YIELD AND DEVELOPMENT OF SOYBEANS (Glycine max L.) AS AFFECTED BY IRRIGATION WITH MUNICIPAL WASTEWATER AND WELL WATER

By

Michael J. Cordonnier

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ABSTRACT

YIELD AND DEVELOPMENT OF SOYBEANS (Glycine max L.) AS AFFECTED BY IRRIGATION WITH MUNICIPAL WASTEWATER AND WELL WATER

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Considerable research has demonstrated that soybean (Glycine max (L.) Merr) yields can be increased with supplemental water during the reproductive stage, but very few experiments of this nature have been conducted in Michigan. Additionally, little information is available concerning the use of municipal wastewater as the water source for irrigating soybeans. The objectives of this study were to determine if soybean yields in Michigan could be increased with supplemental irrigation and to investigate the feasibility of using secondarily treated municipal wastewater as the water source. The study was conducted on a Miami silt loam soil (Typic Hapludalfs) in 1979 and 1980. A split plot experimental design with three replications was used with either wastewater, well water or no water assigned to the main plots. Each water treatment was split into eight subplots consisting of two soybean cultivars, Nebsoy and Harcor, each planted in two row spacings, 51 and 76 cm, and two populations, 20 and 32 plants/m of row. The irrigated plots received a total of 9.8 cm of either well water or wastewater as spary irrigation in 1979 and 9.4 cm in 1980. Data were collected for seed yield, agronomic characteristics, dry matter production, apparent photosynthesis and leaf chemical analysis.

Seed yields were significantly different for water treatments in 1979 with 2434, 2580 and 2786 kg/ha for no water, well water and wastewater, respectively. Yields generally increased as plant population increased, with the greatest yield recorded for both cultivars occurring at the highest plant population (645,500 plants/ha). Irrigated plants were 4-5 cm taller, matured 5-6 days later, had larger seeds and lodged slightly more than nonirrigated plants. The apparent photosynthetic rate of Harcor was increased by wastewater irrigation, whereas the rate of Nebsoy was not affected by either water treatment. Results of this experiment indicate that Harcor responds much better than Nebsoy to additional water and to the spatial arrangement of plants. Harcor also appears to have a higher water requirement than Nebsoy. The 1980 growing season was wetter than normal and there was little or no yield response to irrigation.

The two cultivars responded differently to the wastewater, with Harcor exhibiting a positive response and Nebsoy responding negatively for such things as leaf area index, leaf weight and stem weight. Under the conditions of soil, climate and wastewater quality during this experiment, wastewater was generally superior to well water in increasing yields.

To my smiling daughter Vanessa.

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INTRODUCTION

Water is the earth's most abundant compound and yet, on a worldwide scale, a deficit of water is the single most important factor limiting crop yields. Although soybean plants seldom die from lack of water in the major soybean producing regions of the U.S., growth-limiting water stresses within the soil and plant are common and no other single factor limits production so extensively and unpredictably.

The state of Michigan is nearly surrounded by four of the five Great Lakes. Even in the midst of all this water, the lower peninsula of Michigan receives the least amount of precipitation during the growing season of any other state east of the Mississippi River. This lack of precipitation, in conjunction with many sandy soils, has led to large scale irrigation of crop land, predominately in the western portion of the lower peninsula.

Currently, the major crop which receives most of the irrigation is maize, but many of the local farmers are interested in including soybeans in their irrigation rotation. Before they can include soybeans in their irrigation scheme, they need to know if irrigation will increase soybean yields in Michigan. Additional information is also needed concerning timing of irrigation and what cultural practices and cultivars perform best.

To answer these questions, a field experiment was designed with following objectives:

1. To establish if soybean yields in Michigan are increased with supplemental irrigation during the reproductive phase.

2. To determine which row spacing, plant population and cultivars perform best under irrigation.

3. To monitor the effect of irrigation and wastewater on the growth and development of soybeans.

4. An finally, to determine if wastewater from the city of East Lansing, Michigan, could be used as a water source for soybean irrigation without adversely affecting plant growth.

LITERATURE REVIEW

Irrigation has played a strategic role throughout history in the transition from a hunting and food collecting way of life to one based on agricultural food production. In most of the early civilizations of the western hemisphere, as in many nations today, irrigated agriculture provided, and continues to provide, the agrarian basis of society (43).

The modern history of irrigation agriculture in North America began with the cultivation of wheat (*Triticum aestivum* L.), barley (*Hordium vulgare* L.) and olives (*Olea europaea* L.) in the arid western regions of the U.S. Irrigation has grown to such an extent that present agricultural production in many areas of the U.S. relies almost entirely on irrigation as the primary source of water.

The objective of irrigation is to supply the soil with the amount of water required by crop plants to produce optimum yields.

Soil Factors

The soil system acts as a reservoir for water that permits transpiration to continue day by day between periods of rainfall and irrigation. The maximum amount of water that can be stored in the soil is determined by the total volume of the voids or pore spaces. Soil made up of small particles, such as clay, has a large amount of pore space and thus holds more water than a soil made up of large particles, e.g. sand. However, in the plant root zone this quantity may have little significance, since more fundamental importance is the tenacity with which water is held in the soil by adsorptive and capillary forces. This tenacity is measured in terms of the potential energy of the water in the soil usually measured with respect to free water. As the water content of the soil decreases, the potential energy with which the remaining water is held decreases accordingly.

The energy of soil water is related to the amount of water present. No general expression exists relating the water content of all soils to the energy of the water, and there is no unique relationship for any given soil. The most fundamental way to describe the energy of soil water is to give the energy per unit mass of water with free water as the reference level. This water potential is usually negative and expressed in pressure units of bars (10^6 dyne cm^{-2}) or atmospheres (1.013 bars).

A number of different concepts of the availability of soil moisture have been proposed over the years (44,73). Although the relationships may differ, they all fit under the theoretical concept of Gardner (37) which recognizes the importance of the amount of moisture in the soil, the texture of the soil and the atmospheric demand for water. The atmospheric demand is a function of the energy available (solar radiation), the movement of moisture away from the evaporating surface (wind), the dryness of the atmosphere (humidity), and the temperature of the air.

Gardner's radial flow model illustrates that the degree of water potential difference created between the plant roots and the soil depends on the soil water content and the transpiration rate. If transpiration rates are low, the differences are minimal, but if soil moisture is low, the differences are greater in magnitude.

The radial flow model also indicates that there is a limit to the rate at which water can be supplied to an individual plant root and that the extension of plant roots into regions of high soil moisture content increases the rate at which water is supplied to the plant. Reicosky (78) indicated that the largest amount of root growth and water uptake occurred in those regions of a soil column with the highest water potential. His data demonstrate that the soil water flow characteristics, as well as soil water potential, interact to control water absorption by plant roots.

The water that enters the plant must enter the root zone either from above or below and this movement must be considered simultaneously with the movement to individual roots. An important part of soil water movement is the infiltration rate, or water movement into the soil profile.

Parr and Bertrand (70) reviewed the phenomena of water infiltration into soils. They concluded that the infiltration rate depends upon the same factors as the hydraulic conductivity. Some factors that influence the infiltration rate of water are: initial water content, texture of the soil surface, profile characteristics of the soil and organic matter content. The infiltration rate of a soil over a long time cannot be greater than the lowest permeability rate of any layer in the soil profile.

If the irrigation application rate is greater than the inflitration rate of the soil surface, runoff may be a problem. This may be caused by a high percentage of non-water-stable aggregates at the soil surface. Rainfall and irrigation tend to break down these aggregates leading to filling of large pores with fine clay along the surface crust. This limits water and air movement into the profile resulting in an unfavorable air and water relationship for root growth. With a slow infiltration rate, "ponding" may result, and this could lead to increase disease problems in soybeans (48,90) and root damage from restricted oxygen supply.

As mentioned earlier, an important source of water to plants under many conditions is the upward movement from a water table by means of capillary rise. Gardner and Ehlig (38), while working with alfalfa field plots, found that about 20 percent of the upward water flux below 120 cm was in the soil rather than in the plant roots. Ogata et al. (67) seem to offer additional evidence for the resistance of water movement through these lower roots. Therefore, it cannot be assumed that water below the root zone is unavailable.

Other soil conditions such as pH and fertility must also be considered in determining the amount of water that will be available to the plant (96). A suitable pH and high fertility levels will permit an extensive root system to develop provided there are no impervious layers (71), and a large rooting system will allow greater water uptake by the plant.

Plant-Water Relations

Several comprehensive reviews on the physiological responses to water deficits have been published in recent years (7,16,40,86). This review will deal with physiological processes associated with crop productivity and yield.

Water deficits occur as an inevitable consequence of the flow of water along a pathway in which frictional and gravitational potentials have to be overcome. This internal water deficit is influenced by two main factors: (i) the level of soil water potential, and (ii) the diurnal lag of absorption behind transpiration. In turn, each of these factors is influenced by other factors, both environmental and physiological (55).

At the beginning of each day transpiration initially removes water from the leaf surface and the water potential in the plant drops. Absorption commences as soon as potential gradients extend down to and across the soil-root interface. The magnitude of the internal water devicit continues to increase until the rate of absorption equals the rate of transpiration (85).

Growth and Yield

Growth refers to the overall process by which new tissues and organs develop. This depends on the progressive initiation of tissue and organ primordia and on the differentiation and expansion of the component cells (86).

A plant water deficit can cause a complete suspension of primordial initiation without the potential for subsequent development being impaired, as long as the stress is not too severe or too protracted (40). This process is superficially similar to dormancy, in that, upon relief of stress, renewed development occurs. Cell division is also sensitive to stress, resulting in continuing cell division during stress, though at a reduced rate (39), thus providing an opportunity for relative rapid resumption of growth when the stress is removed.

Cell enlargement, the other essential component of growth, is greatly affected by stress. This is usually the first observable symptom of water deficits, and is a main cause of stunting, which is the most common sign of water stress in the field. Meyer and Boyer (64) drew attention to the possibility of equal sensitivity of cell division and enlargement to water stress in soybeans and sorghum.

Work done on maize clearly demonstrates the sensitivity of cell enlargement to water deficits found in some species (13). Leaf enlargement declined rapidly at leaf water potentials below -2 bars and ceased at potentials of -7 to -9 bars. Boyer (13) also found that for soybeans, the rate of change in leaf enlargement was very rapid at leaf water potentials greater than -4 bars. At potentials less than -4 bars the rate of leaf enlargement declined rapidly and approached zero at about -12 bars.

One of the most important consequences of the sensitivity of cell enlargement to water deficits is a reduction in leaf area. This reduction will reduce crop growth rate, particularly during the early growth stages when there is incomplete light interception (7). One of the damaging features of this reduction is the fact that the effect is permanent, and, in the case of a determinate type soybean, there is little flexibility for compensation via an increase in the number of leaves. This reduction in size of the photosynthetic surface has been slown to reduce crop growth rate and ultimately yield, unless leaf area is not limiting net assimilation rate (86).

In most plants root growth diminishes as water stress is imposed (71). Since root interception is one of the mechanisms by which plant nutrients reach the surface of a growing root, reduced root growth, as a result of water stress, may affect the absorption of essential nutrients as suggested by Barbar (5). Both ion diffusion and the transport of ions to the root surface by mass flow appear to be dependent on soil moisture content (20).

Mederski (62) studied the effect of irrigation on the mineral content of soybeans. Compared to stressed, irrigation increased the concentration of all elements except Ca and Mn. Additionally, a 30 percent yield increase was recorded with irrigation.

Whether a reduction in mineral content of the plant has an effect on plant development will depend upon whether the mineral concentration within the plant falls below growth-limiting levels. Mederski (62) points out that reduced mineral concentrations, and its influence on plant growth, depend on the fertility level of the soil. If mineral concentrations within the plant are above optimum, a small decrease may not adversely affect plant development.

Root growth may also be affected by water deficits depending on the plant's physiological stage of growth. In many crops, root growth is retarded or ceases completely during flowering or fruit formation (81). If root growth is reduced, severe water stress may occur under conditions of high evaporative demand. The reduced root activity during the development of the reproductive organs may explain the beneficial effect of irrigation at such times (83). While working with soybeans, Shaw and Laing (83) found that the maximum reduction in yield, due to moisture stress, occurred during the week of pod development and during the bean filling stage. Moisture stress had less effect during flowering, but did reduce yields below those of nonstressed plants.

Photosynthesis and Stomatal Behavior

Since stomata act as regulators for CO_2 exchange, as well as regulators or water loss, water deficits sufficient to close stomata must also depress photosynthesis. The initial reduction in photosynthesis due to an increase in plant or soil moisture stress arises from changes in conductance of CO_2 through the stomata (7).

