar noon the temperature of treated leaves was about 1 to $2^\circ C$ higher than that of untreated leaves. They related the unexpected temperature increase to two major factors. The first was a decrease in the long wave emissivity of the treated crop which reduced cooling rates and the second factor was the observed reduction in transpiration rates for the reflectorized crop.

**Inheritance of Heat Resistance**

Martineau et al. (1979a) reported that soybean genotypes are inherently different for heat tolerance (membrane thermostability). Significant genetic variance for heat tolerance was observed in all populations studied by Martineau et al. (1979b). However, genotypic correlations between heat tolerance and other traits were significant only with maturity. On the average, early maturing genotypes tended to have relatively greater heat tolerance than later maturing genotypes. A high estimate of heritability for heat tolerance was found comparable to other agronomic traits indicating that selection for heat tolerance would be effective (Martineau et al., 1979b). A similar finding was reported by Brim (1973).
Heyne and Brunson (1940) reported that heat tolerance in corn was controlled by several genes whose effects ranged from intermediate to fully dominant. Coffman (1957) observed that heat resistance in oats (*Avena sativa* L.) behaved as a recessive in several crosses. However, the mean of the soybean progeny in tolerant x intolerant crosses was intermediate although closer to the tolerant parent. No definitive conclusion was reached as to the number of genes involved in heat tolerance in soybean due to the relatively small number of progeny examined (Martineau et al., 1979b).
MATERIALS AND METHODS

Two experiments were conducted at The Ohio State University Agonomy farms, Columbus, Ohio, and The Ohio Agricultural Research and Development Center (OARDC), Wooster, Ohio, during the 1981 season. The objective was to study the effect of heat and light enhancement on some genotypes of soybean by using sunlight reflectors under field conditions. In 1982, another two field and greenhouse experiments were conducted at Columbus, Ohio to study the effect of high temperature on some soybean genotypes selected from the previous experiments. The selection was according to their positive and negative response in yield to heat and light enhancement caused by using reflectors.

Reflector Experiments, 1981

Two different soybean germplasm populations, AP10 and AP14 (which were developed by the Iowa Agriculture and Home Economics Experiment Station and the Puerto Rico Agricultural Experiment Station), were used (Fehr and de Cianzio, 1981). Twenty-eight S3 lines were used from each population, representing maturity groups I to IV plus two check cultivars ('Williams 79' and 'Beeson').
A split-plot design was used at both locations with heat treatments (with and without reflectors) as whole plots and genotypes as subplots in two replications at each location. Entries for each treatment were subdivided into four sets. Each set included 14 different genotypes (7 genotypes from each of AP10 and AP14) and the two check cultivars. The entries were seeded by hand in 30cm long rows and 30cm apart between entries (15 seeds/row) in an east-west direction and in a wide row spacing of 150cm to avoid inter-row shading by the reflector boards. Planting dates were May 13 and May 17 at Columbus and Wooster, respectively.

The soil at The Ohio State University Agronomy farm, Columbus, was Crosby silt loam (fine, mixed, mesic Aeric Ochragualfic). At the OARDC, Wooster, the soil type was a Wooster silt loam (typic Eragindalf).

Weed control was obtained with a uniform pre-plant incorporated application of Lasso (Alachlor) at a rate of 1.5 kg active ingredient (ai) per hectare, Amiben (Chloramben) at a rate of 0.5 kg ai per hectare and Sencor (Metribuzin) at 0.25 kg ai per hectare at Columbus. At OARDC the plots were sprayed preemergence with 1.5 kg ai Lasso + 0.33 kg ai Lorox (Linuron) per hectare. The plots were sprayed with Sevin (Carbaryl) at the rate of 0.45 kg ai/ha to protect against Japanese beetle (*Popillia japonica*) on July 15 and August 20 at Wooster and Columbus, respectively.
At early flowering (plants had at least one flower) the light and heat enrichment treatment was provided for each treated genotype by installing 1.2m high reflectors constructed of white painted plywood. Reflectors were placed at a right angle to the ground on the north side of treated rows until harvest maturity. The right angle position of reflectors on the north side of treated rows was suggested to: (a) enhance heat and light (up to 30 percent more than controls); (b) avoid shading the row to the north of the reflectors; and (c) avoid the variance in the amount of rainfall between treated and untreated plots. No irrigation was used at either location.

At various periods during the vegetative and reproductive stages, temperature and irradiance at the surface of the plant canopy was measured for treated and untreated plants. Reflected radiation was measured by placing a photodiode surface of the quantum sensor (Lambda Instruments Corp, Model LI-190S) about 80cm above the ground and about 25cm from and parallel to the reflector surface. Output from the sensor was compared to the output of a sensor pointed skyward with its surface parallel to the ground for the same height. Temperature measurements were made by using an infrared thermometer (Barnes Engineering Co., Model PRI-10L) for obtaining the mean temperature of soil surface, reflectors, and treated and untreated plants from midday through the afternoon.
Development of the soybeans was recorded by noting the days from planting to first flowering, the days from planting to physiological maturity, and mature plant heights. Maturity was determined when 35 percent of pods had turned brown and about 90 percent of leaves turned yellow (Tekrony et al., 1971). Plant heights for each entry were recorded at maturity as an average of three plants from the soil surface to the tip of the main stem. Lodging scores were taken as visual ratings at maturity using a rating scale of 1 to 5, where 1 = nearly all plants erect and 5 = about 80 percent or more of the plants lodged flat.

Seed Yield and Yield Components

Plants of each entry were hand-harvested and separated into one-third segments by height as upper, middle, and lower segments, and the average number of pods for each segment was determined.

Pods were hand-threshed to avoid mechanical damage to seeds, and the seeds were weighed after drying to a uniform moisture content. Seed size was determined from the weight of 50 seeds taken at random for each segment. The number of seeds per plant was obtained by calculation.

Oil and Protein Concentration

Oil and protein analyses of soybean seeds were made at the laboratories of the Northern Regional Research Center, Peoria, Illinois. Seed samples were taken from whole plant
samples after they had been mixed for each heat treatment-genotype-location combination (two field replications were composited to form a single sample).

Seed Germination and Accelerated Aging Tests

Standard germination and accelerated aging tests were conducted on seeds from the different plant segments for 6 genotypes selected randomly from the two populations and two check cultivars for both locations.

Two hundred seeds were taken randomly from each segment and the seeds were germinated using a standard rolled paper towel procedure according to the "Rules for Testing Seeds" (AOSA, 1978). After seven days, normal germinated seedlings were counted and expressed as percent standard germination.

Accelerating aging tests were conducted by placing two hundred seeds from each segment on a copper wire-mesh tray in a plastic box containing 30ml water according to the method described by McDonald and Phaneendranth (1978). The boxes were placed in a chamber maintained at 41°C and nearly 100 percent relative humidity for 72 hours. The seeds were then germinated using the conditions outlined in the standard germination test above. Normal seedling counts were taken after 7 days and the results expressed as percent accelerated aging germination.

Statistical analysis of the data was accomplished through the use of the SAS computer program (Helwig and
Council, 1979). In conjunction with SAS GLM (General Linear Model) for individual locations and a combined analysis for both locations. For the combined analysis of variance, F tests were made using the appropriate mean square as indicated by their expected values (Steel and Torrie, 1960). Entries and locations were considered random factors and the reflector treatment was a fixed factor. Phenotypic correlations (ignoring entry structure, locations with, without and averaged over reflector treatments) for all the plant characteristics with one another were obtained.

**High Temperature Experiments, 1982**

Field and greenhouse experiments were conducted in 1982 at The Ohio State University Agronomy farm at Columbus, Ohio, to evaluate the yield, yield component and seed quality response of soybean genotypes to high temperature. Twenty genotypes from the populations used in 1981 (AP10 and AP14) were selected for positive and negative response in yield to heat and light enhancement caused by using the reflectors in 1981. These 20 genotypes (10 genotypes from each population) with the same two cultivars (Williams 79 and Beeson) were grown in a greenhouse under high temperature, and under prevailing field conditions (Table 1).

**Greenhouse High Temperature Experiment**

In this experiment the selected genotypes with the two check cultivars were grown in 22 x 22cm plastic pots filled
Table 1. Genotypes used in 1982 experiment from different populations selected according to their response in yield to the reflector treatments in 1981.

<table>
<thead>
<tr>
<th>Population</th>
<th>Negative response</th>
<th>Positive response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AP10 Population</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative response</td>
<td>617-6</td>
<td>617-11</td>
</tr>
<tr>
<td></td>
<td>618-14</td>
<td>617-20</td>
</tr>
<tr>
<td></td>
<td>618-35</td>
<td>618-28</td>
</tr>
<tr>
<td></td>
<td>617-37</td>
<td>618-133</td>
</tr>
<tr>
<td></td>
<td>618-153</td>
<td></td>
</tr>
<tr>
<td></td>
<td>618-239</td>
<td></td>
</tr>
<tr>
<td><strong>AP14 Population</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative response</td>
<td>623-6</td>
<td>623-1</td>
</tr>
<tr>
<td></td>
<td>623-10</td>
<td>623-11</td>
</tr>
<tr>
<td></td>
<td>623-13</td>
<td>624-3</td>
</tr>
<tr>
<td></td>
<td>624-85</td>
<td>624-68</td>
</tr>
<tr>
<td></td>
<td>624-159</td>
<td></td>
</tr>
<tr>
<td></td>
<td>624-199</td>
<td></td>
</tr>
<tr>
<td><strong>Check Cultivars Population</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative response</td>
<td>Williams 79</td>
<td>Beeson</td>
</tr>
</tbody>
</table>
with Crosby silt loam soil. Two treatments were used, with and without nitrogen fertilizer application, to determine the effect of high temperature on soybean nodulation and to compensate for the expected reduction of nitrogen fixation due to high temperatures in the greenhouse. A split-plot design was used with two nitrogen treatments as main-plots and the 22 entries as sub-plots with two replications.

Each pot was planted with 10 seeds on May 18, 1982 and thinned after 16 days, leaving the five most vigorous seedlings. On the same day, the first half dosage of urea fertilizer was added to the treated entries at a rate of 26 ppm N. The second half dosage of nitrogen fertilizer was added a month later at the prebloom stage. Plants were grown under natural light and irrigated once or twice daily with tap water. There were no obvious signs of wilting during the season, but no attempt was made to measure the water status of the plants. Greenhouse temperature was controlled by adjusting window openings and heater fans to maintain high temperature (up to 44°C) inside the greenhouse. Greenhouse air temperature was continuously recorded with a thermograph. Air temperature and relative humidity in the greenhouse and under field conditions through the growing season are detailed in Table 2. Days from planting to first flowering, days from planting to physiological maturity and plant height were recorded as
Table 2. Daily air temperature (°C) and relative humidity for the field and greenhouse during the growing season of 1982.

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Daily Air Temperature °C</th>
<th>Relative Humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum Field</td>
<td>Greenhouse</td>
</tr>
<tr>
<td>First</td>
<td>22.9</td>
<td>31.6</td>
</tr>
<tr>
<td>Second</td>
<td>23.1</td>
<td>33.3</td>
</tr>
<tr>
<td>Third</td>
<td>25.5</td>
<td>36.4</td>
</tr>
<tr>
<td>Fourth</td>
<td>27.8</td>
<td>32.2</td>
</tr>
</tbody>
</table>

| Mean for June | 25.9 | 33.4 | 13.0 | 16.2 | 19.5 | 24.8 | 68 | 55 |
| First         | 28.6 | 36.6 | 15.8 | 19.6 | 22.2 | 28.1 | 65 | 54 |
| Second        | 31.1 | 43.8 | 16.8 | 23.3 | 24.0 | 33.6 | 68 | 52 |
| Third         | 31.1 | 40.4 | 18.0 | 22.2 | 24.6 | 31.3 | 71 | 50 |
| Fourth        | 31.4 | 39.2 | 16.3 | 19.0 | 23.9 | 29.1 | 76 | 52 |

| Mean for July | 30.5 | 40.0 | 16.8 | 21.0 | 23.6 | 30.5 | 70 | 52 |
| First         | 29.8 | 39.4 | 16.1 | 17.0 | 23.0 | 28.2 | 72 | 53 |
| Second        | 27.5 | 37.4 | 14.6 | 19.1 | 21.1 | 28.3 | 74 | 59 |
| Third         | 28.7 | 40.5 | 13.1 | 14.9 | 20.9 | 27.7 | 58 | 62 |
| Fourth        | 26.5 | 38.6 | 14.0 | 17.3 | 20.3 | 28.0 | 74 | 66 |

| Mean for August | 27.5 | 38.2 | 13.9 | 16.7 | 20.6 | 27.4 | 69 | 60 |

Data taken from The Ohio State University Agronomy Farm Monthly Weather Report and Weekly Weather and Crop Bulletin, USDA.
described previously for the reflector experiment. Visual ratings of lodging were taken using a rating scale of 1 to 5 as previously described.

**Seed Yield and Yield Components**

All pods from each pot were counted and hand-threshed. Yield of air-dried seeds was measured and seed size determined from the weight of 50 seeds taken at random.