Decreases in transpiration have been shown to occur concurrently with decreases in net photosynthesis, reflecting the closure of the stomata in response to leaf desiccation (14). Troughton (97) presented additional evidence that stomatal closure was the primary cause of depressed photosynthesis under water limiting conditions. The stomatal conductance of CO_2 in cotton leaves decreased at a relative water content (RWC) of 80 percent, whereas the internal conductance of CO_2 was only reduced at a RWC of 75 percent. A subsequent study (98) showed that internal conductance of CO_2 in cotton was unchanged when the RWC varied between values of 92 to 56 percent. Work done on soybeans (14,60,61) illustrated that internal conductance of CO_2 was unaffected at water deficits much greater than those required to close the stomata.

Soybean photosynthesis is little affected in the range of 90 .to 95 percent RWC (93). Boyer (14) measured photosynthesis in maize and soybeans as a function of water potential. Maize photosynthesis was reduced at potentials as high as -3.5 bars, but soybeans photosynthesis was not reduced until potentials reached -11 bars (about 90 percent RWC). An extensive study conducted in Onio (62), examining the relationship between CO_2 assimilation and leaf water content, revealed that photosynthesis levels were often near zero when the minimum RWC was 70 percent. A minimum of 85 percent RWC depressed photosynthesis 0 to 30 percent.

In some species nonstomatal effects on CO_2 exchange may be equally as sensitive as stomata are to water deficits. While working with sunflowers, Boyer and Potter (17) suggested that changes in the chloroplast activity level probably accounts for the change in photosynthetic activity. Others have reported that leaf desiccation results in inhibition of electron transport and phosphorylation (34,75) as well as carbon dioxide fixation by isolated chloroplasts (74).

A general conclusion then is that photosynthesis declines initially as a result of stomatal closure, but prolonged and severe water stress can lead to depression of chloroplast and enzyme activity and to nonstomatal effects on photosynthesis. This conclusion takes into consideration the involvement of many variables such as differences between species, stages of plant maturity, as well as prior history of the plant.

Respiration

The effect of water deficits on respiration is somewhat difficult to determine due to the difficulty in distinguishing between dark respiration and photorespiration in those species which exhibit the latter, including soybeans.

With regard to dark respiration, recent studies have indicated that it is relatively unaffected by water deficits until the deficit is sufficiently great to close stomata and decrease photosynthesis. Even then, the decrease in respiration is less than that of net photosynthesis (41). Respiration in tomatoes was depressed at leaf potentials below -8 bars, but at -14 bars net photosynthesis was zero whereas the dark respiration was depressed only 30 percent (19). Boyer (13) showed that the dark respiration rate of soybeans and sunflowers decreased steadily when leaf water potentials declined from -8 to -16 bars, but was unchanged at potentials from -16 to -40 bars.

Since substrates for photorespiration arise from products of the photosynthetic pathway, any decrease in photosynthesis must ultimately depress photorespiration (46). Boyer (15) showed that photorespiration was decreased by an increased water deficit. It appears that photorespiration is unaffected by short-term water stress, but ultimately decreases as the substrates for photorespiration are depleted.

Translocation

Although photosynthesis is important, the transport of photosynthetic products within the plant is also essential to yield. Long distance transport of assimilate from the site of assimilation to the point of utilization is affected by the rate of assimilation, the rate of utilization, and the velocity of assimilate movement in the sieve tubes. Any changes in the water status of the sources and sinks may significantly alter patterns of synthesis and utilization of assimilates.

While working with wheat, Wardlaw (99,100) showed that the rate of translocation was reduced when plants were grown under desiccating conditions. This reduction could result from either a reduction in the amount of photosynthate available for transport or from a direct inhibition of the translocation process. He interpreted the results to indicate that the translocation mechanism was relatively unaffected, and that the effects of desiccation on the source and sink accounted for most of the changes in translocations. He suggested that the primary effect of water stress was to reduce sink activity, thus indirectly slowing translocation.

Thaine et al. (92) found that for soybeans, translocation of ^{14}C from leaves to the apex increased when leaves between the source and apex sink were removed. Darkening of a young expanding leaf (sink) reduced movement of ^{14}C assimilate from the leaf below the expanding leaf (94). Additional evidence that sink activity influences the rate of translocation was presented by Thrower (95) who found that movement of ^{14}C downward in the steam from a source leaf was enhanced when the root was deprived of assimilate from other leaves by defoliation.

Consistent with these findings is the work by Asana and Basu (2). They found that translocation of stem reserves compensated for an inhibition of photosynthesis early in the grain-filling period of wheat. Thus, there seems to be no reason to alter the basic conclusion of Wardlaw (99) that reduced translocation under water stress is the result of a reduction in photosynthesis of the source or growth of the sink rather than any direct effect on the conducting system.

Metabolism and Nutritional Quality

Miller (65) pointed out that the bread-baking quality of wheat is affected by the dryness of the growing season. For wheat, the percentage of protein increases during a drought, although total yield decreases. Protein production is inhibited but carbohydrate production is inhibited even more. Work done with tobacco (54) showed that water stress reduces cytokinin activity in xylem exudate and leave. Apparently water stress affects shoot metabolism (protein synthesis in thise case) through the stress-sensitive cytokinin hormones. This leads to speculation that the sensitivity of sink activity to water deficits may be caused by a direct effect of stress on growth-mediating hormones.

Fukui and Ojima (35) studied changes in starch, sugar, total carbohydrate, and nitrogen in soybeans under various soil moisture regimes imposed at either early vegetative, flowering or ripening stages of development. The sugar concentration of leaves and stems increased under deficit moisture, and starch increased under excessive moisture. Nitrogen concentration decreased under both deficit and excessive moisture. Accumulation of carbohydrate in plants was reduced by deficit moisture and increased under excessive moisture, with the greatest effect during flowering.

Soybean Irrigation

Soybean yields depend upon the amount and distribution of rainfall throughout the growing season, with the most critical stage occurring just before flowering and during flowering and pod development. Peters and Johnson (72) in Illinois found that approximately 134 kg/ha of soybeans were produced for each 2.5 cm of water available from 1 July to 20 September. Peak water use rate may be as much as 0.76 cm daily, but this depends on the stage of growth, available soil moisture and weather (101). Thus, in areas of low rainfall, irrigation is a necessary and a profitable practice.

It has been well established that the effects of water stress on growth and yield depend on the degree of stress and the stage of growth at which stress occurs (30,52,80,83,84,93).

Shaw and Laing (83) studied the effects of water stress applied at selected periods during flowering, pod initiation, and bean filling stages. The maximum reduction in yield occurred when plants were stressed during the bean filling stage and the last week of the pod development period. There was significantly less yield reduction when stressed only during flowering. The long flowering period of indeterminate soybean plants enables the plant to escape or survive short periods of moisture stress. Failure of early flowers to set pods due to water stress may be offset by excellent pod set of late flowers if moisture becomes available. They showed that the yield change between stressed and nonstressed plants resulted from differences in the number of pods per plant, number of seeds per pod and individual seed weight. A significant reduction in the number of pods in the lower part of the plant occurred when stressed at the time of flowering at the fourth node down from the uppermost unrolled leaf. The largest decrease in pods in the upper part of the plant occurred when stressed during pod development. The maximum reduction in pod number on a whole-plant basis occurred between late flowering to mid-seed filling. The number of mature seeds per pod showed a significant reduction from the controls when stressed during seed filling, with the difference being due to more immature seeds in pods on stressed plants. Water stress interferred with the pod filling process, resulting in a reduction in the number of seeds filled. The greatest reduction in seed size occurred when stress was imposed during mid-seed filling.

Sionit and Kramer (84) also noted the effect of controlled water stress applied at various stages of soybean development. The stress period was terminated in all the treatments when the leaf water potential reached a maximum of about -23 bars. They reported similar results in that stress applied during pod filling resulted in greater yield reductions than stress applied during flower induction or flowering. Doss et al. (30) also obtained the lowest yield of soybean seeds when they withheld irrigation during late pod filling. Sionit and Kramer (84) found that the smallest numbers of pods and of seeds per plant were produced by the plants subjected to stress during early pod formation. They also found that the seed weight was not affected by the water stress. However, the seeds on plants which were stressed during pod filling were significantly smaller. The percentages of oil and protein in the seeds were not significantly affected by stress at any stage of development. They concluded that water stress is most detrimental when it occurs during pod formation and filling.

Many studies have shown that soybeans respond with increased yields to additions of supplemental water during most years (30,42,59,87,89). The general conclusions have been that (a) moderate water supply produces about the same yield response as a high supply, (b) irrigation during the vegetative growth period is of less importance than during flowering, pod set and pod fill stages, (c) response to irrigation varies with cultivars and (d) plant lodging is frequently a problem when soybeans are irrigated.

Ashley and Ethridge (e), working in Georgia, found that irrigations applied throughout the season and irrigation begun at bloom stage produced higher yields than the unirrigated checks. Beginning irrigation during the pod filling period led to increased yields only during the drier years. Matson (59) conclude that beginning irrigation at bloom stage and ending one month before maturity did not result in greatly reduced yield compared to full season irrigation.

Extensive studies in Arkansas (89) and Mississippi (42) also revealed that irrigation water applied before first bloom had no beneficial effects on yield. Doss and Thurlow (30) found that intermediate irrigation amounts resulted in yields equal to high amounts of irrigation.

In almost all the studies cited in this section the researchers have noted that cultivars exhibit different responses to irrigation. Additionally if irrigation was started during the early vegetative stage or if too much water was applied, severe lodging resulted.

A shortage of moisture during the pod-filling stage reduced yields more than during the flowering stage. Therefore, if limited water is available for irrigation, application during the pod-filling stage should prove most beneficial (79,87).

Wastewater

Land treatment is considered by many as a favorable approach to disposing of the increasing volumns of wastewater. Irrigation, one of the principal methods of land treatment, is used very often to prevent wastewater from being an environmental hazard (25,26,76,88,91).

Irrigation systems, using wastewater, were reported as early as 1881 in Cheyenne, Wyoming, and in 1891 in Fresno, California (76). Effluent has been used successfully on cropland and forests in Europe as well as in the U.S. In Muskegon County, Michigan, 4,500 ha of land are used to grow maize, beans (*Phaseolus vulgaria* L.), wheat, and sudangrass (Sorghum bicolor L.) with wastewater irrigation (22). Wastewater has also been used to irrigate grassland and sugarcane (Saccharum efficinarum L.) in Hawaii (31), arid desert regions of Israel (49) and alfalfa (Medicago sativa L.) hay and pasture in California (24).

In addition to supplying needed water, wastewater can also be a source of plant nutrients for crop plants (10,51,91) with N and P being the main nutrients. Crops that uptake large amounts of nitrogen and phosphorus are desirable to maximize removal of these nutrients from the wastewater.

Day et al. (27,28) reported higher grain yields from cereal grains irrigated with wastewater than from cereal grains irrigated with pump water. The nutritional quality of small grains can also be influenced by wastewater. Day et al. (27) reported that wheat grain grown with wastewater contained more total protein than did grain supplied with well water plus suggested amounts of N, P and K.

While working at the Water Quality Management Facility at Michigan State University, Tesar et al. (91) developed a program in which wastewater could be used the entire growing season. He suggested using a combination of maize, alfalfa and/or orchardgrass (Dactylis glomerata L.) in humid areas such as Michigan. Maize would receive the wastewater irrigation during July and August because of its rapid growth during the hot summer. Alfalfa and orchardgrass would be irrigated in the spring and fall before and after maize's peak need.

Normal city sewage treatment, consisting of a primary sedimentation and secondary biological treatment, will not remove soluble salts.

The salt load of a typical urban effluent can be characterized as containing the following nine elements: sodium, potassium, calcium, magnesium, chlorine, sulfate, silicate, phosphate, and nitrogen (9). If the original source water has a significant amount of salt, then this added salt could become very important when considering effluent for use as irrigation water. Any water having more than 1000 ppm total dissolved solids of inorganic salt will have severe limitations as irrigation water unless a large portion of the cations are calcium (9).

The most common salinity effect is a general stunting of plant growth. As salt concentrations increase above a threshold level, both the growth rate and ultimate size of most plant species progressively decrease. Maas (58) classified soybean plants as moderately salt tolerant. Abel and MacKenzier (1) evaluated six cultivars in the field in soil differing in salinity from 5.0 to 10.2 millimhos/cm. They found that increased salinity caused: (1) increased plant mortality, (2) increased leaf necrosis, (3) reduced green leaf color, (4) decreased dry stem production, (5) decreased seed yield, (6) decreased seed quality, and (7) increased accumulation of chloride in stems and leaves. They also found varietal differences in salt tolerance. Plant mortality occurred in salt sensitive cultivars when the chloride content of stems and leaves reached 15,000 ppm. Bernstein and Ogata (8) found that nodulation of soybeans was strongly suppressed by increased salinity, and that relative yields declined more sharply when plants were dependent on symbiotic nitrogen fixation than when nitrate was supplied. It can be concluded that soybeans can withstand a moderate salinity level, but increasing the salinity results in reduced plant growth and ultimately yield.

The desirable characteristic of wastewater is the additional primary plan nutrients (N, P, K). The concentration of these nutrients during a typical irrigation is low in terms of parts per million, but continued use of such effluent water for irrigation at high rates could add a significant amount of these plant nutrients. Chapman (23) estimated that the nitrogen, phosphorus, and potassium present in 10.3 ha/cm of Madison, Wisconsin, wastewater were the equivalent of 125 kg of a 20-20-10 fertilizer. Therefore, the amount of fertilizer applied as part of the effluent will be a positive factor and must be taken into consideration when planning the fertilizer requirements of crop plants.

MATERIALS AND METHODS

An experiment involving the irrigation of soybeans with municipal wastewater and well water was conducted on the Water Quality Management Facility (WQME) at Michigan State University at East Lansing, Michigan, during the 1979 and 1980 growing seasons.

A one-hectare site with soil classified as a Miami silt loam (Typic Hapludalfs, fine loamy, mixed, mesic) was used during both years. The site had been abandoned for several years and consisted of a mixed sod cover with small tree saplings. Soil samples taken prior to planting in 1979 revealed a pH of 5.5 and P and K levels equaling 30 and 230 kg/ha, respectively, with no fertilizer being applied either year. Prior to planing in 1980, 6.7 metric tons/ha of line were applied raising the pH to 6.1 for the 1980 growing season.

Two weeks before planting in 1979 Roundup (glyphosate) herbicide was applied at 2.5 kg/ha to control existing vegetation. The field was plowed and disked twice followed by pre-plant incorporation of a mixture of 2.2 kg/ha Ambien (chloramben) and 1.1 kg/ha Treflen (trifuralin). The planting date was 22 May in both 1979 and 1980.

A split-plot experimental design with three replications was used with either wastewater, well water or no water assigned to the main plots. Each water treatment was split into eight subplots consisting of two soybean cultivars, Nebsoy and Harcor, each planted in two row spacings and two populations. Nebsoy, a cross between C1432 and C1430, is a short stature indeterminate maturity Group II soybean that has good lodging resistance. Harcor, a cross between Corsoy and OX-383 (Crosoy X Harsoy 63), is a high-yielding normal stature maturity Group II variety which matures about five days later than Nebsoy. These were planted in both 50 and 76 cm rows with either 20 or 32 seeds/m. These treatement combinations resulted in populations of 258,200, 387,300, 430,300 and 645,500 plants/ha for both cultivars. Each plot was eight rows wide and 10 m long.

Stand establishment was less than optimum in 1979 due to cool damp conditions during May and poor seedbed condition, but a good stand was established in 1980. Spot applications of Basagrem (bentazon) and Roundup (glyphosate) herbicides were used to control weeks in addition to hand hoeing.

Irrigation

The two types of water used for irrigation were municipal wastewater from the city of East Lansing, Michigan, and well water.

The secondary treated wastewater was derived from a residential community with no major industrial imputs. There are no heavy metal or organic toxicant problems, with concentrations being very low for all of these constituents. Nitrogen and phosphorus were the principal macro nutrients found in the water with their concentrations being relatively low due to dilution from groundwater entering municipal sewers and a local ban on phosphate detergents in East Lansing. High levels of sodium and chloride were present in the water due to salt in the human diet and the nature of the water use.

The water was pumped directly from the East Lansing sewage treatment plant into lake number one (Figure 1) from which it flows by gravity to lakes two, three and four. The system has the flexibility of obtaining irrigation water from any lake or combination of lakes in any desired ratio. Wastewater for this study was obtained solely from lake number one.

A row of 7.6 cm diameter aluminum pipe was placed on each side of a main plot which contained eight subplots. A rainbird 25A sprinkling head, on top of a 0.6 m riser, was positioned every 9.1 m along the row. Each sprinkling head was allowed to rotate 180^{0}, hence, drift between main plots was kept to a minimum. This pipe arrangement allowed each area of soil to be irrigated by four or five sprinkling heads. The amount of water applied was measured at five randomly selected locations in each replication. Water application rate was approximately 1.0 cm per hour for both wastewater and well water.

In 1979, irrigations were applied on 19 July, 9, 21 August and 4 September for a total of 9.8 cm. The 1980 application dates were 23 July and 5, 15 and 25 August for a total of 9.4 cm. The approximate plant growth stages during the irrigation period for both years were as follows: state R4.0 on 1 August, R5.0 on 15 August and R6.0 on 1 September. Both water types were applied to their respective plots on the same day.

Soil irrometers were placed at 17 and 38 cm depths in various irrigated and nonirrigated plots during mid-June. In a Miami silt loam soil, a reading of 60 centibars would equate to a 50 percent depletion of the available soil moisture. The irrometers were read approximately every three days and this assisted in scheduling irrigations.

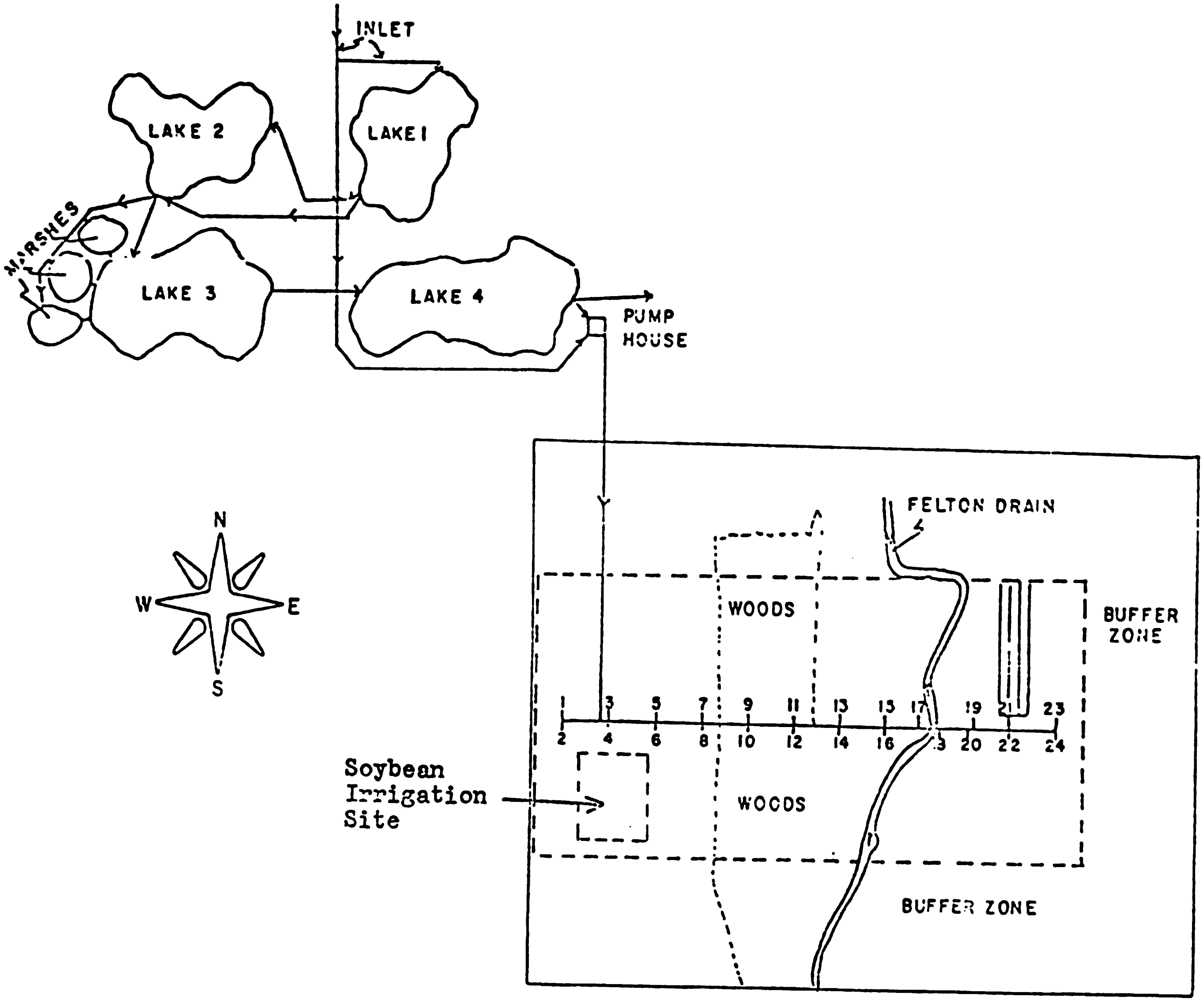

Figure 1. Schmeatic drawing of the Water Quality Management Facility at Michigan State University.

Water samples were collected at midpoint of each irrigation and analyzed for pH, N, P and Cl in 1979 and pH, N, P, K. Cl, Mg. Mn, Fe, Cu, Zn, Na and soluble salts in 1980. Plastic bottles used to collect samples in 1980 were pre-washed with Liqui-Nox phosphate free detergent and then rinsed first in dilute hydrocholoric acid and then distilled water. This rinsing process was not used in 1979.

Soil and Leaf Samples

Soil samples were collected before the initiation of irrigation and seven days after each irrigation. The samples were taken between the two center rows of each plot and all the cores taken from a main plot were combined into one sample which was air dired and analyzed for macro- and micro-nutrients.

A random sample of leaves was taken from the upper canopy of the center four rows of each plot seven days after each irrigation. The four subplots within each main plot that consisted of one cultivar were combined into one sample. The samples were forced-air dried at 32 C for three days then ground in a Whiley Mill to pass a 0.5 mm screen and stored in plastic bags.

The leaf tissue was analyzed for total nitrogen (not including nitrates) using the micro-kjeldahl procedure described by Parkinson and Allen (69). This is based on sulphuric acid and hydrogen peroxide as oxidants with the addition of lithium sulphate, to evaluate the digestion temperature, and selenium as catalyst. The same digest was then analyzed for P, K, Mg, Mn, Na and Ca using a Spectrameties IIIA Atomic Plasma Emission Spectraphotometer.

Plant Sampling

Whole plant samples were taken for dry weight determinations when the plants were at stage R6.5 in 1979 and at R6.0 in 1980. All the plants in one-half meter of two adjacent rows were cut at ground level and separated according to leaves, petioles, stems and pods (including seeds). The samples were then forced-air dried at 32 C until they were at a uniform moisture after which they were weighed. A leaf area index (LAI) was obtained for each subplot by removing all the leaf blades from 25 percent of the plants in each sample and measuring their combined area using a Li Cor leaf area meter.

Agronomic characteristics determined for both years consisted of plant height, number of nodes, internode length, number of branches, pods per branch, lowest pod height, pods per node and total pods per plant. These characteristics were determined for all the plants taken from one-third meter of row from each plot.

Photosynthesis Readings

Photosynthetic readings were conducted in the field on sunny days between 11:00 AM and 1:00 PM EDT when the plants had reached the R6.0 stage during both years. The 1979 samples were taken on 3 September from the upper sunlit leaves and also in the middle portion of the canopy. In 1980 the samples were taken on 29 August and only from the sunlit leaves in the upper canopy due to lodging.

Apparent photosynthesis measurements were conducted using $^{14}CO_2$ and a system similar to that described by Mendoze (63). This method has been suggested for measurement of apparent photosynthetic rates by various researchers (4,18,53). This procedure entailed exposing a

1 cm^2 leaf area to a gaseous mixture containing 336 ppm $^{14}CO_2$, 21 percent O_2, N_2 balance, with a specific activity of 11.0 u Ci/liter for 20 seconds at a flow rate of 125 ml/minute. The photosynthesis chamber consisted of an aluminum pistol grip and two transparent plexiblass jaws which house the photosynthesis chamber.

The exposed area of the leaf, which was outlined with zinc oxide, was then removed using a leaf punch of the same diameter. The leaf disc was placed in a 20 ml scintillation vial containing 1 ml of Beckman BTS-450 digestive liquid (0.5 N quaternary ammonium hydroxide in toluene) and allowed to digest for 48 hours at room temperature. The vials were protected from light during the digestion period. After digestion was complete, the solution was bleached with 2 ml of a saturated solution of benzoyl peroxide in toluene. Nine ml of Beckman Ready-Solve NA (non-aqueous) pre-mised liquid scintillation cocktail were then added to the vial and the samples were counted with a Beckman LS 8100 Liquid Scintillation Counter (Irvine, CA).

Leaf Water Potentials

Leaf water potentials were obtained using a portable pressure bomb (PMS Instrument Company, Corvallis, Oregon) and nitrogen gas as the pressure source. The fourth leaf from the top of a plant growing within the center of the plot was used for all measurements. The petiole was cut with a razor blade and secured in the pressure bomb using molding clay. The pressure was increased in one-half bar increments with the end point pressure being recorded when air bubbles were seen rising from the xylem vessels. The duration of a typical measurement was 5-7 minutes with all measurements being completed before 11:00 AM EDT while the plants were at stage R5.0-6.0.