**Shrivelled Seeds**

The percentage of shrivelled seeds was obtained from a count made on random sample of 100 seeds from each entry.

**Oil and Protein Concentration**

Oil and protein concentration for 7 genotypes that showed a high and low percentage of shrivelled seeds from the positive and negative response groups were analyzed with and without nitrogen treatment. The analyses were made at the laboratories of the Northern Regional Research Center, Peoria, Illinois.

**Standard Germination and Accelerated Aging Tests**

The standard germination and accelerated aging tests were conducted on seeds for some genotypes that showed a high and low percentage of shrivelled seeds from the positive and negative response groups. The methods and the procedures used were the same as described previously for the reflector experiments of 1981.
Nodule Weights

As an accessory to the seed yield and quality studies, nodulation was assessed in a separate greenhouse study. Four genotypes were selected randomly from the same genotypes utilized for the greenhouse high temperature experiment. These four genotypes were grown in the same size plastic pots with and without nitrogen application and were placed in the same greenhouse. Another four pots without nitrogen application were placed outside the greenhouse under normal air temperature. At the time of pod formation, during the second half of July, plants were harvested and the roots were carefully washed with water and whole nodules were detached. Fresh weight of nodules was recorded for each genotype inside and outside the greenhouse.

The procedure used for statistical analysis was the same as described previously. Phenotypic correlations (ignoring entry structure and averaged over nitrogen treatments) for all the characteristics with one another were also obtained. Orthogonal comparisons were made between the genotype groups that showed a positive or negative response in their yield to heat and light enhancement by reflectors in 1981 and their yield under high temperature in greenhouse in 1982.

Field Experiment

The same 22 entries which were grown in the greenhouse were also grown in the field at Columbus, Ohio in on May 18,
1982. A randomized complete block design was used with four replications. Each entry was planted in a hill plot, 15 seeds per plot, spaced 70 cm apart. All hill plots were thinned to eight or fewer plants. Where fewer than four seeds per hill plot germinated or seedlings were destroyed by birds it was considered a missing plot.

The plant characteristics studied and statistical analysis were the same as described previously for the greenhouse experiment.

In 1983, 5 genotypes that showed heat tolerance and produced seeds with good quality (very low percentage of shrivelled seeds) and 5 heat sensitive genotypes (with high percentage of shrivelled seeds) were grown in a greenhouse to study plant water status under high temperature. Five plants per genotype in each 8 liter pot were watered daily to maintain high plant water potential. Beginning at the time of pod formation, daily maximum greenhouse temperature was adjusted to 35-42°C and minimum temperature was 27°C.

Leaf water potentials were determined on September 8 and 12 at the full pod stage twice a day (before and after noon) using a pressure cell as described by Boyer and Ghorashy (1971). Leaves were cut from the middle nodes of the plants and their equilibrium water potentials were determined with the pressure cell using N₂ gas to express sap from the cut end of the petioles.
RESULTS AND DISCUSSION

Reflector Experiments - 1981

Days from Planting Until First Flowering

Analysis of variance for days to first flowering (Table 3) shows highly significant differences among genotypes, locations, and a significant interaction of genotype X location. Significant differences among genotypes were expected since they represented widely divergent genetic composition. The two locations represent different environments both in climate and in soil. Mean temperatures and total precipitation for the period from planting to first flowering which encompasses most of May and June were slightly higher at Columbus than at Wooster (Appendix 1 and 2).

Generally, genotypes at Columbus flowered about 6 days earlier than those grown at Wooster and the check cultivars flowered about one day earlier (52 days) than genotypes from the two other populations (53 days).

Days from Planting Until Physiological Maturity

No variation in physiological maturity was found between genotypes grown with and without reflectors (Table 34).
<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>Days to First Flowering</th>
<th>Days to Maturity</th>
<th>Lodging</th>
<th>Plant Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (Loc)</td>
<td>1</td>
<td>5189.26**</td>
<td>11259.38**</td>
<td>34.03</td>
<td>17515.60*</td>
</tr>
<tr>
<td>Set</td>
<td>3</td>
<td>51.26</td>
<td>8.89</td>
<td>2.95</td>
<td>146.65</td>
</tr>
<tr>
<td>Loc x Set</td>
<td>3</td>
<td>10.18</td>
<td>7.75</td>
<td>5.79</td>
<td>1102.43**</td>
</tr>
<tr>
<td>Replication (Rep)/(Loc x Set)</td>
<td>8</td>
<td>16.08</td>
<td>11.15</td>
<td>2.24</td>
<td>74.68</td>
</tr>
<tr>
<td>Reflector Treatment (Trt)</td>
<td>1</td>
<td>0.78</td>
<td>0.24</td>
<td>20.32*</td>
<td>1250.31</td>
</tr>
<tr>
<td>Set x Trt</td>
<td>3</td>
<td>9.82</td>
<td>2.71</td>
<td>1.76</td>
<td>194.37</td>
</tr>
<tr>
<td>Loc x Trt</td>
<td>1</td>
<td>4.13</td>
<td>43.36</td>
<td>0.63</td>
<td>32.77</td>
</tr>
<tr>
<td>Loc x Set x Trt</td>
<td>3</td>
<td>9.39</td>
<td>12.77</td>
<td>1.49</td>
<td>62.71</td>
</tr>
<tr>
<td>Rep x Trt/(Loc x Set)</td>
<td>8</td>
<td>5.09</td>
<td>5.22</td>
<td>2.54</td>
<td>421.00</td>
</tr>
<tr>
<td>Genotype (Gen)/Set</td>
<td>60</td>
<td>60.01**</td>
<td>192.96**</td>
<td>3.71**</td>
<td>416.03**</td>
</tr>
<tr>
<td>Trt x Gen/Set</td>
<td>60</td>
<td>8.54</td>
<td>12.75</td>
<td>0.80</td>
<td>35.53</td>
</tr>
<tr>
<td>Loc x Gen/Set</td>
<td>60</td>
<td>22.87**</td>
<td>9.02</td>
<td>1.01</td>
<td>176.14**</td>
</tr>
<tr>
<td>Loc x Trt x Gen/Set</td>
<td>60</td>
<td>6.32</td>
<td>11.89</td>
<td>0.87</td>
<td>60.68</td>
</tr>
<tr>
<td>Error</td>
<td>240</td>
<td>6.67</td>
<td>7.75</td>
<td>0.77</td>
<td>45.13</td>
</tr>
</tbody>
</table>

CV%  | 4.83 | 2.34 | 45.71 | 9.21 |
Days from Planting Until Physiological Maturity

No variation in physiological maturity was found between genotypes grown with and without reflectors (Table 3). The number of days from planting until physiological maturity was the same (119 days) for treated and untreated genotypes (Table 4). This might have been expected, based on the study of Major and Johnson (1974). With a 24 hour day length established with incandescent floodlights, they observed that light intensity had no detectable effect on days from flowering to beginning pod fill, number of flowering days, and days from flowering to physiological maturity.

The variation in physiological maturity among genotypes and between locations was highly significant but there was no significant interaction between genotypes and reflector treatments (Table 3). However, the soybeans grown at Columbus matured about 10 days earlier (114 days) than those grown at Wooster (124 days) mainly due to differences in heat units.

High temperatures as well as short days hasten days to maturity (Steinberg and Carner, 1936; Thomas and Raper, 1976, 1978; and Van Schaik and Probst, 1958), whereas light intensity either has no effect or produces no consistent pattern in the way it affects post-flowering development. The lack of response of plant maturity to reflectors might be due to the use of wide rows (150 cm) where more sunlight
Table 4. Days to first flowering, days to physiological maturity, lodging score, and plant height (cm) of soybean genotypes grown with and without reflectors, 1981.

<table>
<thead>
<tr>
<th>Plant Character</th>
<th>Treatment Without Reflectors</th>
<th>Treatment With Reflectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days to first flowering</td>
<td>53.5</td>
<td>53.4</td>
</tr>
<tr>
<td>Days to physiological maturity</td>
<td>119</td>
<td>119</td>
</tr>
<tr>
<td>Lodging score (1 to 5)</td>
<td>1.7</td>
<td>2.1*</td>
</tr>
<tr>
<td>Plant height</td>
<td>71.4</td>
<td>74.5</td>
</tr>
</tbody>
</table>

* Difference between reflector treatments significant at 0.05 level, according to F test.
than normal on untreated rows could reduce the possible variation. Moreover, the variation in plant temperature grown with and without reflectors was not enough to induce a detectable difference (only 1 to 2°C).

Plant Height

Reflectors had no significant effect on mature plant height (Table 3). This result is in agreement with those of Schou et al. (1978) where nodes per plant and plant height at harvest were not affected by reflectors. However, plant height and the period from planting to flowering were the only plant characters for which an effect of light intensity was detected by Major and Johnson (1974). Plant height increased as light intensity increased.

Plant height among genotypes varied significantly, and there was also a significant interaction of genotypes and locations on plant height (Table 3). Plants were taller on the average at Wooster (79 cm) than at Columbus (67 cm). There was no significant interaction of genotypes and reflector treatments on plant height.

Plant Lodging

The use of reflectors produced a significant increase in lodging (Table 3). Genotypes grown with reflectors were lodged more (2.1 score) than the control (1.7 score) (Table 4). This might be due to the reflector treated plants being taller, since there usually exists a positive correlation
between height and lodging. But in this study there was a significant difference in plant height but not in lodging between locations. Genotypes varied significantly in lodging, but there was no significant interaction of genotypes and reflector treatments on lodging.

**Pods per Plant**

Reflectors had no significant effect on number of pods per each plant segment (upper, middle, or lower) nor on total number of pods (Table 5). These results are contrary to those obtained by Schou et al. (1978) who found an increase in number of pods in upper, middle, and lower segments of irrigated soybean by 21, 17, and 167% over controls, respectively in 1973 with approximately the same trend in 1974. The different results might be attributed to differences in row spacing (theirs was 51cm and our 150cm between rows and 30cm between entries). Our experiment had minimal shading effect; therefore, light was not a limiting factor. Also, our experiment was not irrigated and moisture stress may have limited pod development of plants exposed to reflectors. Beuerlein and Pendleton (1971) found that apparent photosynthesis in upper and lower leaves of normal canopy plants (5cm apart in 76cm rows) averaged 33 and 20 mg CO$_2$/dm$^2$/hour, respectively. Rates in upper and lower leaves of spaced plants (76cm x 76cm) were equal and averaged 50mg CO$_2$/dm$^2$/hour.
Table 5. Mean squares for pods per plant segment and total pods per plant for the reflector experiment, 1981.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>Upper Pods</th>
<th>Middle Pods</th>
<th>Lower Pods</th>
<th>Total Pods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (Loc)</td>
<td>1</td>
<td>11552.00</td>
<td>16009.31</td>
<td>61578.56</td>
<td>232476.76</td>
</tr>
<tr>
<td>Set</td>
<td>3</td>
<td>12806.11</td>
<td>15302.12</td>
<td>40141.50</td>
<td>171699.21</td>
</tr>
<tr>
<td>Loc x Set</td>
<td>3</td>
<td>7616.13*</td>
<td>5964.79</td>
<td>8658.50*</td>
<td>61553.82*</td>
</tr>
<tr>
<td>Replication (Rep)/(Loc x Set)</td>
<td>8</td>
<td>1789.22</td>
<td>4289.91</td>
<td>1556.72</td>
<td>13640.58</td>
</tr>
<tr>
<td>Reflector Treatment (Trt)</td>
<td>1</td>
<td>1313.28</td>
<td>14845.80</td>
<td>14143.52</td>
<td>41832.78</td>
</tr>
<tr>
<td>Set x Trt</td>
<td>3</td>
<td>843.04</td>
<td>1212.21</td>
<td>2812.10*</td>
<td>11980.87**</td>
</tr>
<tr>
<td>Loc x Trt</td>
<td>1</td>
<td>892.53</td>
<td>16578.38**</td>
<td>1803.75**</td>
<td>40434.57**</td>
</tr>
<tr>
<td>Loc x Set x Trt</td>
<td>3</td>
<td>481.60</td>
<td>207.30</td>
<td>52.07</td>
<td>1114.80</td>
</tr>
<tr>
<td>Rep x Trt/(Loc x Set)</td>
<td>8</td>
<td>2060.49</td>
<td>2189.47</td>
<td>1575.40</td>
<td>13801.48</td>
</tr>
<tr>
<td>Genotype (Gen)/Set</td>
<td>60</td>
<td>3215.60**</td>
<td>8478.94**</td>
<td>4591.20**</td>
<td>36516.09**</td>
</tr>
<tr>
<td>Trt x Gen/Set</td>
<td>60</td>
<td>1429.30*</td>
<td>2428.71</td>
<td>1748.63</td>
<td>12521.63</td>
</tr>
<tr>
<td>Loc x Gen/Set</td>
<td>60</td>
<td>2265.80*</td>
<td>6398.90**</td>
<td>5192.44**</td>
<td>35441.22**</td>
</tr>
<tr>
<td>Loc x Trt x Gen/Set</td>
<td>60</td>
<td>844.20</td>
<td>2306.98</td>
<td>1725.52</td>
<td>10118.60</td>
</tr>
<tr>
<td>Error</td>
<td>240</td>
<td>1337.30</td>
<td>2755.33</td>
<td>2050.43</td>
<td>13500.28</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td>31.25</td>
<td>25.58</td>
<td>29.52</td>
<td>24.43</td>
</tr>
</tbody>
</table>
There was no significant location effect on number of pods per segment nor of whole plants, but there was a significant interaction between locations and reflector treatments in both pods per plant and pods per lower and middle segments. Highly significant differences were found among genotypes for plant segments and whole plants. There was also an interaction between genotypes and reflector treatments on pod numbers in upper segments. Some genotypes responded by increasing upper pod set with reflector treatments, while others had no response. A significant interaction was also found between locations and reflector treatments in number of pods produced on the middle and lower segments and whole plants. Reflectors decreased the number of pods at the middle and lower segments and whole plants at Wooster from 22.2, 17.2, and 51.5 to 20.0, 15.7, and 47.9, respectively. At Columbus, reflectors decreased number of pods from 14.6 to 13.9 at the lower segment only (Appendix 3).