Harvesting

Prior to harvesting, lodging, maturity and height measurements were taken on each plot. Lodging ratings were from 1 to 5 with 1 equaling all plants upright and 5 equaling all plants procumbent. The plants were considered mature when 95 percent of the pods turned brown and would crack under finger pressure. Plant height was measured in centimeters from the soil surface to the top node on the main stem.

All plots were trimmed to a uniform length before harvesting the six inner rows using a Hege research plot harvester. Harvest dates were 19 October in 1979 and 10 October in 1980. Yields are expressed as kg/ha at 13 percent moisture.

Pest Control

Due to the site's remote location and proximity to non-agricultural land, extra precautions were exercised in controlling pests. The main problem was deer (*Odocileius virginianus*) and woodchucks (*Marmota monax*) eating the emerging plants.

The deer were successfully controlled using a baited electric fence. The fence was placed 75 cm above the soil surface with pieces of aluminum foil, 7.6 X 10.0 cm, secured to the fence very 1.2 m using masking tape. The underside of the foil was coated with a mixture of peanut butter and peanut oil in a 50-50 combination. The foil was then bent downward with the shiny side outward. The deer approached the fence and received a shock whenever they attempted to lick the peanut butter, after which they would not attempt to cross over the fence. This arrangement worked extremely well in keeping deer out of the plot area.

The woodchucks were partially controlled by spraying the perimeter of the plots and field with two repellents, one an ammonia based and the other a capsicin based product. Live traps were also used, but several plots had to be discarded due to excessive foraging.

Ph Study

A separate study was conducted in 1980, subjecting Nebsoy and Harcor to different pH levels in order to try to explain results obtained in 1979. A completely randomized experiment was designed in which each cultivar was grown in pots under one of eight pH regimes ranging from 5.0 to 6.75 in three replications. The entire experiment was conducted outside.

Washed silica sand was used as the growth medium in 40 liter plastic containers. Each container, filled with 50 kg of sand, had a drainage hole cut in the bottom which was covered with cheesecloth. The seeds were germinated in a growth chamber and transplanted into the containers five days after germination on 29 May at a rate of 16 seedlings per container. Inoculum of the proper Rhizobium species was mixed into the sand at the time of planting.

All the containers received 1500 ml of water with a pH of 6.5 as needed for the first four weeks as well as nutrients in the form of Peters Soluble Fertilizer, 15-20-20 formulation, and Peters Trace Elements at recommended amounts. The pH regimes were initiated on 29 June with phosphoric acid or sodium hydroxide added to the water and nutrients to achieve the desired pH. Additional magnesium was added in the form of magnesium sulfate at mid-season to correct for visible nutrient deficiencies seen primarily on plants growing in the lower pH containers. Additional inoculum was applied in mid-July after check plants revealed very little nodulation.

Several times during the growing season, equal number of plants were harvested from each container and dry weights were determined. At maturity, agronomic characteristics similar to those conducted in the field were determined on all the remaining plants.

RESULTS AND DISCUSSION

Precipitation and Soil Moisture

A breakdown of the total amount of rainfall and irrigation received by the plot areas is presented in Table 1. In 1979 the June rainfall was slightly above normal, the amount received in July was less than one-half the normal amount, the rainfall received in August was one and one-half times normal and the month of September received only a trace of precipitation with the total for the growing season being 20 percent below normal. During 1980, rainfall in June and July was approximately normal while rainfall in August and September was twice the normal amount, for a total during the growing season of 46 percent above normal.

The critical aspect of this precipitation data is the amount of rainfall recorded during the month of August which is the main pod filling period for soybeans in Michigan. Various studies (21,30,83) have shown that adequate moisture is critical at this time and substantial yield reductions can result if severe moisture stress is encountered during this period.

The amount of precipitation recorded for August during both years was substantially above normal. In 1979 the months before and after August were relatively dry, whereas in 1980 the rainfall for July was normal and that for September was above normal. In addition to low moisture stress, excessive moisture can also cause problems in soybean

Table 1. Total water received by plot areas during the 1979 and 1980 growing seasons.

	1979		1980		
MONTH	RAINFALL	IRRIGATION	RAINFALL	IRRIGATION	NORMAL RAINFALL*
	cm				
JUNE	10.7	0.0	9.7	0.0	8.8
JULY	3.0	1.9	7.5	2.3	7.2
AUGUST	10.1	5.7	15.3	7.1	7.1
SEPTEMBER	0.1	2.2	11.0	0.0	6.7
TOTAL	23.9	9.8	43.5	9.4	29.8

* 30 year average.

growth. Water-logged soils can result in decreased root efficiency and increased root and stem diseases (48).

Irrometer readings taken during both growing seasons and averaged across the two irrometer depths are presented in Figure 2 and 3. During 1979 only small differences in soil moistures occurred between irrigated and nonirrigated plots until mid-August. Between mid-August and mid-September the nonirrigated plots averaged approximately 60 centibars indicating that about 50 percent of the total field capacity moisture had been removed. The irrigated plots averaged about 15 centibars during the same period reflecting a 20 percent moisture removal.

In 1980 the largest differences in soil moistures between plots occurred during the first three weeks of August when nonirrigated and irrigated plots averaged approximately 60 to 20 centibars, respectively. Heavy rains on 20 August increased the moisture levels of the nonirrigated plots to nearly that of the irrigated. By the end of August a sizeable difference between the soil moistures of the two treatments had once again been established.

The objective of the irrometers was to monitor the soil moisture and thus aid in irrigation scheduling. This objective was met in 1979 during the first three irrigations when the average irrometer reading was approximately 50 centibars at the time of irrigation. The fourth irrigation was applied before the moisture levels of the irrigated plots had been significantly depleted because it was deemed desirable to maintain the high moisture status for the remaining portion of the growing season.

During the 1980 growing season, irrometer readings played a significant role in the scheduling of only the first irrigation. Since

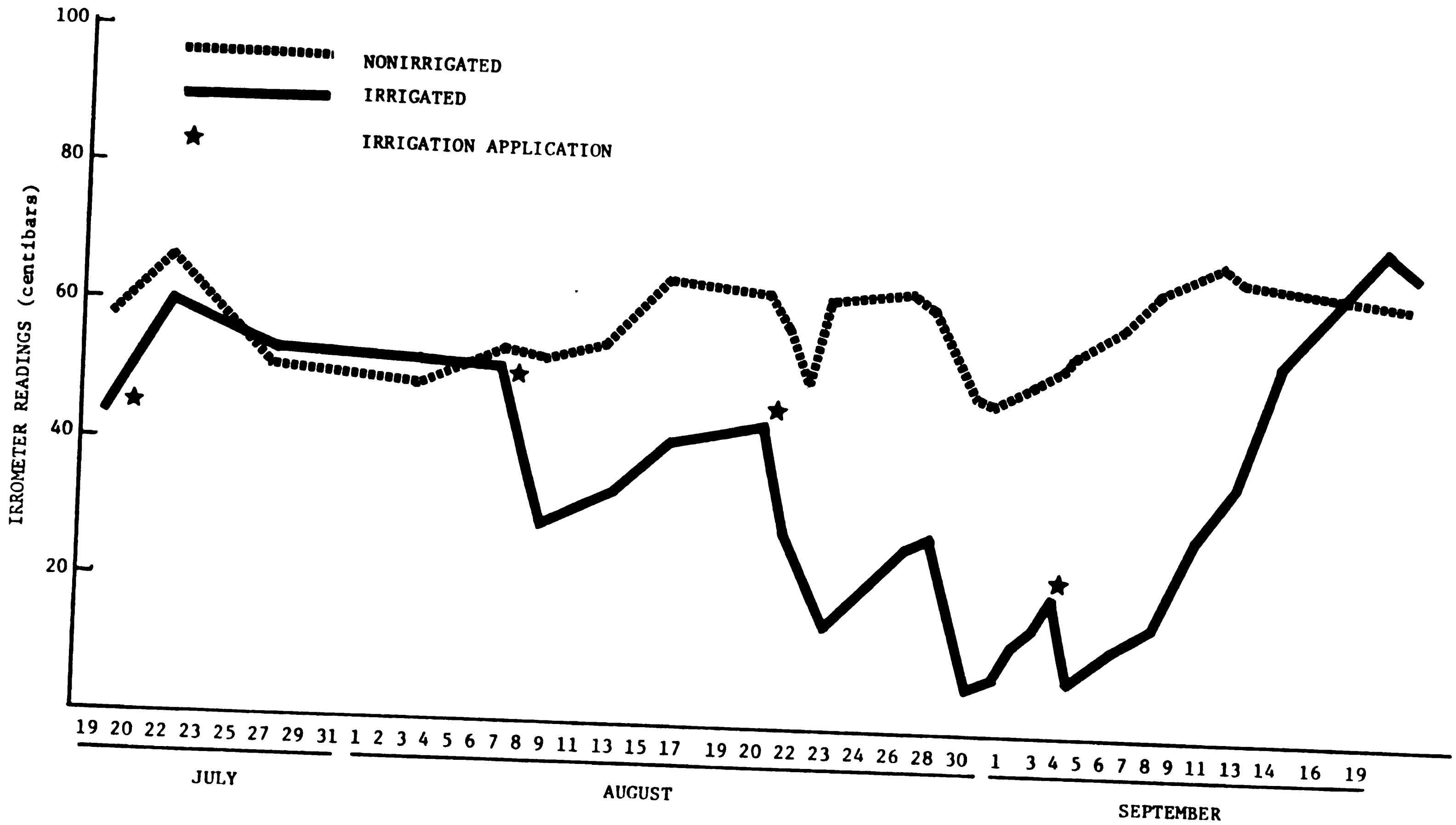

Figure 2. Soil irrometer readings in 1979.

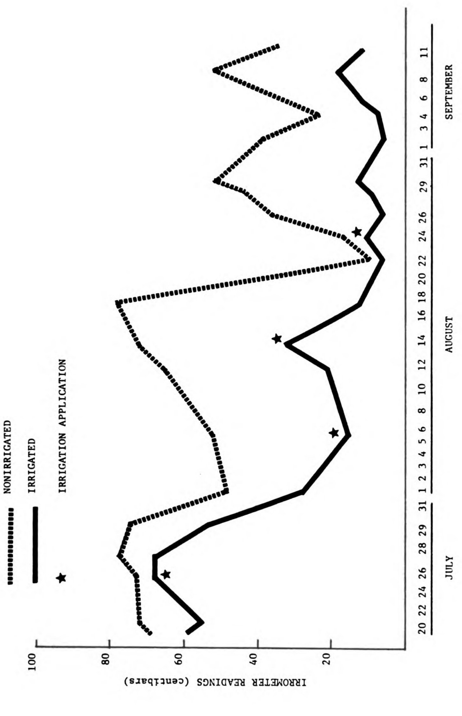

Figure 3. Soil irrometer readings in 1980.

in 1979 the irrigated plots were maintained at high moisture levels during the last month of the growing season, it was desirable to maintain the irrigated plots under similar conditions in 1980. Therefore, the subsequent three irrigations were scheduled with this objective in mind.

There were no differences in irrometer readings between plots irrigated with wastewater and well water and at no time were there any visible signs of wilting in any of the plots during either season.

As mentioned earlier, the secondarily treated wastewater had relatively low concentrations of plant nutrients. A complete breakdown of the chemical composition is presented in Table 2, and the total amount of major plant nutrients applied during irrigations is presented in Table 3. The total amount of nitrogen and phosphorus applied in the wastewater in 1979 was 9.43 and 1.57 kg/ha, respectively. The element applied in the greatest amount was chloride at 95.2 kg/ha. The 1979 water samples were inadvertently discarded before micronutrients and soluble salts could be analyzed. In 1980 the total amount of nitrogen, phosphorus and chloride applied during the four irrigations was 6.95, 2.80 and 93.6 kg/ha, respectively.

One of the major concerns with the use of wastewater for irrigation is the added salts it contains. The type and amount of soluble salts depend on the original water source, type of use the water has undergone, the predominance of self-recharging home water softeners and the type of renovation the water has received. The wastewater used in this experiment had a salinity of 0.86 millimhos/cm which places it in the moderate salinity classification. Given the fact that soybeans are

Table 2. Chemical composition of East Lansing municipal wastewater and well water used to irrigate soybeans.

	1979		1980	
CONSTITUENT	WASTEWATER	WELL WATER	WASTEWATER	WELL WATER
Total Kjeldahl Nitrogen, mg/l	1.14	0.23	2.61	0.40
Nitrate Nitrogen, mg/l	8.58	0.10	3.60	0.01
Nitrite Nitrogen, mg/l	0.34	0.02	0.60	0.02
Ammonia Nitrogen, mg/l	0.05	0.01	0.16	0.01
Ortho Phosphorus, mg/l	1.39	0.003	2.91	0.004
Total Phosphorus, mg/l	1.61	0.82	2.98	0.07
Chloride, mg/l	95.70	10.80	100.50	10.80
Potassium, ppm			10.00	2.00
Calcium, ppm			142.00	92.00
Magnesium, ppm			26.30	29.70
Zinc, ppm			0.00	0.03
Manganese, ppm			0.03	0.03
Copper, ppm			0.00	0.00
Iron, ppm			0.70	0.00
Soluble Salts, MMHO			0.86	0.59
PH			8.00	7.60

Table 3. Total accumulation of nutrients applied during the four irrigations for both the 1979 and 1980 growing seasons.

	1979		1980	
CONSTITUENT	WASTEWATER	WELL WATER	WASTEWATER	WELL WATER
	kg/ha			
Total Kjeldahl Nitrogen	0.86	0.22	2.86	0.61
Nitrate Nitrogen	8.22	0.10	3.40	0.01
Nitrite Nitrogen	0.31	0.02	0.58	0.02
Ammonia Nitrogen	0.04	0.01	0.11	0.01
Ortho Phosphorus	1.38	0.003	2.72	0.003
Total Phosphorus	1.57	0.76	2.80	0.08
Chloride	95.20	11.40	93.50	10.00

moderately salt tolerant (58), and that only approximately 10 cm of wastewater were applied during the growing season, salinity of the water probably was not a major problem.

1979 Results

Yield

The results of each year will be handled separately, since the growing conditions differed greatly. The 1979 results will be considered first. All statistical significance will be at the 5 percent level unless otherwise stated.

Both cultivars exhibited similar patterns of yield increases due to the irrigation treatments (Figure 4). Nebsoy showed a significant yield increase due to the well water irrigation, with wastewater irrigation tending to increase yields above that of the well water. With Harcor, the well water seemed to increase yields above the no water treatment and wastewater significantly increased yields above the other two treatments.

Harcor consistently yielded better than Nebsoy, which was expected, since Harcor has the higher yield potential (Table 4). More importantly though, Harcor seemed to respond much better to irrigation than Nebsoy, as will be discussed later. This might be explained by the fact that Harcor was developed in a more humid region (Ontario, Canada) than Nebsoy (Nebraska) and the supplemental moisture was needed for Harcor to reach its fullest potential. The additional moisture was probably not as necessary for the full development of Nebsoy. Additionally, Harcor responded much more favorably to the wastewater than did Nebsoy. This will be a recurring "theme" throughout this section.

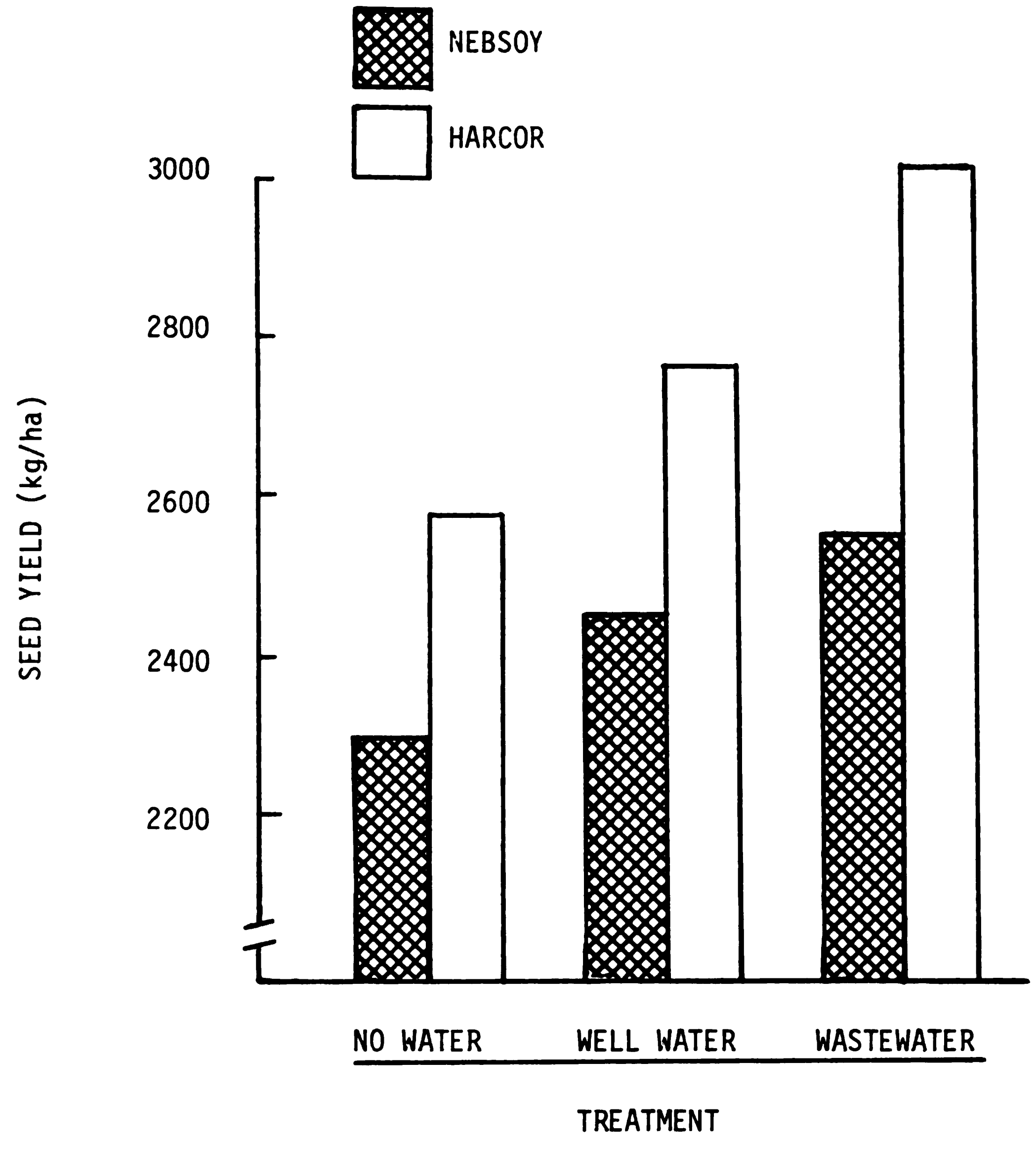

Figure 4. Effect of irrigation and water type on seed yield in 1979 when averaged across row width and plant population.

Table 4. Effect of irrigation, water type, row width and plant population on yield, lodging, plant height, seed size and harvest maturity averaged over other factors in 1979.

TREATMENT	YIELD	LODGING	HEIGHT	SEED SIZE	MATURITY
	kg/ha		cm	g/100	month-day
Water Type					
No Water	2434	1.0	33.2	15.4	9-28
Well Water	2580	1.6	38.1	16.2	10-3
Wastewater	2786	1.7	37.5	16.3	10-4
LSD .05	239	0.5	4.1	0.66	0.97
Cultivar					
Nebsoy	2433	1.2	33.0	15.9	10-2
Harcor	2767	1.7	39.5	16.1	10-1
LSD .05	108	0.26	1.4	NS	0.45
Row Width(cm)					
51	2851	1.6	36.6	16.2	10-1
76	2349	1.3	35.9	15.7	10-1
LSD .05	108	0.26	NS	0.32	NS
Population(plants/m)					
20	2492	1.3	35.7	16.0	10-1
32	2708	1.6	36.8	16.0	10-1
LSD .05	108	0.26	NS	NS	NS

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Plants in the narrow row spacing yielded much better than in the wide row spacing and the high populations were better than low populations. Yields generally increased as the population increased, with the greatest yield recorded for both cultivars occurring at the highest plant population (645,500 plants/ha) as seen in Table 5. It appears that high plant populations are better suited for maximum utilization of the available resources found in high yield environments such as under irrigation.

Even though heavy rainfall occurred during the month of August, precipitation during the growing season was 20 percent below normal and it appears that this deficit was sufficient to suppress the full yield potential of the two cultivars. The last of the four irrigations, which was applied in early September, was at a very critical time. Since only a trace or precipitation was recorded in September, the last irrigation probably helped to extend the pod filling period of the irrigated plants 5-6 days beyond that of the nonirrigated plants.

Harvest maturity for the nonirrigated and irrigated plots was approximately 28 September and 3 October, respectively. The wastewater treated plants matured one day later than plants receiving well water. Row spacing and plant population did not seem to have any effect on maturity. Normally, Harcor would mature approximately five days later than Nebsoy at this latitude, but in 1979 it reached harvest maturity one day after Nebsoy.

The irrigated plants were 4-5 cm taller than the nonirrigated plants, and there were no height differences as a result of water type, row width or population.

Table 5. Effect of irrigation, water type, row width and plant population on yield, lodging, plant height, seed size and harvest maturity in 1979.

				NEBSOY					HARCOR				
WATER TYPE	ROW WIDTH	PLANT POPULATION	(POP. RANK)	YIELD	LODGING	HEIGHT	SEED SIZE	MATURITY	YIELD	LODGING	HEIGHT	SEED SIZE	MATURITY
	cm	plants/m		kg/ha		cm	g/100	month-day	kg/ha		cm	g/100	month-day
No Water	51	20	2	2523	1.0	31.7	16.0	9-29	2776	1.0	34.3	15.3	9-28
		32	4	2620	1.0	31.7	15.6	9-29	2880	1.3	36.0	15.7	9-27
	76	20	1	1962	1.0	30.7	15.3	9-29	2396	1.0	35.3	15.3	9-27
		32	3	2068	1.0	32.0	15.4	9-28	2246	1.0	33.7	15.4	9-27
			Mean	2293	1.0	31.5	15.6	9-29	2575	1.1	34.8	15.4	9-27
Well Water	51	20	2	2298	1.0	31.3	16.7	10-4	2858	2.0	41.7	16.6	10-2
		32	4	2891	1.3	36.7	16.7	10-3	3148	2.5	43.7	16.9	10-2
	76	20	1	2220	1.0	35.0	15.6	10-3	2173	1.3	40.7	15.6	10-2
		32	3	2352	2.0	34.0	15.8	10-3	2704	2.0	41.7	16.2	10-2
			Mean	2440	1.3	34.3	16.2	10-3	2721	2.0	42.0	16.3	10-2
Wastewater	51	20	2	2535	1.0	31.3	15.6	10-4	3135	2.5	42.7	17.0	10-5
		32	4	3286	1.5	34.7	16.4	10-5	3258	2.8	44.0	16.7	10-3
	76	20	1	2131	1.0	31.7	15.9	10-4	2901	1.8	42.0	16.8	10-3
		32	3	2306	1.3	35.3	15.4	10-5	2733	1.3	38.7	16.4	10-2
			Mean	2565	1.2	33.3	15.8	10-5	3007	2.1	41.9	16.7	10-3
		LSD .05 within water type		187	0.45	2.4	0.55	0.77	187	0.45	2.4	0.55	0.77
		LSD .05 between means		209	0.49	2.9	0.61	0.86	209	0.49	2.9	0.61	0.86

Lodging is one of the primary concerns with irrigated soybeans (30,42,59), and severe lodging can result from starting to apply irrigations in the early vegetative stage or applying too much water at any stage. That is the major reason why Nebsoy, a good lodging resistant cultivar, was chosen for this experiment. The irrigation treatements were not started until late July in order to help avoid this lodging problem.

The irrigation treatments resulted in a significant increase in lodging (Tables 4 and 5), but the magnitude of these lodging scores (1.3 for Nebsoy and 2.0 for Harcor) did not seem to cause any problem at harvesting or any apparent yield reductions. As expected, Hebsoy showed good lodging resistance and Harcor exhibited moderate amounts of lodging. The highest lodging scores resulted from Harcor being planted at the highest population and receiving irrigation. In general, the irrigation scheme in 1979 did not result in severe lodging.

Seed size (grams per 100 seeds) increased as a result of irrigation (Table 4). Harcor's seed size responded very well to well water and to the wastewater, whereas Nebsoy responded to well water but not to the wastewater, where it actually declines (Figure 5). In both cultivars the highest plant population had the largest seed size. An inverse relationship between seed size and plant population has been observed (50,56), but the seed weight data reported in this experiment did not agree. Instead of an inverse relationship between seed size and population the largest seed sizes were associated with the highest plant population. Nor do these results support other studies (6,57,77) indicating no relationship between plant population and seed size.