Seed Size (100 seed weight)

Difference in seed size between reflector treatments was significant at the middle and lower segments and for whole plants (Table 6). Reflectors caused a reduction in seed size at all plant positions (Table 7). This agrees with results of Johnston et al. (1969) who used reflective plastic and supplemental light on soybeans. They found that
Table 6. Mean squares for seed size (100 seed weight) by plant segments and whole plants for the reflector experiment, 1981.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>Upper Seed Size</th>
<th>Middle Seed Size</th>
<th>Lower Seed Size</th>
<th>Whole Seed Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (Loc)</td>
<td>1</td>
<td>942.97**</td>
<td>1048.25*</td>
<td>1312.51**</td>
<td>1091.98**</td>
</tr>
<tr>
<td>Set</td>
<td>3</td>
<td>25.52</td>
<td>7.71</td>
<td>0.62</td>
<td>7.15</td>
</tr>
<tr>
<td>Loc x Set</td>
<td>3</td>
<td>11.11*</td>
<td>4.80</td>
<td>2.77</td>
<td>4.48</td>
</tr>
<tr>
<td>Replication (Rep)/(Loc x Set)</td>
<td>8</td>
<td>1.96</td>
<td>1.97</td>
<td>3.87</td>
<td>2.18</td>
</tr>
<tr>
<td>Reflector Treatment (Trt)</td>
<td>1</td>
<td>29.13</td>
<td>26.39*</td>
<td>55.49**</td>
<td>36.55**</td>
</tr>
<tr>
<td>Set x Trt</td>
<td>3</td>
<td>1.44</td>
<td>3.42</td>
<td>1.36</td>
<td>1.09</td>
</tr>
<tr>
<td>Loc x Trt</td>
<td>1</td>
<td>5.04*</td>
<td>0.07</td>
<td>0.09</td>
<td>0.81</td>
</tr>
<tr>
<td>Loc x Set x Trt</td>
<td>3</td>
<td>0.49</td>
<td>1.02</td>
<td>1.66</td>
<td>0.85</td>
</tr>
<tr>
<td>Rep x Trt/(Loc x Set)</td>
<td>8</td>
<td>5.03</td>
<td>1.79</td>
<td>1.75</td>
<td>2.15</td>
</tr>
<tr>
<td>Genotype (Gen)/Set</td>
<td>60</td>
<td>19.74**</td>
<td>21.53**</td>
<td>17.87**</td>
<td>19.13**</td>
</tr>
<tr>
<td>Trt x Gen/Set</td>
<td>60</td>
<td>0.99</td>
<td>1.20</td>
<td>1.10</td>
<td>0.79</td>
</tr>
<tr>
<td>Loc x Gen/Set</td>
<td>60</td>
<td>3.70**</td>
<td>3.76**</td>
<td>3.28**</td>
<td>3.24**</td>
</tr>
<tr>
<td>Loc x Trt x Gen/Set</td>
<td>60</td>
<td>1.25</td>
<td>1.00</td>
<td>1.16</td>
<td>0.73</td>
</tr>
<tr>
<td>Error</td>
<td>240</td>
<td>1.27</td>
<td>1.19</td>
<td>1.15</td>
<td>0.92</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td>7.24</td>
<td>6.71</td>
<td>6.88</td>
<td>6.04</td>
</tr>
</tbody>
</table>
Table 7. Seed size (100 seed weight) for plant segments and whole plants of soybean genotypes grown with and without reflectors, 1981.

<table>
<thead>
<tr>
<th>Plant Segment</th>
<th>Without Reflectors</th>
<th>With Reflectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>15.80</td>
<td>15.32</td>
</tr>
<tr>
<td>Middle</td>
<td>16.51</td>
<td>16.05*</td>
</tr>
<tr>
<td>Lower</td>
<td>15.89</td>
<td>15.23**</td>
</tr>
<tr>
<td>Whole Plant</td>
<td>16.13</td>
<td>15.60**</td>
</tr>
</tbody>
</table>

*, ** Difference between reflector treatments significant at 0.05 and 0.01 levels, respectively, according to F test.
plants receiving 3 to 5 times as much light as normal produced smaller seed than control plants. In the earlier Ohio studies (Schou et al., 1978), seed size was not affected by treatments of reflectors, black boards or shades imposed during late flowering and early pod formation.

According to Shaw and Laing (1966) decreases in seed size and seeds per pod were mostly responsible for the reduction in yield under drought stress. Both our results and those of Shaw and Laing (1966) tend to agree with the conclusion of Shibles et al. (1975) that in case of stress, soybean yield is usually related to seed size. Plants under drought and heat stress during pod filling experience a decline in net photosynthesis and translocation causing a shortening of the pod-filling period and a decrease in seed size.

There were highly significant differences in seed size among genotypes for all plant segments (Table 6). Variation in seed size between locations and the interaction between locations and genotypes were highly significant for all plant segments. Locations x reflector treatment was significant for the upper segment and whole plants. Reflectors caused a reduction in seed size at both locations, but it was greater at Wooster compared to Columbus. No interaction between reflectors and genotypes was observed.
Seeds per Pod

At all plant positions, no significant variation was found in number of seeds per pod produced by plants grown with and without reflectors or at the two locations (Table 8). Average number was about 1.6 seeds per pod. Schou et al. (1978) also found no effect of reflectors, black boards or shades. However, genotypes did not vary significantly in seeds per pod, but there was a significant interaction between locations and genotypes. No interaction between genotypes and reflector treatment was found.

Generally, number of seeds per pod in soybean is the least yield component sensitive to environmental factors. Therefore, a genotype effect would have been expected but not an environmental effect on seeds per pod.

Seeds per Plant

The number of seeds per plant varied as a function of number of pods per plant and number of seeds per pod. The analysis of variance (Table 9) showed that neither reflectors nor locations had significant influence on number of seeds for plant segments or whole plants. Similar results were found when pods per plant and seeds per pod were analyzed independently. Average values were 19, 33 and 23 seeds per plant for upper, middle, and lower segments, respectively (Appendix 4).

Genotypes showed highly significant differences in seeds per plant for all plant segments. A significant
Table 9. Mean squares for number of seeds per plant segment and total seeds per plant for the reflector experiment, 1981.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>Upper Seeds</th>
<th>Middle Seeds</th>
<th>Lower Seeds</th>
<th>Total Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location (Loc)</td>
<td>1</td>
<td>19360</td>
<td>4412</td>
<td>115729</td>
<td>297842</td>
</tr>
<tr>
<td>Set</td>
<td>3</td>
<td>2869</td>
<td>30980</td>
<td>54764</td>
<td>284259</td>
</tr>
<tr>
<td>Loc x Set</td>
<td>3</td>
<td>63469**</td>
<td>103725*</td>
<td>67058**</td>
<td>681556**</td>
</tr>
<tr>
<td>Replication (Rep)/(Loc x Set)</td>
<td>8</td>
<td>6805</td>
<td>18223</td>
<td>6850</td>
<td>78556</td>
</tr>
<tr>
<td>Reflector Treatment (Trt)</td>
<td>1</td>
<td>6375</td>
<td>49188</td>
<td>39690</td>
<td>116393</td>
</tr>
<tr>
<td>Set x Trt</td>
<td>3</td>
<td>4550</td>
<td>4788**</td>
<td>1774</td>
<td>27664*</td>
</tr>
<tr>
<td>Loc x Trt</td>
<td>1</td>
<td>220</td>
<td>27560**</td>
<td>6013</td>
<td>66770**</td>
</tr>
<tr>
<td>Loc x Set x Trt</td>
<td>3</td>
<td>3592</td>
<td>27</td>
<td>1321</td>
<td>1782</td>
</tr>
<tr>
<td>Rep x Trt/(Loc x Set)</td>
<td>8</td>
<td>11411</td>
<td>12529</td>
<td>2232</td>
<td>66162</td>
</tr>
<tr>
<td>Genotype (Gen)/Set</td>
<td>60</td>
<td>13789**</td>
<td>33311**</td>
<td>16520**</td>
<td>158054**</td>
</tr>
<tr>
<td>Trt x Gen/Set</td>
<td>60</td>
<td>3106</td>
<td>4309</td>
<td>3346</td>
<td>20812</td>
</tr>
<tr>
<td>Loc x Gen/Set</td>
<td>60</td>
<td>4063</td>
<td>7669</td>
<td>5310</td>
<td>36011</td>
</tr>
<tr>
<td>Loc x Trt x Gen/Set</td>
<td>60</td>
<td>2650</td>
<td>5454</td>
<td>3736</td>
<td>25430</td>
</tr>
<tr>
<td>Error</td>
<td>240</td>
<td>2951</td>
<td>5107</td>
<td>3721</td>
<td>22783</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td>29</td>
<td>22</td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>Source of Variation</td>
<td>D.F</td>
<td>Upper Seeds/Pod</td>
<td>Middle Seeds/Pod</td>
<td>Lower Seeds/Pod</td>
<td>Whole Seeds/Pod</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>-----</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Location (Loc)</td>
<td>1</td>
<td>0.05</td>
<td>0.41</td>
<td>0.04</td>
<td>0.16</td>
</tr>
<tr>
<td>Set</td>
<td>3</td>
<td>0.23</td>
<td>0.22</td>
<td>0.39</td>
<td>0.27</td>
</tr>
<tr>
<td>Loc x Set</td>
<td>3</td>
<td>1.01**</td>
<td>1.13**</td>
<td>0.88**</td>
<td>1.01**</td>
</tr>
<tr>
<td>Replication (Rep)/(Loc x Set)</td>
<td>8</td>
<td>0.12</td>
<td>0.15</td>
<td>0.18</td>
<td>0.12</td>
</tr>
<tr>
<td>Reflector Treatment (Trt)</td>
<td>1</td>
<td>0.01</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>Set x Trt</td>
<td>3</td>
<td>0.31**</td>
<td>0.18</td>
<td>0.32</td>
<td>0.21**</td>
</tr>
<tr>
<td>Loc x Trt</td>
<td>1</td>
<td>0.26*</td>
<td>0.08</td>
<td>0.01</td>
<td>0.07*</td>
</tr>
<tr>
<td>Loc x Set x Trt</td>
<td>3</td>
<td>0.01</td>
<td>0.03</td>
<td>0.07</td>
<td>0.01</td>
</tr>
<tr>
<td>Rep x Trt/(Loc x Set)</td>
<td>8</td>
<td>0.10</td>
<td>1.07</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Genotype (Gen)/Set</td>
<td>60</td>
<td>0.30</td>
<td>0.29</td>
<td>0.29</td>
<td>0.28</td>
</tr>
<tr>
<td>Trt x Gen/Gen/</td>
<td>60</td>
<td>0.08</td>
<td>0.10</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>Loc x Gen/Gen/</td>
<td>60</td>
<td>0.25**</td>
<td>0.24**</td>
<td>0.21**</td>
<td>0.22**</td>
</tr>
<tr>
<td>Loc x Trt x Gen/Gen/</td>
<td>60</td>
<td>0.11</td>
<td>0.09</td>
<td>0.11</td>
<td>0.09</td>
</tr>
<tr>
<td>Error</td>
<td>240</td>
<td>0.09</td>
<td>0.07</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td>18.29</td>
<td>16.57</td>
<td>18.67</td>
<td>16.29</td>
</tr>
</tbody>
</table>
interaction between reflector treatments and locations in seeds per plant was found for the middle segment and whole plants where reflectors caused a reduction in seeds per plant at Columbus but not at Wooster. However, no significant interaction was found between genotypes and locations or between genotypes and reflector treatments.

**Seed Yield**

Reflectors had a significant influence on seed yield at the lower plant segments (Table 10), but failed to affect significantly seed yield of upper or middle plant segments or of the total plant. Genotypes grown with reflectors yielded the same as controls for upper segments (Table 11), but were about 11 percent less for middle and lower segments and for the total plants.

These results are in contrast with those obtained by Schou et al. (1978) and Park et al. (1974) who found that using reflectors increased the seed yield of soybean. Such inconsistency might be due to differences in the way of conducting each experiment, especially the row spacing, plant populations, and water supply. Schou et al. (1978) used a narrow row spacing of 51 cm and irrigation, whereas Park et al. (1974) used aluminum reflectors placed on each side of a plant one-skip one row pattern compared to 150 cm between rows in our experiment. Major and Johnson (1974) supplied continuous light of an intensity range from 2 to 100 lux on
Table 10. Mean squares for seed yield for plant segments and total plants for the reflector experiment, 1981.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>Upper Segment</th>
<th>Middle Segment</th>
<th>Lower Segment</th>
<th>Total Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (Loc)</td>
<td>1</td>
<td>5823.23</td>
<td>13246.83</td>
<td>18103.48*</td>
<td>106246.09</td>
</tr>
<tr>
<td>Set</td>
<td>3</td>
<td>537.75</td>
<td>397.20</td>
<td>1136.46</td>
<td>5445.28</td>
</tr>
<tr>
<td>Loc x Set</td>
<td>3</td>
<td>1759.34**</td>
<td>3474.40*</td>
<td>1703.98*</td>
<td>1991.66**</td>
</tr>
<tr>
<td>Replication (Rep)/(Loc x Set)</td>
<td>8</td>
<td>203.83</td>
<td>479.11</td>
<td>226.13</td>
<td>2336.65</td>
</tr>
<tr>
<td>Reflector Treatment (Trt)</td>
<td>1</td>
<td>0.05</td>
<td>2981.37</td>
<td>2428.61*</td>
<td>10743.03</td>
</tr>
<tr>
<td>Set x Trt</td>
<td>3</td>
<td>123.45</td>
<td>194.20**</td>
<td>21.83</td>
<td>839.56</td>
</tr>
<tr>
<td>Loc x Trt</td>
<td>1</td>
<td>35.86</td>
<td>1123.08**</td>
<td>334.92</td>
<td>3341.0*</td>
</tr>
<tr>
<td>Loc x Set x Trt</td>
<td>3</td>
<td>35.99</td>
<td>18.90</td>
<td>78.17</td>
<td>102.37</td>
</tr>
<tr>
<td>Rep x Trt/(Loc x Set)</td>
<td>8</td>
<td>330.57</td>
<td>402.99</td>
<td>79.29</td>
<td>2143.79</td>
</tr>
<tr>
<td>Genotype (Gen)/Set</td>
<td>60</td>
<td>372.86**</td>
<td>1014.99**</td>
<td>369.64**</td>
<td>4354.70**</td>
</tr>
<tr>
<td>Trt x Gen/Set</td>
<td>60</td>
<td>84.94</td>
<td>133.40</td>
<td>86.13</td>
<td>627.60</td>
</tr>
<tr>
<td>Loc x Gen/Set</td>
<td>60</td>
<td>108.81</td>
<td>249.80*</td>
<td>168.16*</td>
<td>1142.64*</td>
</tr>
<tr>
<td>Loc x Trt x Gen/Set</td>
<td>60</td>
<td>75.95</td>
<td>134.67</td>
<td>92.21</td>
<td>672.39</td>
</tr>
<tr>
<td>Error</td>
<td>240</td>
<td>82.84</td>
<td>149.55</td>
<td>102.85</td>
<td>667.19</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td>31.00</td>
<td>23.00</td>
<td>28.00</td>
<td>21.75</td>
</tr>
</tbody>
</table>
Table 11. Seed yield in g. per plot for plant segments and whole plants of soybean genotypes grown with and without reflectors, 1981.

<table>
<thead>
<tr>
<th>Plant Segment</th>
<th>Seed Yield (g./plot)</th>
<th>Without Reflectors</th>
<th>With Reflectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>29.36</td>
<td>29.38</td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>55.59</td>
<td>50.76</td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>38.40</td>
<td>34.04*</td>
<td></td>
</tr>
<tr>
<td>Whole Plants</td>
<td>123.34</td>
<td>114.18</td>
<td></td>
</tr>
</tbody>
</table>

* Difference between reflector treatment significant at 0.05 level, according to F test.
two soybean cultivars from planting until maturity, resulting in no effect on seed yield.

Variation in seed yield due to reflectors (Table 11) was a function of seed size (Table 7) since number of pods or number of seeds per plant did not show a significant difference due to reflectors. Reductions of total seed yield are attributed to the lower and middle segments.

With respect to seed yield, the lower segment was the only part that varied significantly between locations (Table 10). A significant interaction was found between locations and reflector treatments for middle segments and whole plants. Reflectors caused a reduction in seed yield for middle segments and whole plants at both locations but it was greater at Wooster compared to that at Columbus. Significant variation among genotypes occurred for seed yield for all plant segments and for whole plants. Also, significant interactions were found between genotypes and locations, but the interaction between genotypes and reflector treatments was not significant (Table 10). The non-significant interaction between genotypes and reflector treatments suggested that genotypes did not respond enough to reflectors to allow a potential interaction to be expressed.

**Oil and Protein Concentration**

Reflectors affected neither oil nor protein concentration in soybean seeds (Table 12). Average concentrations of
Table 12. Mean squares for oil and protein concentrations in soybeans for the reflector experiment, 1981.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>Mean Squares Oil</th>
<th>Mean Squares Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (Loc)</td>
<td>1</td>
<td>46.92*</td>
<td>1.40</td>
</tr>
<tr>
<td>Set</td>
<td>3</td>
<td>0.54</td>
<td>2.68</td>
</tr>
<tr>
<td>Loc x Set</td>
<td>3</td>
<td>1.83</td>
<td>3.79</td>
</tr>
<tr>
<td>Reflector Treatment (Trt)</td>
<td>1</td>
<td>0.09</td>
<td>0.22</td>
</tr>
<tr>
<td>Set x Trt</td>
<td>3</td>
<td>0.40</td>
<td>0.88</td>
</tr>
<tr>
<td>Loc x Trt</td>
<td>1</td>
<td>0.70</td>
<td>0.87</td>
</tr>
<tr>
<td>Loc x Set x Trt</td>
<td>3</td>
<td>0.29</td>
<td>1.15</td>
</tr>
<tr>
<td>Genotype (Gen)/Set</td>
<td>60</td>
<td>2.53**</td>
<td>7.20**</td>
</tr>
<tr>
<td>Trt x Gen/Set</td>
<td>60</td>
<td>0.31</td>
<td>0.44</td>
</tr>
<tr>
<td>Loc x Gen/Set</td>
<td>60</td>
<td>0.88**</td>
<td>1.73**</td>
</tr>
<tr>
<td>Error</td>
<td>60</td>
<td>0.32</td>
<td>0.48</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td>3.17</td>
<td>1.72</td>
</tr>
</tbody>
</table>
oil and protein for all treatments were 17.9 and 40.5 percent, respectively. Generally, there is a tendency for increasing oil concentration with increasing air temperature, especially just before maturity (Howell and Cartter, 1958). Mack and Ivarson (1972) reported that oil concentration remained fairly constant near 18 - 19 percent with soil temperatures between 11.2 and 31.2°C. They also estimated protein concentration and found it nearly constant under low soil moisture. But protein concentration increased with increasing temperatures under medium and high levels of soil moisture.

According to Johnston et al. (1969) with additional light enhancement, caused by reflective plastic and supplemental light, soybean seeds had higher oil concentrations than seeds from control plants. However, Donovan et al. (1967) studied the interaction of light intensity and air temperature and found that with high air temperatures, oil concentration and the length of time exposed to sunlight may be negatively correlated. In our experiments, the difference in temperature or light intensity with and without reflectors was not enough to show a detectable variation in oil or protein concentrations.

Genotypes varied significantly in both oil and protein concentration. The effect of location was significant only in the case of oil concentration, but the interaction between genotypes and location was significant for both oil
and protein. No significant interaction was found between genotypes and the reflector treatments (Table 12).

**Seed Quality (Germination and Vigor)**

The reflector treatments had no significant effect on standard germination or results of accelerated aging tests (Table 13). There was a significant difference in the accelerated aging test between seeds developed at the different segments. Seeds from the upper and middle segments were significantly higher in their accelerated aging test germination than seeds from the lower segment (Table 14).

Generally, there was a small decline in both germination and aging tests with reflectors, but more so with the aging test. In general, high temperature has a negative effect on soybean seed quality (Green and Pinnell, 1968; Cartter and Hartwig, 1962; Hesketh et al., 1973; and Green, 1961). A similar trend was reported for snap beans (*Phaseolus vulgaris* L.) (Siddique and Goodwin, 1980). In our experiment, the temperature increases caused by reflectors was not high enough to cause such effects.

Germination is usually better in seeds from upper than from lower parts of plants. Thomison (1983) reported high germination and accelerated aging vigor tests in seeds from top halves of plants compared to that from bottom halves. Although results obtained by Adam (1983) were not consistent in favor of a particular seed position, germination in accelerated aging tests was slightly higher in seeds from top
Table 13. Mean squares for standard germination and accelerated aging tests from the reflector experiment, 1981.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>Germination</th>
<th>Aging Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment (Trt)</td>
<td>1</td>
<td>21.98</td>
<td>113.92</td>
</tr>
<tr>
<td>Plant Segment (Seg)</td>
<td>2</td>
<td>108.18</td>
<td>431.17*</td>
</tr>
<tr>
<td>Genotype</td>
<td>5</td>
<td>861.83**</td>
<td>2975.40**</td>
</tr>
<tr>
<td>Trt x Seg</td>
<td>2</td>
<td>35.79</td>
<td>6.82</td>
</tr>
<tr>
<td>Trt x Genotype</td>
<td>5</td>
<td>49.04</td>
<td>56.73</td>
</tr>
<tr>
<td>Seg x Genotype</td>
<td>10</td>
<td>36.45</td>
<td>93.49</td>
</tr>
<tr>
<td>Trt x Seg x Genotype</td>
<td>10</td>
<td>29.66</td>
<td>47.77</td>
</tr>
<tr>
<td>Error</td>
<td>105</td>
<td>63.60</td>
<td>125.98</td>
</tr>
</tbody>
</table>
Table 14. Standard germination and accelerating aging test results for selected soybean genotypes from the reflector experiment, 1981.

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>Germination (%) without reflectors</th>
<th>Germination (%) with reflectors</th>
<th>Aging Test (%) without reflectors</th>
<th>Aging Test (%) with reflectors</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U* M L</td>
<td>U* M L</td>
<td>U M L</td>
<td>U M L</td>
<td>Means</td>
</tr>
<tr>
<td>618-130</td>
<td>92 95 90</td>
<td>93 94 86</td>
<td>92 35 33 29</td>
<td>28 31 18</td>
<td>29</td>
</tr>
<tr>
<td>618-28</td>
<td>96 96 94</td>
<td>96 97 92</td>
<td>95 57 51 32</td>
<td>53 51 37</td>
<td>47</td>
</tr>
<tr>
<td>624-136</td>
<td>97 97 97</td>
<td>93 94 94</td>
<td>95 67 54 54</td>
<td>54 52 48</td>
<td>55</td>
</tr>
<tr>
<td>624-140</td>
<td>93 93 86</td>
<td>89 88 92</td>
<td>90 16 19 13</td>
<td>12 13 11</td>
<td>14</td>
</tr>
<tr>
<td>Williams</td>
<td>96 98 94</td>
<td>96 98 98</td>
<td>97 36 31 20</td>
<td>37 31 27</td>
<td>30</td>
</tr>
<tr>
<td>Beeson</td>
<td>87 85 76</td>
<td>87 84 78</td>
<td>83 26 11 29</td>
<td>26 18 18</td>
<td>21</td>
</tr>
<tr>
<td>Means</td>
<td>93.5† 94.0 89.5</td>
<td>92.3 92.5 90.0</td>
<td>39.5 33.2 29.5</td>
<td>35.0 32.7 26.5</td>
<td>34.0 31.4</td>
</tr>
</tbody>
</table>

* U = upper, M = middle, L = lower plant segments
† LSD.05 for plant segments = 4.56; and for genotypes = 6.42
halves. Our results conform to the previous findings; seeds from upper and middle plant segments have better germination than those from the lower part.

There was a highly significant difference among genotypes in both standard germination and accelerated aging tests (Table 13). No significant interactions were found between reflector treatments and genotypes or reflector treatments and plant segments in either seed quality test.

**Phenotypic Correlation**

Phenotypic correlations among some agronomic characters of soybean genotypes were calculated for reflector treated plants only, control plants only and averaged over both treatments (Table 15, 16, and 17). The number of days to first flowering was positively correlated with maturity, plant height, and lodging score in all three cases. Without reflectors days to first flowering was positively correlated with seed size and negatively correlated with seeds per pod.

However, no relationship was found between days to first flowering and number of pods or seed yield. The period to physiological maturity was highly correlated with plant height and with seed yield in all three cases, and also with lodging score where reflectors were used.