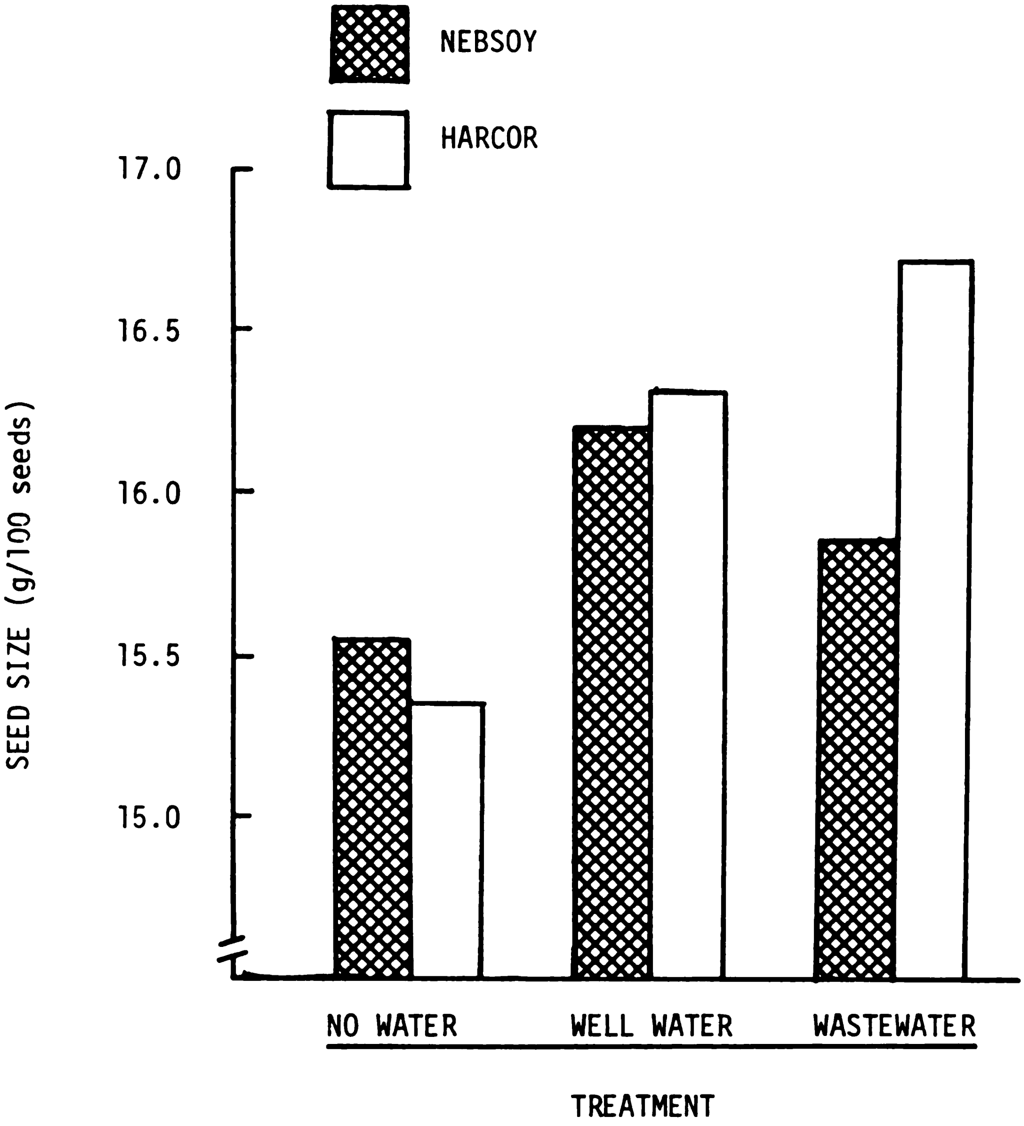

Figure 5. Effect of irrigation and water type on seed size in 1979 when averaged across row width and plant population.

Agronomic Characteristics

Nebsoy tended to have an increased number of nodes per plant when irrigated (Table 6). Wastewater irrigation tended to increase the number of pods per node even though well water had no effect. The combination of these two yield components resulted in a pattern of increasing pods per plant when going from no water to well water to wastewater. This increase in total pods per plant, plus a moderate increase in seed size, account for the yield increases reported for Nebsoy.

Row width and plant population did not significantly affect any of the above mentioned agronomic characteristics in Nebsoy, even though the tendency was for increased agronomic characteristics in wide rows and low populations. The number of branches per plant was not affected by irrigation or row width, but it did increase with low plant population. The height above the soil of the lowest pod seemed to be increased by irrigation and high population.

Harcor also exhibited the pattern of increasing nodes per plant with irrigation and wastewater. The number of pods per node were almost identical for the no water and wastewater treatments and slightly lower for well water. The resulting number of pods per plant was greatest for wastewater, intermediate for no water and lowest for well water. Since total pods per plant does not show a definitive cause for the yield increase exhibited by Harcor, seed size must be considered. Harcor seed sizes were highest, intermediate and lowest for wastewater, well water and no water, respectively. The combination of increased total pods per plant and a larger seed size was the major cause of the yield increase for Harcor.

Table 6. Effect of irrigation, water type, row width and plant population on agronomic characteristics averaged over all other factors in 1979.

	NEBSOY					HARCOR				
TREATMENT	NODE PLANT	PODS PLANT	PODS NODE	LOW POD HEIGHT	BRANCHES PLANT	NODE PLANT	PODS PLANT	PODS NODE	LOW POD HEIGHT	BRANCHES PLANT
				cm					cm	
Water Type										
No Water	13.6	19.4	1.43	9.5	0.8	13.7	29.6	2.12	8.8	1.8
Well Water	14.3	20.1	1.40	11.3	0.9	14.2	26.9	1.89	11.1	1.6
Wastewater	14.1	21.8	1.53	11.7	1.0	14.4	31.6	2.13	10.0	1.6
LSD .05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row Width(cm)										
51	13.9	19.6	1.40	11.4	0.8	13.9	25.6	1.82	11.1	1.4
76	14.0	21.3	1.51	10.3	1.0	14.3	33.1	2.27	8.9	2.0
LSD .05	NS	NS	NS	NS	NS	NS	4.5	0.27	NS	0.3
Population(plants/m)										
20	14.2	22.5	1.57	8.7	1.2	14.7	35.9	2.40	8.1	2.3
32	13.8	18.5	1.33	13.0	0.6	13.5	22.8	1.69	11.9	1.1
LSD .05	NS	NS	NS	2.2	0.3	0.56	4.5	0.27	2.2	0.3

The number of branches per plant was greatest with the wide row spacing and low plant population. Once again the only factor to affect the height of the lowest pod was the population, with higher populations resulting in higher pod heights. The data for agronomic characteristics presented here parallel results of others (6,50,57) who found increased agronomic characteristics as plant density decreased.

Harcor seemed to be more responsive in its agronomic characteristics than Nebsoy to the spatial arrangement of the plants. A look at the growth habits of the two cultivars may help explain this differential response. Nebsoy is a shorter cultivar that exhibits less branching than Harcor and may not have the genetic potential for fully exploiting the advantages of a wider row spacing or lower plant density. Nebsoy was originally selected as a cultivar suitable for use under irrigation because of its short stature and good lodging resistance, and it appears to be better suited to a high population environment. Harcor, on the other hand, is much taller and has nearly twice the number of branches which allows it to more fully utilize the opportunities found in a low density environment.

Dry Matter Production

Leaf dry matter (DM) for Nebsoy was not significantly affected by water type in 1979, even though a definite downward trend resulted when going from no water to wastewater (Figure 6). The decline resulted from a combination of leaf area index (LAI) and specific leaf weight. Wastewater irrigated plants had the lowest LAI with no water and well water being almost equal (Figure 7). Specific leaf weights for the no water, well water and wastewater treatments were 46.0, 41.8 and 43.8 g/m^2

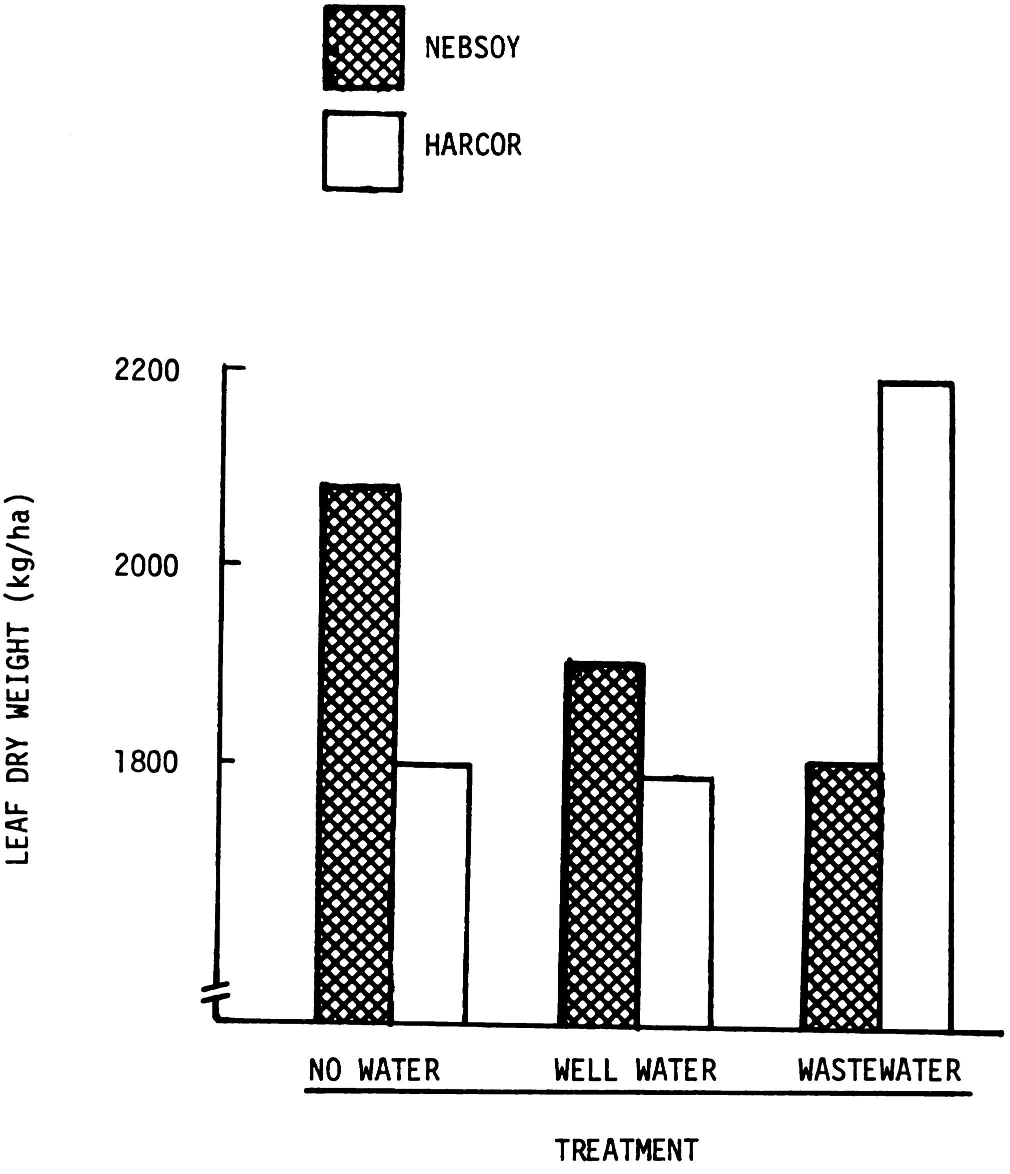

Figure 6. Effect of irrigation and water type on the leaf dry weight accumulation in 1979 averaged across row width and plant population.