Plant height was positively correlated with lodging, number of pods and seed yield in the three cases, with number of seeds in reflector treated plants and with seed size in control plants. Using reflectors had no detectable
Table 15. Phenotypic correlations of some agronomic characters in the presence of reflectors for the reflector experiment, 1981.

<table>
<thead>
<tr>
<th>Days to flowering</th>
<th>Days to maturity</th>
<th>Plant height</th>
<th>Lodging score</th>
<th>Pods per plant</th>
<th>Seed size</th>
<th>Seeds per pod</th>
<th>Seed yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days to flowering</td>
<td>0.54**</td>
<td>0.46**</td>
<td>0.33**</td>
<td>0.02</td>
<td>0.05</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>Days to maturity</td>
<td></td>
<td>0.60**</td>
<td>0.34**</td>
<td>0.18</td>
<td>0.24</td>
<td>0.23</td>
<td>0.42**</td>
</tr>
<tr>
<td>Plant height</td>
<td></td>
<td></td>
<td>0.57**</td>
<td>0.42**</td>
<td>0.13</td>
<td>0.33**</td>
<td>0.62**</td>
</tr>
<tr>
<td>Lodging score</td>
<td></td>
<td></td>
<td></td>
<td>0.32*</td>
<td>0.06</td>
<td>0.24</td>
<td>0.46**</td>
</tr>
<tr>
<td>Pods per plant</td>
<td></td>
<td></td>
<td></td>
<td>-0.21</td>
<td>-0.09</td>
<td>0.59**</td>
<td></td>
</tr>
<tr>
<td>Seed size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.17</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Seeds per pod</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.59**</td>
</tr>
<tr>
<td>Seed yield</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*, ** Significant at 0.05 and 0.01 levels, respectively.
Table 16. Phenotypic correlations of some agronomic characters in the absence of reflectors for the reflector experiment, 1981.

<table>
<thead>
<tr>
<th>Phenotypic Measure</th>
<th>Days to flowering</th>
<th>Days to maturity</th>
<th>Plant height</th>
<th>Lodging score</th>
<th>Pods per plant</th>
<th>Seed size</th>
<th>Seeds per pod</th>
<th>Seed yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days to flowering</td>
<td>0.68**</td>
<td>0.43**</td>
<td>0.32**</td>
<td>0.16</td>
<td>0.34**</td>
<td>-0.27*</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>Days to maturity</td>
<td>0.62**</td>
<td>0.25</td>
<td>0.32*</td>
<td>0.20</td>
<td>-0.12</td>
<td>0.36**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant height</td>
<td>0.48**</td>
<td>0.56**</td>
<td>0.25*</td>
<td>-0.07</td>
<td>0.62**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lodging score</td>
<td>0.43**</td>
<td>0.10</td>
<td>-0.08</td>
<td>0.39**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pods per plant</td>
<td>-0.20</td>
<td>-0.22</td>
<td>0.72**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed size</td>
<td>-0.37**</td>
<td>0.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeds per pod</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.34**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed yield</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*, ** Significant at 0.05 and 0.01 levels, respectively.
Table 17. Phenotypic correlations of some agronomic characters averaged over the reflector treatment for the reflector experiment, 1981.

<table>
<thead>
<tr>
<th></th>
<th>Days to flowering</th>
<th>Days to maturity</th>
<th>Plant height</th>
<th>Lodging score</th>
<th>Pods per plant</th>
<th>Seed size</th>
<th>Seeds per pod</th>
<th>Seed yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days to flowering</td>
<td>0.65**</td>
<td>0.49**</td>
<td>0.37**</td>
<td>0.12</td>
<td>0.22</td>
<td>-0.06</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Days to maturity</td>
<td></td>
<td>0.65**</td>
<td>0.32*</td>
<td>0.33**</td>
<td>0.22</td>
<td>0.06</td>
<td>0.44**</td>
<td></td>
</tr>
<tr>
<td>Plant height</td>
<td></td>
<td></td>
<td>0.55**</td>
<td>0.55**</td>
<td>0.20</td>
<td>0.14</td>
<td>0.65**</td>
<td></td>
</tr>
<tr>
<td>Lodging score</td>
<td></td>
<td></td>
<td></td>
<td>0.45**</td>
<td>0.10</td>
<td>0.10</td>
<td>0.49**</td>
<td></td>
</tr>
<tr>
<td>Pods per plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.08</td>
<td>-0.04</td>
<td>0.69**</td>
<td></td>
</tr>
<tr>
<td>Seed size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.38**</td>
<td>0.20</td>
</tr>
<tr>
<td>Seeds per pod</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.50**</td>
</tr>
<tr>
<td>Seed yield</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*, ** Significant at 0.05 and 0.01 levels, respectively.
effect on the correlation of lodging with other agronomic traits. However, lodging was highly correlated with both number of pods and total seed yield. Although lodging in the field often decreases yield, the response is complex and may be due to self-shading and incomplete harvesting rather than to the horizontal stem position itself (Mann and Jaworski, 1970). Leffel (1961) found that natural lodging of soybean did not significantly affect yield when compared with unlodged plants. Also, high yielding plants are often more prone to lodging because of large size.

Phenotypic correlations with reflector treated plants, with control plants only and as averaged over both indicate that number of pods was highly positively correlated to seed yield. A nonsignificant negative correlation was found among number of pods and each of the other yield components (seed size and seeds/pod). An inverse relationship exists between seed size and number of seeds per pod, but no significant correlation was found between seed size and seed yield. Number of seeds per pod, however, positively correlated to seed yield. In general, using reflectors did not greatly affect the phenotypic correlations among plant characters.

Phenotypic correlations were also calculated between seed yield from different plant segments (upper, middle, and lower parts) and whole plants (Table 18). All plant segments similarly contributed to total seed yield; highly
Table 18. Phenotypic correlations of yield and yield components calculated in the presence, absence, and averaged over the reflector treatments for the reflector experiment, 1981.

<table>
<thead>
<tr>
<th>Plant Traits</th>
<th>With Reflectors</th>
<th>Without Reflectors</th>
<th>Averaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total yield and upper yield</td>
<td>0.91**</td>
<td>0.90**</td>
<td>0.93**</td>
</tr>
<tr>
<td>middle yield</td>
<td>0.95**</td>
<td>0.96**</td>
<td>0.96**</td>
</tr>
<tr>
<td>lower yield</td>
<td>0.88**</td>
<td>0.83**</td>
<td>0.87**</td>
</tr>
<tr>
<td>Upper yield and middle yield</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lower yield</td>
<td>0.71**</td>
<td>0.60**</td>
<td>0.70**</td>
</tr>
<tr>
<td>pods/plant</td>
<td>0.50**</td>
<td>0.63**</td>
<td>0.60**</td>
</tr>
<tr>
<td>seed size</td>
<td>0.09</td>
<td>0.22</td>
<td>0.17</td>
</tr>
<tr>
<td>seeds/pod</td>
<td>0.61**</td>
<td>0.29*</td>
<td>0.52**</td>
</tr>
<tr>
<td>Middle yield and lower yield</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pods/plant</td>
<td>0.53**</td>
<td>0.63**</td>
<td>0.64**</td>
</tr>
<tr>
<td>seed size</td>
<td>0.26*</td>
<td>0.26*</td>
<td>0.27*</td>
</tr>
<tr>
<td>seeds/pod</td>
<td>0.54**</td>
<td>0.30*</td>
<td>0.45**</td>
</tr>
<tr>
<td>Lower yield and pods/plant</td>
<td>0.59**</td>
<td>0.64**</td>
<td>0.68**</td>
</tr>
<tr>
<td>seed size</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>seeds/pod</td>
<td>0.49**</td>
<td>0.33**</td>
<td>0.43**</td>
</tr>
</tbody>
</table>

*, ** Significant at 0.05 and 0.01 levels, respectively.
positive correlations were found between segment yield and total yield in all cases. Also, seed yields from each segment were positively correlated with each other. Number of pods and seeds per pod were the two yield components that positively correlated to seed yield from each segment. Seed size had a positive correlation with seed yield from the middle segment only. The use of reflectors did not influence the phenotypic correlations among traits presented in Table 18.

A significant negative correlation was found between oil and protein concentration \( (r = -0.75) \). A similar relationship was reported by Weiss et al. (1952).

**Genotypic Response to Reflectors**

Summarized data are presented in Table 19 to show effects of reflectors on soybean genotypes as categorized into positive and negative groups according to their response in yield to reflectors. Reflectors had no effect on either days to flowering or days to maturity in positive and negative response groups. But reflectors caused an increase in mature plant height and lodging score in both groups.

Generally, genotypes which responded negatively in yield to reflector treatments were high in their yield and yield components when grown without reflectors compared to the positive group. When reflectors were used, there was a decline in all agronomic characters studied with the
Table 19. Means for various characters of groups of soybean genotypes as categorized into positive and negative response in yield to reflectors for the reflector experiment, 1981.

<table>
<thead>
<tr>
<th>Plant Characters</th>
<th>Positive Response</th>
<th>Negative Response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without Reflectors</td>
<td>With Reflectors</td>
</tr>
<tr>
<td>Days to flowering</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>Days to maturity</td>
<td>118</td>
<td>118</td>
</tr>
<tr>
<td>Lodging score</td>
<td>1.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Plant height</td>
<td>70</td>
<td>74</td>
</tr>
<tr>
<td>Upper pods</td>
<td>10.7</td>
<td>12.4</td>
</tr>
<tr>
<td>Middle pods</td>
<td>20.3</td>
<td>21.1</td>
</tr>
<tr>
<td>Lower pods</td>
<td>15.6</td>
<td>15.9</td>
</tr>
<tr>
<td>Total pods</td>
<td>46.6</td>
<td>49.5</td>
</tr>
<tr>
<td>Upper seed size</td>
<td>15.9</td>
<td>15.4</td>
</tr>
<tr>
<td>Middle seed size</td>
<td>16.7</td>
<td>16.4</td>
</tr>
<tr>
<td>Lower seed size</td>
<td>16.2</td>
<td>15.5</td>
</tr>
<tr>
<td>Total seed size</td>
<td>16.4</td>
<td>15.9</td>
</tr>
<tr>
<td>Upper seeds per pod</td>
<td>1.6</td>
<td>1.7</td>
</tr>
<tr>
<td>Middle seeds per pod</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Lower seeds per pod</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Total seeds per pod</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Upper seeds per plant</td>
<td>16.3</td>
<td>20.4</td>
</tr>
<tr>
<td>Middle seeds per plant</td>
<td>31.4</td>
<td>33.7</td>
</tr>
<tr>
<td>Lower seeds per plant</td>
<td>22.4</td>
<td>24.7</td>
</tr>
<tr>
<td>Total seeds per plant</td>
<td>70.2</td>
<td>78.7</td>
</tr>
<tr>
<td>Upper seed yield</td>
<td>26.1</td>
<td>31.6</td>
</tr>
<tr>
<td>Middle seed yield</td>
<td>52.1</td>
<td>55.3</td>
</tr>
<tr>
<td>Lower seed yield</td>
<td>36.4</td>
<td>38.3</td>
</tr>
<tr>
<td>Total seed yield</td>
<td>114.5</td>
<td>125.2</td>
</tr>
<tr>
<td>Oil %</td>
<td>17.85</td>
<td>18.33</td>
</tr>
<tr>
<td>Protein %</td>
<td>40.61</td>
<td>40.47</td>
</tr>
</tbody>
</table>
negative response group. In contrast, the positive response group showed an increase with reflectors in all agronomic characters except the seed size. However, it seems that the decreasing effect of reflectors on the negative response group is greater than the increasing effect on the positive response group. For instance, total seed yield per plot decreased about 14 percent with reflector treatment in the negative response group, whereas the increase in seed yield due to reflectors in the positive group was 9 percent.

In the case of oil and protein concentrations, reflector treatments had a very small effect. In the negative response group reflectors caused a slight reduction in oil and a very small increase in protein concentration. In contrast, reflector treatments caused an increase in oil concentration and a reduction in protein concentration in the positive response group.
RESULTS AND DISCUSSION

Greenhouse High Temperature and Field Experiments

Effect of Nitrogen Treatments

Nitrogen fertilizer application showed no significant effect on any of the soybean traits studied in the greenhouse under high temperature conditions. Moreover, analysis of variance showed no significant interactions between nitrogen applications and soybean genotypes among the traits studied except plant height and shrivelled seeds (Table 20). The nonsignificant effect of supplied nitrogen may be due to the effect of high temperature (up to 44°C) above the optimum. There is a general trend that high temperature is stimulatory for the growth of soybeans supplied with nitrogen up to an optimum temperature above which the plant growth is restricted (Munevar and Wollum, 1981). Although soybeans show little response to nitrogen fertilizer under field conditions, it is evident from these results that under excessively high temperature, soybeans showed no response to nitrogen applications.

The significant interactions between added nitrogen and genotypes for plant height and percentage of shrivelled
Table 20. Analysis of variance for various characters of soybean genotypes grown in the greenhouse, 1982.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>Days to Flowering</th>
<th>Days to Maturity</th>
<th>Plant Height</th>
<th>Lodging Score</th>
<th>Pods per Plant</th>
<th>Seed Size (g/100)</th>
<th>Seed Yield</th>
<th>Shrivelled Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>1</td>
<td>6.011</td>
<td>0.557</td>
<td>117.30</td>
<td>1.38*</td>
<td>3.40</td>
<td>0.07</td>
<td>14.55</td>
<td>72.73</td>
</tr>
<tr>
<td>Nitrogen Treatment (NTRT)</td>
<td>1</td>
<td>15.557</td>
<td>1.920</td>
<td>18.77</td>
<td>0.56</td>
<td>0.06</td>
<td>2.14</td>
<td>2.07</td>
<td>58.91</td>
</tr>
<tr>
<td>Genotypes</td>
<td>21</td>
<td>30.126**</td>
<td>23.516**</td>
<td>470.00**</td>
<td>1.30**</td>
<td>68.02**</td>
<td>13.52**</td>
<td>81.24*</td>
<td>753.35**</td>
</tr>
<tr>
<td>Genotypes x NTRT</td>
<td>21</td>
<td>5.009</td>
<td>10.754</td>
<td>168.08**</td>
<td>0.46</td>
<td>30.89</td>
<td>2.68</td>
<td>45.69</td>
<td>269.58*</td>
</tr>
<tr>
<td>Error</td>
<td>43</td>
<td>3.128</td>
<td>6.417</td>
<td>69.14</td>
<td>0.35</td>
<td>26.18</td>
<td>1.55</td>
<td>41.22</td>
<td>150.22</td>
</tr>
</tbody>
</table>

CV%  
4.34  2.47  8.21  13.99  31.75  12.96  40.64  80.13

*, ** Significant at 0.05 and 0.01 levels, respectively, according to F test.
seeds indicated that soybean genotypes responded differently to supplied nitrogen in respect to those traits. Genotypes supplied with nitrogen fertilizer produced seeds with about 2 percent less shrivelled than unfertilized genotypes (Table 21). However, it seems that supplied nitrogen had more influence on the negative response genotypes and caused about 3.4 percent reduction in the percentage of shrivelled seeds. Non replicated data presented in Table 22 showed that supplied nitrogen reduced the weight of nodules developed on soybean roots. Weight of nodules developed on some genotypes grown in the greenhouse was about half the weight of those developed on the same genotypes outside the greenhouse. Difference among means was significant between inside and outside treatments, but not significant between nitrogen applications (Table 22).

**Effect of High Temperature**

Significant variation was found among soybean genotypes grown in the greenhouse and the field in all traits studied except for number of days to physiological maturity under field conditions (Tables 20, 23). Such significant variation is expected due to these genotypes representing broad-based populations. However, the mean number of days to first flowering and physiological maturity in the greenhouse was 9 and 10 days, respectively earlier than those grown under field conditions (Table 21). This difference may be attributed mainly to the effect of high
Table 21. Agronomic characters studied for soybean genotypes grown in greenhouse and field, 1982.

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Treatments</th>
<th>Days to Flowering</th>
<th>Days to Maturity</th>
<th>Plant Height (cm)</th>
<th>Lodging Score (1-5)</th>
<th>Pods Per Plant</th>
<th>Seed Size (g/100)</th>
<th>Yield Per Plot (g.)</th>
<th>Percent Shrivelled Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse</td>
<td>Without N</td>
<td>41.1</td>
<td>102.7</td>
<td>100.9</td>
<td>4.2</td>
<td>16.1</td>
<td>9.8</td>
<td>16.0</td>
<td>16.1</td>
</tr>
<tr>
<td></td>
<td>With N</td>
<td>40.3</td>
<td>102.4</td>
<td>101.8</td>
<td>4.3</td>
<td>16.1</td>
<td>9.5</td>
<td>15.6</td>
<td>14.5</td>
</tr>
<tr>
<td>Field</td>
<td>---</td>
<td>49.3</td>
<td>112.9</td>
<td>70.5</td>
<td>1.4</td>
<td>31.9</td>
<td>14.5</td>
<td>69.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Table 22. Effect of nitrogen fertilizer applications on weight of nodules from some soybean genotypes grown in pots inside and outside the greenhouse, 1982.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Genotype</th>
<th>Means (g.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>618-35</td>
<td>618-28</td>
</tr>
<tr>
<td>Outdoor</td>
<td>4.02</td>
<td>4.52</td>
</tr>
<tr>
<td>Indoor</td>
<td>1.72</td>
<td>3.55</td>
</tr>
<tr>
<td></td>
<td>N⁻</td>
<td></td>
</tr>
<tr>
<td>Indoor</td>
<td>0.08</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>N⁺</td>
<td></td>
</tr>
</tbody>
</table>

† LSD$_{0.05}$ = 2.45 for treatments.

N⁻ = without nitrogen, N⁺ = with nitrogen.
Table 23. Analysis of variance for various characters of soybean genotypes grown in the field, Columbus, 1982.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>Days to Flowering</th>
<th>Days to Maturity</th>
<th>Plant Height</th>
<th>Lodging Score</th>
<th>Pods per Plant</th>
<th>Seed Size (g/100)</th>
<th>Seed Yield</th>
<th>Shrivelled Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>1</td>
<td>14.50</td>
<td>442.41*</td>
<td>201.64*</td>
<td>0.26</td>
<td>573.99**</td>
<td>4.17*</td>
<td>3436.50**</td>
<td>0.92</td>
</tr>
<tr>
<td>Genotype</td>
<td>21</td>
<td>53.16**</td>
<td>183.47</td>
<td>342.93**</td>
<td>1.39**</td>
<td>178.16**</td>
<td>10.62**</td>
<td>629.71*</td>
<td>4.32**</td>
</tr>
<tr>
<td>Error</td>
<td>61</td>
<td>7.71</td>
<td>150.72</td>
<td>65.18</td>
<td>0.33</td>
<td>77.80</td>
<td>1.33</td>
<td>300.23</td>
<td>1.02</td>
</tr>
</tbody>
</table>

**CV%**

<p>| | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5.54</td>
<td>10.70</td>
<td>11.28</td>
<td>39.08</td>
<td>27.24</td>
<td>7.84</td>
<td>24.68</td>
<td>291.53</td>
</tr>
</tbody>
</table>

*, ** Significant at 0.05 and 0.01 levels, respectively, according to F test.
temperature under the greenhouse conditions. Many investigators (Steinberg and Carner, 1936; Van Schaik and Probst, 1958; Whigham and Minor, 1978; and Thomas and Raper, 1978) have shown that increasing temperature hastened flowering of soybean. Similarly, Egli and Wardlow (1980) found that the time to physiological maturity occurred 3 days earlier when temperature rose to 33/28°C compared to 24/19, 27/22 or 30/25°C under controlled conditions. Peters et al. (1971) reported that high temperature up to 30°C was associated with earlier senescence and maturity.

Plants grown in the greenhouse were about 30cm taller than field-grown plants (Table 21), a difference attributed to high temperature and less light intensity inside the greenhouse compared to field conditions. Results from various studies (Thomas and Raper, 1978; Van Schaik and Probst, 1958; and Overholt, 1974) have revealed that high temperature has a stimulatory effect on plant height. Allen (1975) found that plants grown under lower light intensity under shade cloth were much taller (120cm) than those in the open (80cm) in the greenhouse study. Tall plants were accompanied by high lodging (4.24 score) compared to those grown in the field (1.42 score) (Table 21), a difference attributed to weak stems on greenhouse plants.

With respect to yield components, plants grown in the greenhouse under high temperature developed about half the number of pods per plant and 68 percent of the seed size
compared to those grown in the field (Table 21). Under high temperature conditions abortion is usually severe. Mann and Jaworski (1970) noticed severe pod abortion under high temperature (40 to 46°C), and Mann and Jaworski (1970) found that, when temperature rose above 40°C, pod set was reduced by 57 to 71 percent. On the other hand, reduction in seed size could be related to many factors, such as excessively high temperature, low light intensity, nutrient deficiency, short period of seed filling and other environmental factors. In other studies (Hesketh et al., 1973 and Egli and Wardlow, 1980), temperatures above the optimum had a reducing effect on seed size (weight per seed) due to rapid leaf senescence and a shorter seed filling period.

Generally, seed yield of soybean genotypes grown in the greenhouse was lower than that of field-grown plants. This result, expected under heat stress conditions, is attributed to many factors. Excessive high temperature, especially during the reproductive period could influence many physiological processes essential to the production of seed, such as photosynthesis, translocation, respiration, and water and nutrient uptake. Research has indicated that excessively high temperature has an inhibitory effect on photosynthesis (Mann and Jaworski, 1970; Whigham and Minor, 1978), translocation (Mortimer, 1961; Whitte, 1964; and Thorne, 1982), and nitrogen fixation (Kuo and Boersma, 1971; Lawrie and Wheeler, 1973; and Munevar and Wollum, 1981).
Ahmad (1978) stated that temperatures of 35°C and higher inhibit respiration due to the inactivation of the enzymes involved in the respiratory system. Although there is no clear evidence in the available literature of significant positive correlations between seed yield and any of these processes, there is a significant positive correlation between mean crop growth rate (total dry matter production) and maximum photosynthetic rate over a wide range of both C-3 and C-4 crops (Eastin et al., 1983).

Seeds produced by genotypes grown under high temperature in the greenhouse varied significantly in their visual rating quality (shrivelled seeds). Under field conditions, there were no shrivelled seeds, except for very low percentages (2-4%) observed in a few genotypes. Average shrivelled seed percentage for all genotypes grown in the greenhouse was 15.30 percent versus only 0.34 percent in the field (Table 21). A high percentage of shrivelled seeds is a result of excessively high temperature. Hesketh et al. (1973) obtained the maximum weight per seed of soybean at 27°C, whereas seeds developed at 30°C were small and shrivelled. Cartter and Hartwig (1962) also related the occurrence of shrivelled seeds to very high temperatures under dry conditions.

Generally, soybean genotypes grown in the greenhouse responded to heat stress in three different ways: (a) some genotypes showed a high percentage of shrivelled seeds;
(b) some genotypes showed a low percentage of shrivelled seeds, but small seed size (weight/seed); and (c) some genotypes produced almost normal seeds compared to those produced in the field (Table 24).

**Comparison of Positive and Negative Response Genotypes**

Orthogonal comparisons were performed to partition the genotypes into positive versus negative response groups based on the 1981 reflector experiment (Table 24). The negative response group flowered and matured significantly later than the positive group in the greenhouse and also in the field. Differences between the positive and negative groups in plant height and lodging were significant only under field conditions. The negative response group was taller (74cm) and lodged more (1.75 score) than the positive group (67cm and 1.11 score, respectively). This suggests that the major effect of reflectors was light rather than heat enhancement.