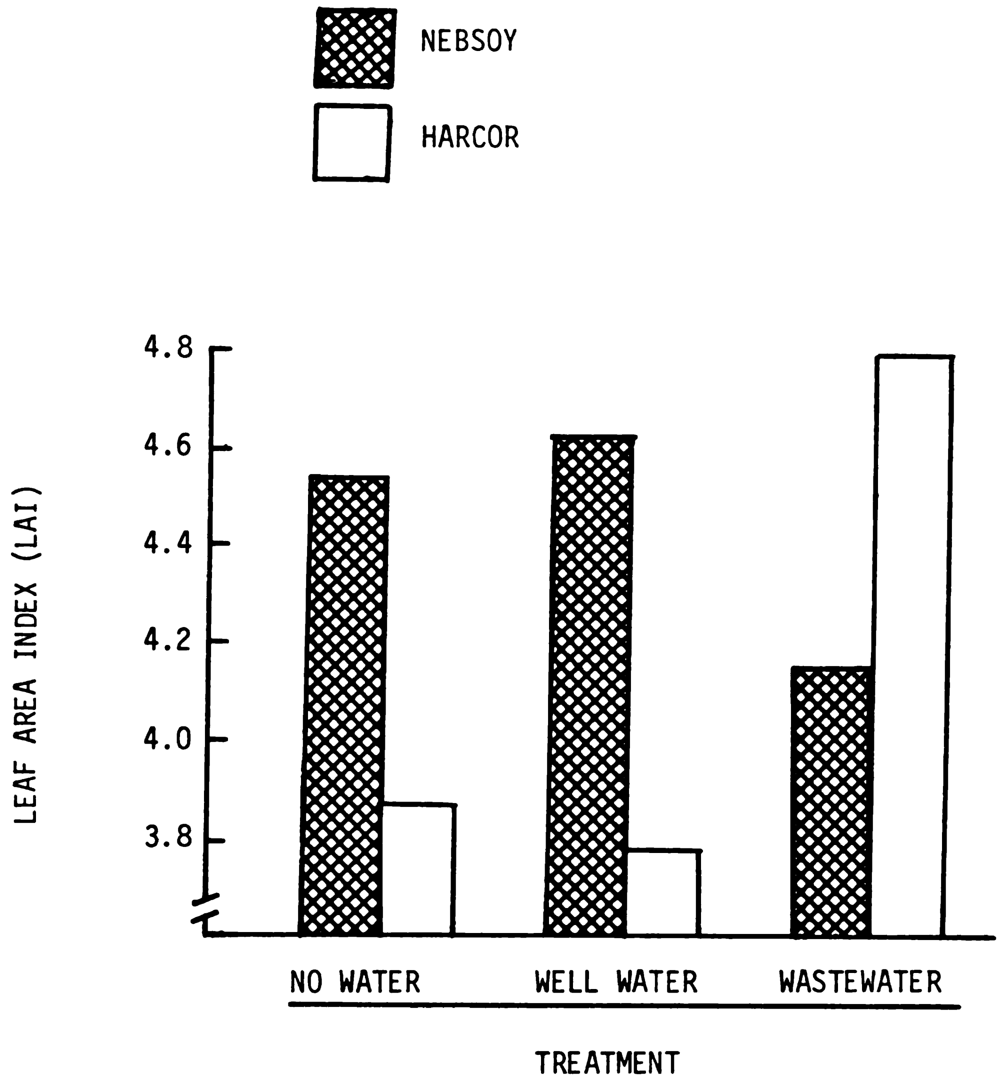

Figure 7. Effect of irrigation and water type on leaf area index in 1979 averaged across row width and plant population.

of leaves, respectively. Thus, the low leaf DM recorded for the wastewater irrigated plants resulted from the lowest LAI and the intermediate specific leaf weight.

Harcor showed a very favorable response to the wastewater which resulted solely from an increase in the LAI. The specific leaf weights differed very little, with no water, well water and wastewater having 45.0, 47.0 and 45.3 g/m^2 of leaves respectively. Nebsoy tended to have higher leaf DM and LAI with the narrow row spacing and high population and Harcor had significant increases with the narrow rows but not with high populations (Tables 7 and 8).

Nebsoy's stem DM nearly paralleled that of its leaf DM with well water having the highest and wastewater the lowest weights (Figure 8). Harcor responded positively to the wastewater, exhibiting a large increase in stem DM. Row width and plant population did not affect the stem DM of Nebsoy, but narrow rows did result in higher stem DM for Harcor. Petiole DM for both varieties followed almost the identical pattern shown by stem DM.

Pod DM, including pod walls plus the enclosed immature seeds, decreased when going from no water to wastewater for Nebsoy. For Harcor, the pod DM was approximately the same with no water and wastewater with well water being the lowest. Narrow rows and high population seemed to increase pod DM for Nebsoy and plants in narrow rows had significantly higher pod DM for Harcor with population having an effect.

As was seen with agronomic characteristics, Nebsoy did not seem to respond very well to the various row spacing and population treatments, with the only response of major significance being its negative dry matter response to wastewater. Harcor's dry matter production responded

Table 7. Effect of irrigation, water type, row width and plant population on dry matter accumulation and leaf area index for Nebsoy soybeans averaged over all other factors in 1979.

	DRY WEIGHTS				
TREATMENT	POD WT.	STEM WT.	LEAF WT.	PETIOLE WT.	LEAF AREA INDEX
	kg/ha				
Water Type					
No Water	3756	1920	2072	742	4.5
Well Water	3302	2128	1921	703	4.6
Wastewater	3074	1810	1795	650	4.1
LSD .05	500	NS	NS	NS	NS
Row Width(cm)					
51	3511	1956	1970	688	4.7
76	3243	1950	1889	709	4.2
LSD .05	NS	NS	NS	NS	NS
Population(plants/m)					
20	3408	1951	1990	704	4.4
32	3346	1955	1869	693	4.5
LSD .05	NS	NS	NS	NS	NS

Table 8. Effect of irrigation, water type, row width and plant population on dry matter accumulation and leaf area index for Harcor soybeans averaged over all other factors in 1979.

	DRY WEIGHTS				
TREATMENT	POD WT.	STEM WT.	LEAF WT.	PETIOLE WT.	LEAF AREA INDEX
	kg/ha				
Water Type					
No Water	4004	1817	1793	762	3.9
Well Water	3488	1904	1785	803	3.8
Wastewater	4120	2375	2175	1014	4.8
LSD .05	500	441	309	149	0.75
Row Width(cm)					
51	4199	2220	2075	929	4.6
76	3542	1843	1764	791	3.7
LSD .05	406	339	263	128	0.6
Population(plants/m)					
20	3740	1998	1878	837	4.1
32	4001	2066	1957	883	4.2
LSD .05	NS	NS	NS	NS	NS

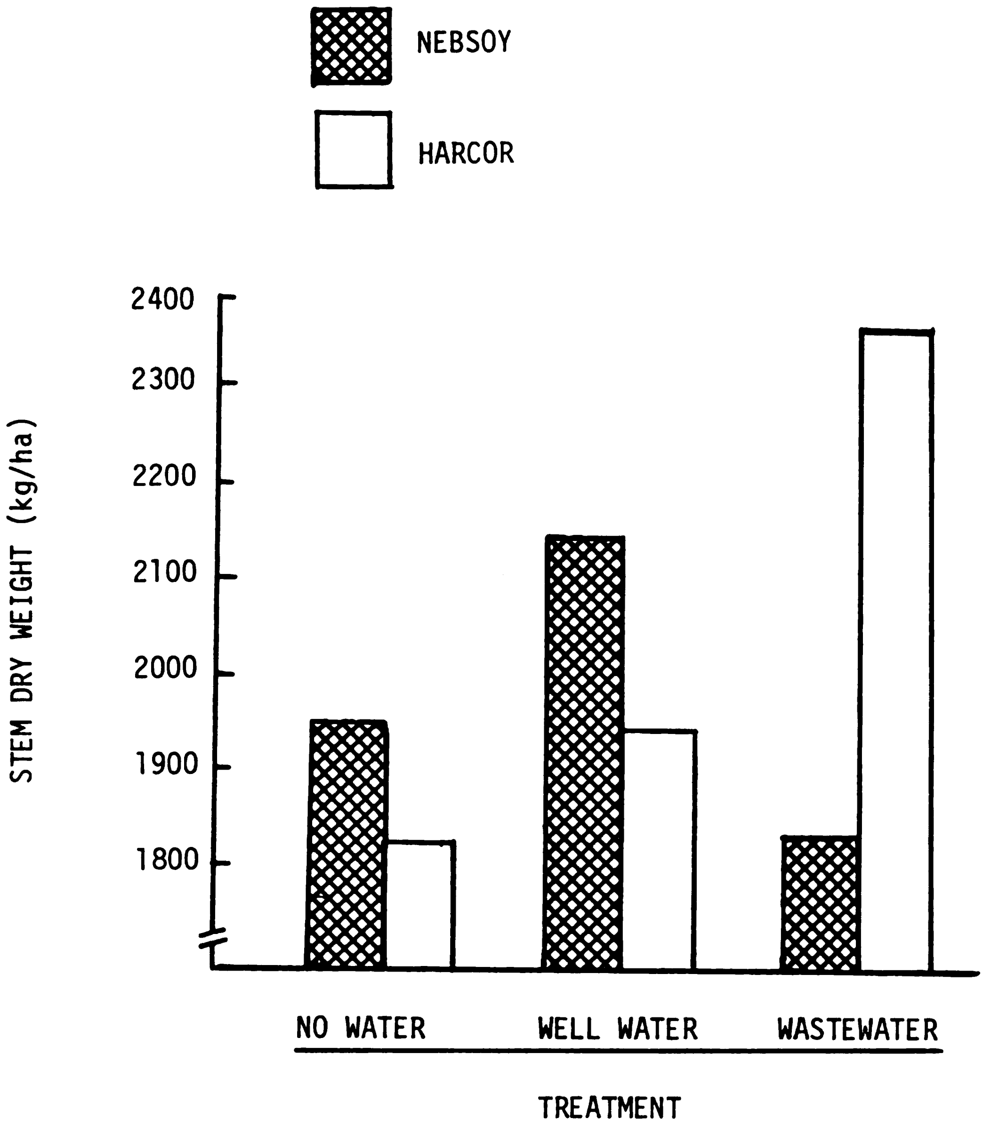

Figure 8. Effect of irrigation and water type on stem dry weight accumulation in 1979 averaged across row width and plant population.

positively to the treatments and especially to wastewater. Other investigators have also shown differences in cultivar response to irrigation (30,32,42).

Generally the additional well water did not have much effect on the dry matter production. This is probably due to the fact that the irrigations were not started until the plants were in the late pod development or early pod fill stages. This confirms the work of Ashley and Ethridge (3) who reported that vegetative development did not differ when irrigation was begun during either the bloom or pod fill reproductive stages.

The positive yield and dry matter response to wastewater exhibited by Harcor could be attributed to the additional nutrients supplied by the water which will be discussed further in the next section. Nebsoy's negative response may be explained by several factors. It has been established that Nebsoy is sensitive to high pH, and high amounts of sodium and also calcium salts (Dr. J. H. Williams, University of Nebraska, personal communication). The wastewater had a pH of approximately 8.0 and it contained large amounts of sodium, and calcium was the major salt. The interaction of these three factors may have contributed to Nebsoy's negative dry matter response.

Leaf Analysis

Both cultivars responded to irrigation with significant increases in their leaves of nitrogen and phosphorus (Table 9). Nebsoy leaves responded to wastewater with slight increases of these elements, whereas Harcor responded to a greater degree to the wastewater. Iron levels in the leaves were significantly higher with the well water treatment, and calcium

Table 9. Analysis of leaves collected from the upper canopy one week after each irrigation averaged over other factors in 1979.

CULTIVAR	WATER TYPE	N	P	K	CA	MG	ZN	MN	CU	FE	CL	NA
		%					ppm					
Nebsoy	No Water	2.99	0.312	1.26	1.5	0.18	67.2	96.8	11.3	107.9	358	366
	Well Water	3.23	0.333	1.27	1.6	0.18	69.8	97.3	11.8	161.9	433	570
	Wastewater	3.27	0.337	1.35	1.4	0.18	65.9	100.3	11.1	99.7	1233	710
	LSD .05	0.20	0.025	NS	NS	NS	NS	NS	NS	21.0	118	320
Harcor	No Water	3.04	0.292	1.04	1.6	0.18	66.1	80.5	8.0	83.0	383	573
	Well Water	3.31	0.328	1.18	1.9	0.20	73.0	88.1	9.6	155.4	433	525
	Wastewater	3.42	0.337	1.18	1.6	0.19	73.0	81.2	10.6	73.1	1483	708
	LSD .05	0.20	0.025	NS	0.25	NS	NS	NS	1.5	21.0	118	NS

tended to be higher. As expected, the levels of chloride were much higher in the wastewater irrigated plants with levels three to four times that of the other treatments. Sodium also tended to be higher in the wastewater irrigated plants. Potassium levels were increased, although not significantly, by irrigation and magnesium, zinc and manganese did not seem to be affected by either irrigation or wastewater.

The levels of N, P, K and Mg declined as the sampling progressed later into the growing season. This is consistent with the results of other investigators (12,45,47) who have found that the vegetative tissue serves as a reservoir for mineral nutrients and that minerals are translocated out of the vegetative tissue to the seed during the pod-filling period. The beneficial effects of wastewater seems to be the addition of plant nutrients during a time when these same minerals are being translocated out of the vegetative tissues. These additional nutrients may help to minimize the impact of this depletion process and thereby delay senescence and the resulting decreases in leaf photosynthesis (36).

The levels of Fe, Mn, Zn and Ca generally increased with later sample times, with the level of Fe and Mn in the last sample being approximately twice that of any previous sample.

Photosynthesis and Leaf Water Potentials

The photosynthetic "system" of Nebsoy did not seem to be affected by irrigation or wastewater (Figure 9). Harcor, in addition to having a much higher inherent photosynthetic rate, had a large rate increase as a result of wastewater irrigation even though not significant. The mid-portion of the canopy exhibited a similar pattern and neither row spacing or plant population had any effect on the photosynthetic rate.