No significant differences in number of pods per plant were found between the genotypes groups either in the greenhouse or in the field, but a significant difference in seed size was observed in the greenhouse. Genotypes which showed a positive response to reflectors gave significantly heavier seed size than those of negative response, indicating significant heat tolerance in the positive response group. The positive response group gave significantly (20%) higher seed yield with a 52% lower percentage
Table 24. Genotype means for percent shrivelled seeds, seed size, pods per plant, and seed yield for the greenhouse experiment and the seed yield for the field experiment, 1982.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Response†</th>
<th>Shrivelled Seeds</th>
<th>Seed Size (g/100)</th>
<th>Pod Per Plant</th>
<th>Seed Yield (g/pot)</th>
<th>Field Seed Yield (g/plot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>617 - 11</td>
<td>+</td>
<td>1.5</td>
<td>12.96</td>
<td>14.6</td>
<td>16.95</td>
<td>58.13</td>
</tr>
<tr>
<td>617 - 20</td>
<td>+</td>
<td>2</td>
<td>12.69</td>
<td>15.2</td>
<td>18.38</td>
<td>66.08</td>
</tr>
<tr>
<td>623 - 1</td>
<td>+</td>
<td>4.8</td>
<td>9.97</td>
<td>20.7</td>
<td>22.33</td>
<td>73.08</td>
</tr>
<tr>
<td>623 - 6</td>
<td>-</td>
<td>5.0</td>
<td>8.45</td>
<td>13.9</td>
<td>10.05</td>
<td>99.33</td>
</tr>
<tr>
<td>Williams 79</td>
<td>-</td>
<td>5.0</td>
<td>9.45</td>
<td>16.0</td>
<td>15.87</td>
<td>81.50</td>
</tr>
<tr>
<td>624 - 68</td>
<td>+</td>
<td>6.5</td>
<td>6.73</td>
<td>21.2</td>
<td>13.55</td>
<td>81.50</td>
</tr>
<tr>
<td>624 - 159</td>
<td>-</td>
<td>6.8</td>
<td>7.21</td>
<td>14.4</td>
<td>13.29</td>
<td>82.63</td>
</tr>
<tr>
<td>624 - 3</td>
<td>+</td>
<td>7.5</td>
<td>9.57</td>
<td>9.3</td>
<td>9.38</td>
<td>67.70</td>
</tr>
<tr>
<td>617 - 37</td>
<td>-</td>
<td>8.0</td>
<td>12.02</td>
<td>11.1</td>
<td>14.37</td>
<td>71.03</td>
</tr>
<tr>
<td>Beeson</td>
<td>+</td>
<td>8.5</td>
<td>10.16</td>
<td>12.9</td>
<td>16.09</td>
<td>72.29</td>
</tr>
<tr>
<td>618 - 28</td>
<td>+</td>
<td>9.5</td>
<td>11.16</td>
<td>15.5</td>
<td>17.38</td>
<td>55.15</td>
</tr>
<tr>
<td>623 - 13</td>
<td>-</td>
<td>10.5</td>
<td>9.08</td>
<td>18.2</td>
<td>15.45</td>
<td>79.25</td>
</tr>
<tr>
<td>618 - 239</td>
<td>-</td>
<td>11.5</td>
<td>9.99</td>
<td>10.5</td>
<td>13.07</td>
<td>76.88</td>
</tr>
<tr>
<td>618 - 133</td>
<td>+</td>
<td>15.8</td>
<td>10.66</td>
<td>21.9</td>
<td>24.40</td>
<td>81.58</td>
</tr>
<tr>
<td>624 - 199</td>
<td>-</td>
<td>17.0</td>
<td>7.49</td>
<td>14.1</td>
<td>9.65</td>
<td>53.30</td>
</tr>
<tr>
<td>618 - 153</td>
<td>-</td>
<td>18.5</td>
<td>9.47</td>
<td>22.6</td>
<td>20.95</td>
<td>53.43</td>
</tr>
<tr>
<td>623 - 10</td>
<td>-</td>
<td>22.0</td>
<td>7.97</td>
<td>20.1</td>
<td>17.93</td>
<td>77.15</td>
</tr>
<tr>
<td>623 - 11</td>
<td>+</td>
<td>27.0</td>
<td>8.49</td>
<td>21.0</td>
<td>19.00</td>
<td>53.37</td>
</tr>
<tr>
<td>624 - 85</td>
<td>-</td>
<td>28.8</td>
<td>8.24</td>
<td>20.6</td>
<td>19.25</td>
<td>66.85</td>
</tr>
<tr>
<td>618 - 35</td>
<td>-</td>
<td>29.5</td>
<td>7.19</td>
<td>10.2</td>
<td>5.93</td>
<td>56.23</td>
</tr>
<tr>
<td>618 - 14</td>
<td>-</td>
<td>30.0</td>
<td>12.46</td>
<td>13.7</td>
<td>14.65</td>
<td>66.28</td>
</tr>
<tr>
<td>617 - 6</td>
<td>-</td>
<td>61.0</td>
<td>10.19</td>
<td>17.2</td>
<td>19.57</td>
<td>46.80</td>
</tr>
</tbody>
</table>

Grand Mean 15.30 9.62 16.12 15.80 69.08
LSD 0.05 17.45 1.77 7.29 9.14 24.94
0.01 23.31 2.37 9.73 12.21 33.17

† Genotype response based on 1981 reflector experiment.
Table 25. Agronomic characters studied for soybean genotypes that responded positively and negatively to reflectors, greenhouse and field experiments, 1982.

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Genotype† Response</th>
<th>Days to Flowering</th>
<th>Days to Maturity</th>
<th>Plant Height (cm)</th>
<th>Lodging Score (1-5)</th>
<th>Pods Per Plant</th>
<th>Seed Size (g/100)</th>
<th>Yield Per Plot (gm)</th>
<th>Percent Shrivelled Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse</td>
<td>Negative</td>
<td>41.85**</td>
<td>103.10*</td>
<td>101.70</td>
<td>4.31</td>
<td>15.58</td>
<td>9.17**</td>
<td>14.62*</td>
<td>19.12**</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>39.08</td>
<td>101.67</td>
<td>100.76</td>
<td>4.14</td>
<td>16.89</td>
<td>10.27</td>
<td>17.50</td>
<td>9.22</td>
</tr>
<tr>
<td>Field</td>
<td>Negative</td>
<td>50.29**</td>
<td>116.14*</td>
<td>73.82**</td>
<td>1.75**</td>
<td>33.86</td>
<td>14.19</td>
<td>71.08</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>47.97</td>
<td>109.64</td>
<td>67.10</td>
<td>1.11</td>
<td>29.86</td>
<td>14.61</td>
<td>67.08</td>
<td>0.50</td>
</tr>
</tbody>
</table>

*, ** Significant at 0.05 and 0.01 levels, respectively, according to F test for orthogonal comparisons.
† Genotype response to reflectors based on 1981 reflector experiment.
of shrivelled seeds compared to that of the negative group under greenhouse conditions. An inverse, but nonsignificant relationship for yield and shrivelled seed existed between genotype groups grown in the field. Similar seed yield results were obtained from the same genotype groups when grown in the field without reflectors in 1981.

The low percentage of shrivelled seeds in the positive response genotypes indicates that these genotypes have some inherited tolerance to high temperature and could be used as good sources for breeding programs. Green and Pinnel (1965) reported that phenotypic variance for shrivelled cotyledons was higher in commercial cultivars than in Japanese strains which consistently had fewer and less severely shrivelled seeds.

That heat tolerance, giving a lower percentage of shrivelled seeds, can be selected for without sacrificing yield (field results) is encouraging. The tolerant group was also earlier and more lodging resistant on the average.

**Oil and Protein Concentrations**

Although the data were not statistically analyzed, means of oil and protein concentrations presented in Table 26 indicate that average oil level in seeds of genotypes grown in the greenhouse was slightly higher than that grown in the field. However, a more interesting result is that the positive response group had a higher oil and lower protein concentration than the negative group.
Table 26. Oil and protein concentrations in seed of positive and negative response groups of genotypes, greenhouse and field experiment, 1982.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Genotype† Response</th>
<th>Concentration (%)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Greenhouse</td>
<td>Field</td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>Positive</td>
<td>19.1</td>
<td>17.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>16.6</td>
<td>17.4</td>
<td></td>
</tr>
<tr>
<td>Protein</td>
<td>Positive</td>
<td>42.5</td>
<td>43.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>43.7</td>
<td>42.8</td>
<td></td>
</tr>
</tbody>
</table>

† Genotype response based on 1981 reflector experiment.
High temperature was the primary factor behind these relationships. Howell and Carter (1958) found a highly positive correlation between high temperature and the oil concentration in soybean seeds. It seems that oil concentration is more affected by high temperature than protein concentration. Mack and Ivarson (1972) noticed that protein concentration was fairly steady at low soil moisture over a wide range of soil temperature between 11.2 and 31.2°C. However, oil concentration in soybean seeds is usually inversely related to protein concentration (Weiss et al., 1952).

Seed Germination Tests

Nitrogen treatments and the interaction of nitrogen x genotypes had a significant effect on the germination level of accelerated aging tests performed on soybean genotypes grown in the greenhouse (Table 27). Significant variation in both standard germination and accelerated aging tests was found among genotypes grown in the greenhouse, but not under field conditions (Table 28).

These results show that the significant variation in germination was mainly due to the differential effect of high temperature on some of these genotypes. Supplied nitrogen greatly affected the accelerated aging test of the negative response genotypes; the germination percentage was about 14% higher with supplied nitrogen (Table 29). This
Table 27. Mean squares for standard germination and accelerated aging tests of seed of genotypes grown in the greenhouse, 1982

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>Mean Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Standard Germination Test</td>
</tr>
<tr>
<td>Replication</td>
<td>1</td>
<td>82.29</td>
</tr>
<tr>
<td>Nitrogen Treatment (NTRT)</td>
<td>1</td>
<td>146.29</td>
</tr>
<tr>
<td>Genotype</td>
<td>6</td>
<td>804.14**</td>
</tr>
<tr>
<td>Genotype x NTRT</td>
<td>6</td>
<td>88.62</td>
</tr>
<tr>
<td>Error</td>
<td>13</td>
<td>117.06</td>
</tr>
</tbody>
</table>

Table 28. Mean squares for standard germination and accelerated aging tests of seed of genotypes grown in the field, 1982

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>Mean Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Standard Germination Test</td>
</tr>
<tr>
<td>Replication</td>
<td>1</td>
<td>1.14</td>
</tr>
<tr>
<td>Genotype</td>
<td>6</td>
<td>254.67</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td>95.81</td>
</tr>
</tbody>
</table>
was mainly due to high percentage of shrivelled seeds observed with the negative response genotypes without supplied nitrogen.

Orthogonal comparisons showed that the positive response genotypes grown in the greenhouse were significantly higher in germination level in both standard germination and accelerated aging tests (Table 29). These differences are attributed to the high percentage of shrivelled seeds accompanying the negative response genotypes. Our results are in agreement with Green et al. (1965), who reported that wrinkled seed coats and shrivelled cotyledons were generally associated with lower laboratory germination and field emergence percentages. A significant difference in standard germination was found between the negative and the positive response groups under field conditions, but the two groups were similar in accelerated aging results.

**Leaf Water Potential**

Measurements of leaf water potential performed at full pod stage on 10 soybean genotypes grown in a high temperature greenhouse indicate a significant difference among genotypes except the reading on 8 September, A.M. (Table 30). Also, the orthogonal comparison between positive and negative groups shows a significant difference except that on 8 September, A.M. (Table 31). The nonsignificant difference at that particular time may be related to low
Table 29. Standard germination and accelerated aging percentages of some soybean genotypes that responded positively and negatively to reflectors, greenhouse and field experiments, 1982

<table>
<thead>
<tr>
<th>Vigor Tests</th>
<th>Genotype Response</th>
<th>Greenhouse, 1982</th>
<th>Field, 1982</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without Nitrogen</td>
<td>With Nitrogen</td>
<td>Mean</td>
</tr>
<tr>
<td>% Standard</td>
<td>Positive</td>
<td>91.33</td>
<td>83.33</td>
</tr>
<tr>
<td>Germination</td>
<td>Negative</td>
<td>59.00</td>
<td>63.75</td>
</tr>
<tr>
<td>% Accelerated</td>
<td>Positive</td>
<td>55.67</td>
<td>56.33</td>
</tr>
<tr>
<td>Aging</td>
<td>Negative</td>
<td>40/75</td>
<td>54.25</td>
</tr>
</tbody>
</table>

*, ** Significant at 0.05 and 0.01 levels, respectively, according to F test for orthogonal comparisons.
Table 30. Mean squares for leaf water potential for some soybean genotypes selected according to their response to reflectors in 1981 (Greenhouse experiment, 1983)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>D.F</th>
<th>September 8</th>
<th></th>
<th>September 12</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before Noon</td>
<td>After Noon</td>
<td>Before Noon</td>
<td>After Noon</td>
</tr>
<tr>
<td>Replication</td>
<td>3</td>
<td>844.27**</td>
<td>154.27</td>
<td>1104.56**</td>
<td>1256.49**</td>
</tr>
<tr>
<td>Genotype</td>
<td>9</td>
<td>250.03</td>
<td>1084.88**</td>
<td>1067.16**</td>
<td>1058.11**</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>138.66</td>
<td>245.84</td>
<td>180.32</td>
<td>292.16</td>
</tr>
</tbody>
</table>

* *, ** Significant at 0.05 and 0.01 levels, respectively, according to F test.
Table 31. Leaf water potential in negative bars for some soybean genotypes selected according to their response to reflectors in 1981 (Greenhouse experiment, 1983)

<table>
<thead>
<tr>
<th>Genotype Response</th>
<th>A.M.</th>
<th>P.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sept. 8</td>
<td>Sept. 12</td>
</tr>
<tr>
<td>Positive†</td>
<td>10.77</td>
<td>9.69*</td>
</tr>
</tbody>
</table>

*, ** Significant at 0.05 and 0.01 levels, respectively, according to F test for orthogonal comparisons.

† Positive Genotypes = 617-11, 617-20, 617-37, 624-3, and Beeson.

Negative Genotypes = 617-6, 623-11, 618-14, 624-85, and Williams.
temperature (28-30°C) compared to all other readings where the temperatures were 30-34°C. At all reading times that showed a significant difference, the positive response genotype group had higher leaf water potential than the negative response group.

These findings may indicate that the positive response group was more tolerant to water deficit than the negative group. The shift in water potential between A.M. and P.M. readings was less in the positive group than in the negative group (Table 31). This suggests that the positive group is a better osmoregulator than the negative group. Mederski et al. (1973) reported that susceptibility to moisture stress among soybean cultivars from different maturity groups was probably related to maturity class and not to some unique plant characteristics. In our study, the positive response genotypes matured significantly earlier than the negative genotypes under the greenhouse and field conditions (Table 25). Mederski and Jeffers (1973) grew 32 soybean cultivars, 8 in each of four maturity groups, under irrigated and nonirrigated conditions. They found a significant interaction between cultivar and soil stress level on yield in all maturity groups.

The compatibility between these results and those obtained in the greenhouse under high temperature indicates that correlations between high temperature and water
deficits show a performance superiority in the positive response genotype group.

Phenotypic Correlations

In the greenhouse, under heat stress conditions, the number of days to first flowering was positively correlated with the period to physiological maturity and negatively correlated with yield (Table 32). Similar correlations were obtained under field conditions (Table 33). Days to physiological maturity showed significant and negative correlations with number of pods per plant and seed yield in the greenhouse. However, no significant correlations were found between days to maturity and these two traits under field conditions, where maturity was significantly correlated only with plant height.

Plant height and lodging score did not show any significant correlation with any of the agronomic characters studied under field conditions. Under greenhouse conditions, lodging score was significantly correlated with seed size. A negative relationship was found between plant height and lodging score as indicated by negative correlation at 0.06 level of significance.

Number of pods per plant was significantly correlated with seed yield under both conditions, but more strongly correlated in the greenhouse. Pods per plant was negatively correlated to seed size significantly in the field and non-significantly in the greenhouse. Seed size did not show
Table 32. Phenotypic correlations of agronomic characters studied on soybean genotypes grown in the greenhouse, 1982

<table>
<thead>
<tr>
<th>Mean Squares</th>
<th>Days to Flowering</th>
<th>Days to Maturity</th>
<th>Plant Height</th>
<th>Lodging Score</th>
<th>Pods per Plant</th>
<th>Seed Size</th>
<th>Seed Yield</th>
<th>Shrivelled Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days to Flowering</td>
<td>0.59**</td>
<td>0.30</td>
<td>0.23</td>
<td>-0.41</td>
<td>-0.05</td>
<td>-0.43*</td>
<td>-0.31</td>
<td></td>
</tr>
<tr>
<td>Days to Maturity</td>
<td>0.10</td>
<td>0.37</td>
<td>-0.54**</td>
<td>-0.23</td>
<td>-0.56**</td>
<td>-0.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant Height</td>
<td>-0.41†</td>
<td>0.01</td>
<td>-0.18</td>
<td>-0.10</td>
<td>-0.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lodging Score</td>
<td>-0.26</td>
<td>0.43*</td>
<td>0.01</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pods per Plant</td>
<td>0.20</td>
<td>0.76**</td>
<td>0.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed Size</td>
<td>0.37</td>
<td>-0.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed Yield</td>
<td>0.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrivelled Seeds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*, ** Significant at 0.05 and 0.01 levels, respectively.
† Significant at 0.06 level.
Table 33. Phenotypic correlations of agronomic characters studied on soybean genotypes grown in the field, 1982

<table>
<thead>
<tr>
<th></th>
<th>Days to Flowering</th>
<th>Days to Maturity</th>
<th>Plant Height</th>
<th>Lodging Score</th>
<th>Pods per Plant</th>
<th>Seed Size</th>
<th>Seed Yield</th>
<th>Shrivelled Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days to Flowering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days to Maturity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant Height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lodging Score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pods per Plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed Size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed Yield</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrivelled Seeds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*, ** Significant at 0.05 and 0.01 levels, respectively.
a significant correlation with any of the soybean traits studied under field and greenhouse conditions. Similarly, the percentage of shrivelled seeds did not reach the level of significance in its correlation with other plant traits. The previous correlations indicate that, generally, agronomic characters studied under heat stress in the greenhouse had similar trends with those in the field except, lodging with plant height and number of pods, and pods/plant with seed weight. There were differences in the magnitude of correlation between the greenhouse and the field.
SUMMARY AND CONCLUSIONS

Sunlight reflectors were used under field conditions at two locations, Columbus and Wooster, Ohio, to study the effect of heat and light enhancement on some soybean genotypes from broad-based populations during the reproductive stage. Response of genotypes to reflector treatments was evaluated with respect to seed yield. Twenty of those genotypes were selected according to their positive and negative response to reflector treatments. These genotypes with two check cultivars were grown in a greenhouse under heat stress (up to 44°C) with and without nitrogen fertilizer application. Nitrogen was used to study the effect of high temperature on nodulation and to compensate for the expected reduction of N fixation due to high temperature.

The results of the reflector experiment indicated that using reflectors had no effect on days to physiological maturity and no interaction was found between genotypes and reflector treatments for days to maturity. Reflector treatments caused a small increase in plant height accompanied by a significant increase in lodging score. This shows that the major effect of reflectors was light- rather than heat-enhancement.
Reflectors had no significant effect on number of pods or number of seeds per pod or per plant. Moreover, there was no significant effect and no consistent pattern in the way reflectors affected any plant segment (upper, middle, or lower) in respect to the above yield components. Seed size was the only yield component affected significantly by reflector treatments. The use of reflectors caused a reduction in seed size in all plant segments. Reflector treatments caused a significant reduction in seed yield only in the lower plant segment. In addition, there was no significant interaction between genotypes and reflectors in respect to seed yield and its components. Nevertheless, the 1982 data comparing positive and negative response groups showed that such interactions exist, though the 1981 treatments may not have been powerful enough to detect them.

Oil and protein concentrations were not influenced by reflector treatments. The reflector treatments had no significant effect on either standard germination or results of accelerated aging tests. A significant difference between seeds developed at different positions was found only in the accelerated aging test. Seed vigor, measured by accelerated aging test, was significantly greater at the upper and middle seed positions compared to those from the lower position.

Generally, genotypes which responded negatively in seed yield to reflector treatments were high in their yield and
yield components compared to the positive response group in the control treatment (without reflectors). The reflector treatments caused a decline in seed yield and its components in the negative response group, whereas an increase in these characters was observed in the positive response group except for seed size. Days to flowering, days to maturity, and oil and protein concentrations did not vary in the absence or presence of reflectors in either genotype group.

Phenotypic correlations were somehow different in the presence or absence of reflectors. Days to flowering was positively correlated to seed size and negatively correlated to number of seeds per pod in the absence of reflectors. No such significant correlations were found in the presence of reflectors. With reflectors, days to maturity was positively correlated with lodging, but not without reflectors. On the other hand, days to maturity was correlated to number of pods per plant only without reflectors. Plant height was positively correlated with seeds per pod and with seed size in the presence and absence of reflectors, respectively. Seed size was negatively correlated with number of seeds per pod, in the absence of reflectors but not in their presence. The use of reflectors did not change the contribution of yield components to seed yield.

Results of the greenhouse experiment conducted under high temperature indicated that supplied nitrogen did not affect significantly any of the soybean traits studied
except the accelerated aging test result. Interaction between supplied nitrogen and genotypes was significant only for plant height, shrivelled seeds, and accelerated aging test. Thus, nitrogen fertilizer was likely not a limiting factor under the excessive high temperatures in this experiment. However, significant variation was found among genotypes grown in the greenhouse where the positive group yielded 20% more than the negative group.

Excessively high temperature in the greenhouse reduced the period to flowering and physiological maturity, yield and yield components, but increased the plant height, lodging and percent of shrivelled seeds compared to field conditions. The reduction in seed size may be related to short period of seed filling caused by high temperature; thus, small seeds or shrivelled seeds developed.

Generally, genotypes responded to high temperature in three different ways: (a) some genotypes showed a high percentage of shrivelled seeds (up to 60%); (b) some genotypes showed a low percentage of shrivelled seeds, but small seed size (weight/seed); and (c) some genotypes produced almost normal seeds compared to that grown in the field.

Orthogonal comparisons between positive and negative response groups (to 1981 reflector treatments) showed that days to flowering, days to maturity, and percentage shrivelled seeds were significantly higher in the negative response group than those in the positive group. In
contrast, seed size, seed yield, and germination and vigor percentages were higher in the positive response group. Plant height, lodging, and pods per plant did not differ significantly. Under field conditions, days to flowering and maturity, plant height, lodging, and standard germination were the only characters that showed a significant difference between genotype groups. These characters were significantly higher in the negative response group except the standard germination.

Phenotypic correlations among agronomic characters studied under high temperature indicated a negative correlation between days to maturity and the number of pods and seed yield, whereas under field conditions days to maturity was positively correlated to plant height only. Lodging was positively correlated to seed weight only in the greenhouse and negative correlations were similar under both conditions.

An analysis of the overall data indicate that selection for heat tolerance and good seed quality in soybeans without sacrificing yield is feasible. Some genotypes with high temperature tolerance were identified as a good source for breeding programs or to grow in relatively high temperature regions.
# Appendix 1. Precipitation and Mean, Maximum, Minimum, and Average Temperature from May through October, 1981 at The Ohio State University Agronomy Farm*

<table>
<thead>
<tr>
<th>Month</th>
<th>Precipitation (cm)</th>
<th>Departure From Normal</th>
<th>Temperature °C</th>
<th>Mean (Max. + Min.)/2</th>
<th>Departure From Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>16.3</td>
<td>-1.1</td>
<td>26.3</td>
<td>2.6</td>
<td>14.5</td>
</tr>
<tr>
<td>June</td>
<td>15.4</td>
<td>-0.2</td>
<td>30.4</td>
<td>10.8</td>
<td>20.7</td>
</tr>
<tr>
<td>July</td>
<td>10.8</td>
<td>1.0</td>
<td>31.8</td>
<td>14.4</td>
<td>23.1</td>
</tr>
<tr>
<td>August</td>
<td>3.9</td>
<td>-6.4</td>
<td>29.1</td>
<td>18.7</td>
<td>23.9</td>
</tr>
<tr>
<td>September</td>
<td>8.5</td>
<td>-0.5</td>
<td>26.8</td>
<td>7.5</td>
<td>17.2</td>
</tr>
<tr>
<td>October</td>
<td>4.5</td>
<td>-3.1</td>
<td>22.9</td>
<td>-1.5</td>
<td>10.7</td>
</tr>
</tbody>
</table>

* Data taken from The Ohio State University Agronomy Farm Monthly Weather Report.
## Appendix 2. Precipitation and Mean, Maximum, Minimum and Average Temperature from May through October, 1981 at OARDC*

<table>
<thead>
<tr>
<th>Month</th>
<th>Precipitation (cm)</th>
<th>Departure From Normal</th>
<th>Temperature °C</th>
<th>Mean (Max. + Min.)/2</th>
<th>Departure From Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>9.2</td>
<td>-0.6</td>
<td>19.3</td>
<td>7.9</td>
<td>13.6</td>
</tr>
<tr>
<td>June</td>
<td>13.5</td>
<td>3.6</td>
<td>25.6</td>
<td>15.1</td>
<td>20.3</td>
</tr>
<tr>
<td>July</td>
<td>8.4</td>
<td>-1.6</td>
<td>26.9</td>
<td>16.7</td>
<td>21.8</td>
</tr>
<tr>
<td>August</td>
<td>5.4</td>
<td>-3.7</td>
<td>28.8</td>
<td>14.7</td>
<td>20.3</td>
</tr>
<tr>
<td>September</td>
<td>9.3</td>
<td>1.4</td>
<td>20.7</td>
<td>11.6</td>
<td>16.1</td>
</tr>
<tr>
<td>October</td>
<td>4.5</td>
<td>-1.4</td>
<td>15.0</td>
<td>3.3</td>
<td>11.0</td>
</tr>
</tbody>
</table>

* Data taken from OARDC from Monthly Weather Report, OARDC, Wooster, Ohio.
Appendix 3. Number of pods for plant segments of soybeans grown with and without reflectors, 1981.

<table>
<thead>
<tr>
<th>Plant Segment</th>
<th>Number of Pods</th>
<th>Without Reflectors</th>
<th>With Reflectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Columbus</td>
<td>Wooster</td>
</tr>
<tr>
<td>Upper</td>
<td></td>
<td>10.9</td>
<td>12.1</td>
</tr>
<tr>
<td>Middle</td>
<td></td>
<td>19.9</td>
<td>22.2</td>
</tr>
<tr>
<td>Lower</td>
<td></td>
<td>14.6</td>
<td>17.2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>45.4</td>
<td>51.5</td>
</tr>
</tbody>
</table>

The reflectors effects were not significant at 0.05 level.
Appendix 4. Number of seeds for plant segments of soybeans grown with and without reflectors, 1981.

<table>
<thead>
<tr>
<th>Plant Segments</th>
<th>Number of Seeds Without Boards</th>
<th>With Boards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>18.46</td>
<td>19.17</td>
</tr>
<tr>
<td>Middle</td>
<td>33.66</td>
<td>31.70</td>
</tr>
<tr>
<td>Lower</td>
<td>24.10</td>
<td>22.34</td>
</tr>
<tr>
<td>Total</td>
<td>76.22</td>
<td>73.20</td>
</tr>
</tbody>
</table>

Reflectors effects were not significant at 0.05 level.
Adam, N.M. 1983. Soybean (Glycine max L. Merr.) Seed quality as affected by planting date, harvesting date, seed position and cultivar. Ph.D. Dissertation, Ohio State University.


Thomison, P.R. 1983. Phomopsis seed infection and seed quality in soybean as influenced by soil moisture fruit load and nutrient accumulation. Ph.D. Dissertation, Ohio State University.