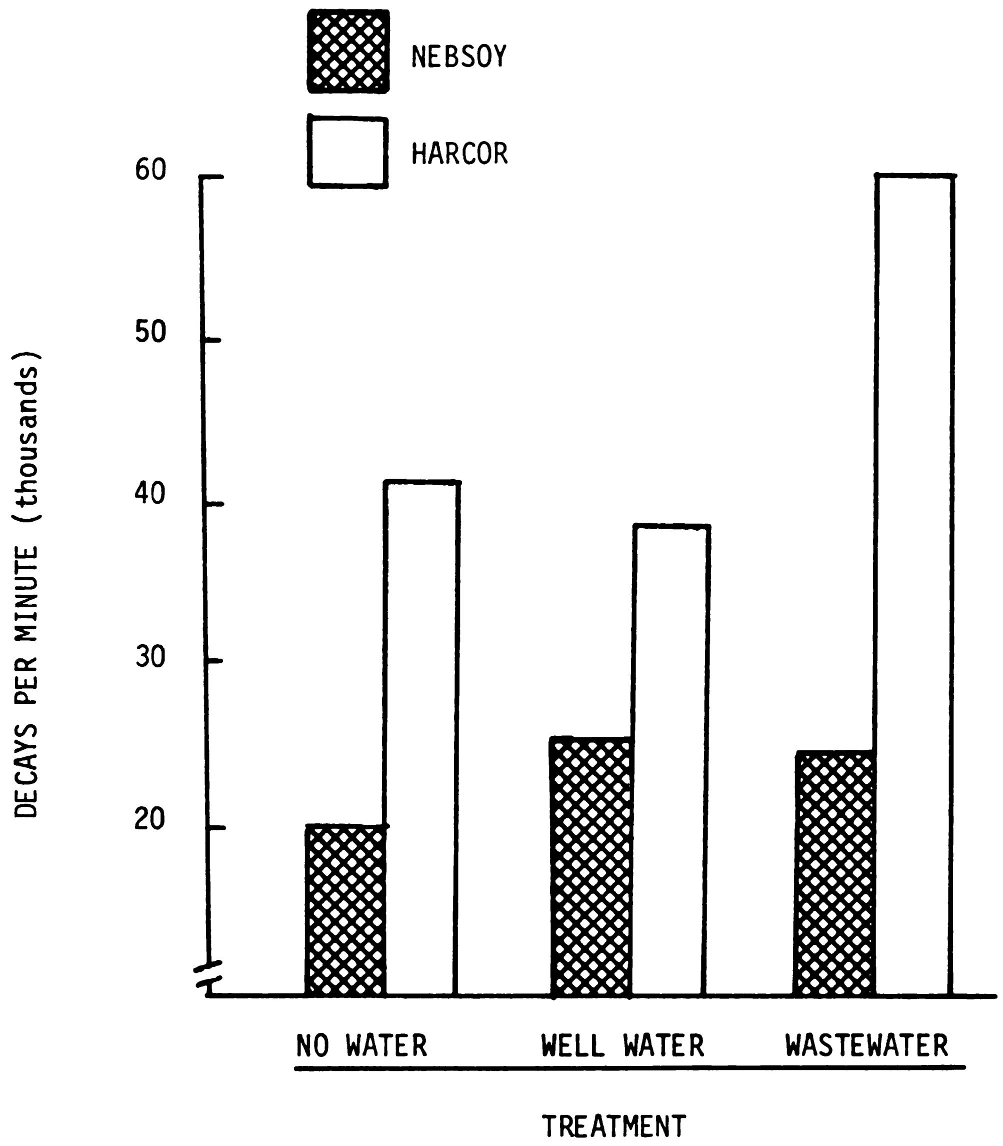

Figure 9. Apparent photosynthesis as affected by irrigation and water type averaged across row width and plant population in 1979.

Boyer (14) and Shaw and Laing (83) determined that the photosynthetic rate of soybeans is little affected until the leaf water potentials reach -11 bars. On the day of the photosynthetic readings the nonirrigated plants averaged approximately -10 bars (Table 10). Therefore, the water deficit experienced by the nonirrigated plants should not have been severe enough to cause photosynthetic reductions, and, likewise, the additional moisture received by the irrigated plants should not have been sufficient to cause photosynthetic increases. Therefore, the increased photosynthetic rate exhibited by Harcor could be due to the increased levels of elements found in the leaves of the wastewater irrigated plants. A decline in the photosynthetic rate of soybeans has been associated with a decline in leaf elements (68) and, in a review on the influence of mineral nutrition on photosynthesis (66), it was suggested that N deficiency was more detrimental than P or K deficiency. It would be a logical assumption then, that increasing the level of nutrients in the leaves during podfilling could result in increased photosynthetic rates. This is the basic idea behind foliar fertilization of soybeans, which itself has showed very mixed results (11,36).

Boote (10) found that increasing the levels of N, P and K in soybean leaves by 6, 21 and 43 percent respectively, with foliar fertilization at the R5.5 growth stage, only slightly increased photosynthesis just prior to leaf abscision. In my study, the levels of N, P and K in the wastewater and wellwater irrigated plants were increased 9, 8 and 7 percent and 8, 7 and 1 percent respectively, above the levels found in the nonirrigated plants for Nebsoy. For Harcor, the increases were 12, 15, 13 percent and 9, 12, 13 percent, respectively. These increases in N, P and K were

Table 10. Effect of irrigation on leaf water potentials during the 1979 and 1980 growing seasons averaged over cultivars, row spacing and plant population.

	1979	
DATE	IRRIGATED	NONIRRIGATED
	——— bars ———	
22 August	6.4	6.2
29 August	5.7	7.6
5 September	8.0	11.7
	1980	
28 August	8.0	8.7

smaller than those reported by Boote and they probably were not sufficient enough to cause the photosynthetic increase.

Another possible explanation for this increase in the photosynthetic rate may be the large increase in the concentration of chlorine found in the wastewater irrigated plants, 240 percent for Nebsoy and 287 percent for Harcor compared to nonirrigated plants. Since chlorine has been shown to enhance photosynthesis, it could be possible that these high concentrations of chlorine resulted in the photosynthetic increases. If this is the case, the question remains as to why only one cultivar responded. Since Nebsoy is the cultivar that did not respond, it is possible that the antagonistic components of the wastewater negated the effect of the chlorine.

Soil Analysis

Soil samples were taken one week after each irrigation, and the zero sample times are samples taken prior to the initiation of the irrigation. The additional water applied with the irrigation treatments resulted in increased leaching which tended to lower the soil pH. The pH seemed to be lowered even further with the wastewater, and this may be due to the additional soluble salts found in the water (Table 11). The magnitude of the pH depression was not very large, but it does take on added importance if the pH of the field is near the lower limit for soybeans, which it was in this case.

Recounting the amount of nutrients applied in the irrigations, it is not surprising to find that none of the major plant nutrients showed any significant increases in the soil. Chlorine, which was the element applied in the largest amount, was significantly increased in the soil under the wastewater treatment.

Table 11. Nutrient element contents (ppm) of soil samples taken one week after each irrigation in 1979.

WATER TYPE	SAMPLE TIME	CONSTITUENT									
		PH	P	K	CA	MG	ZN	MN	CU	FE	CL
		ppm									
No Water	0	5.5	30.0	189	1367	129	1.67	8.7	1.00	16.0	12.6
	1	5.5	32.0	221	1520	127	1.00	13.0	1.67	20.0	12.6
	2	5.7	40.3	231	1622	157	1.67	12.0	1.67	21.3	5.6
	3	5.5	24.7	227	1733	190	1.67	20.0	1.67	18.7	6.6
	4	5.5	47.3	253	1493	155	1.67	14.7	1.00	30.7	4.2
	Mean	5.54	34.9	224	1547	151	1.53	13.7	1.40	21.3	8.3
Well Water	0	5.4	21.7	219	1533	177	2.00	13.7	1.33	17.3	15.9
	1	5.4	23.7	253	1544	181	1.67	18.3	2.33	22.7	15.9
	2	5.6	25.7	223	1651	197	1.67	14.3	1.67	21.3	9.3
	3	5.5	35.0	200	1551	198	1.67	15.0	1.67	22.7	6.4
	4	5.3	25.7	221	1564	193	1.67	16.7	1.00	30.7	5.1
	Mean	5.44	26.3	223	1569	189	1.73	15.6	1.60	22.9	10.5
Wastewater	0	5.5	37.7	211	1233	161	1.67	10.0	1.33	13.3	18.3
	1	5.5	33.0	229	1209	148	1.00	11.7	1.67	18.7	18.3
	2	5.3	42.3	231	1209	179	1.33	11.3	1.33	20.0	14.2
	3	5.3	35.0	221	1296	182	2.33	15.3	1.33	20.0	24.4
	4	5.3	38.3	218	1209	182	1.33	13.3	1.00	28.0	25.2
	Mean	5.36	37.3	222	1231	170	1.53	12.3	1.33	20.0	20.1
LSD .05 between means		NS	NS	NS	NS	NS	NS	NS	NS	NS	4.8

At the fourth sample time, iron levels were nearly 50 percent above those of the other sample times. The levels of Mg, Mn and Ca also tended to increase with later sampling. These are some of the same elements that were also found in higher amounts in the later leaf analysis.

1980 Results

Yield

Nebsoy's yields were lowered under the irrigation treatments, with only well water resulting in a significant decrease (Table 12). Plants in narrow rows tended to yield higher than those in wide rows. Plant population had no effect on yield. Harcor also had its lowest yield with well water but the wastewater did slightly better than the no water treatment. As in 1979, Harcor had significant yield increases with narrow rows and high plant populations.

Precipitation during the 1980 growing season was 46 percent above normal. This, coupled with the additional irrigation, seems to have resulted in excessive moisture. The soil may have become water logged, resulting in reduced root efficiency and poorer plant performance.

Two interesting facts, though, emerge from this yield data. First, the cultivar that may have a lower water requirement, Nebsoy, had the most adverse reaction to the supplemental water. Harcor, which may normally require more water, did not respond as adversely. Secondly, even under these high moisture conditions, the wastewater irrigated plants tended to yield more than the well water for both cultivars.

Unlike 1979, there were no maturity differences due to irrigation. Maturity of Harcor plants was significantly delayed when planted in the

Table 12. Effect of irrigation, water type, row width and plant population on yield, lodging, plant height, seed size and harvest maturity for two cultivats in 1980.

	NEBSOY					HARCOR				
TREATMENT	YIELD	LODGING	HEIGHT	SEED SIZE	MATURITY	YIELD	LODGING	HEIGHT	SEED SIZE	MATURITY
	kg/ha		cm	g/100	month-day	kg/ha		cm	g/100	month-day
Water Type										
No Water	3165	1.2	33.9	16.8	9-30	3449	2.5	39.7	17.4	10-6
Well Water	2904	1.5	35.3	18.5	9-30	3343	2.4	39.3	17.2	10-5
Wastewater	3063	1.4	36.4	18.2	9-29	3482	2.5	38.9	17.0	10-6
LSD .05	233	NS	1.9	NS	NS	NS	NS	NS	NS	NS
Row Width (cm)										
51	3118	1.4	35.2	18.3	9-30	3513	2.7	39.1	17.4	10-7
76	2971	1.4	35.2	17.3	9-30	3336	2.3	39.5	17.0	10-4
LSD .05	NS	NS	NS	NS	NS	167	0.28	NS	NS	2.5
Population (plants/m)										
20	3020	1.4	35.5	18.3	9-30	3334	2.3	39.1	17.1	10-5
32	3068	1.4	35.2	17.3	9-30	3514	2.6	39.6	17.3	10-6
LSD .05	NS	NS	NS	NS	NS	167	0.28	NS	NS	NS

narrow rows, and this may have been due to increased lodging. Even with excessive moisture, Nebsoy's lodging scores did not exceed 1.5 and row spacing and population had no effect on lodging for this cultivar. The taller Harcor exhibited more lodging which was significantly increased with narrow rows and high plant populations.

Nebsoy's height was significantly increased by the wastewater, and its seed size seemed to be increased by irrigation, although not significantly. None of the other treatments affected height or seed size of either variety. It appears that many of the results observed in 1979 were negated by the excessive moisture of 1980. Other researchers (21,82) have found similar lack of significant plant responses to irrigation during wetter than normal seasons or when over irrigating.

Agronomic Characteristics

Agronomic characteristics were not affected as much by irrigation as by row spacing and population. In fact, no significant results were obtained for any water treatment (Table 13).

Nebsoy responded more to the spatial arrangements in 1980 than in 1979. The wider rows and lower populations caused increased numbers of nodes per plant, pods per node and pods per plant. Harcor showed similar results for the various treatments.

As in 1979, Harcor had approximately twice the number of branches compared to Nebsoy, and in both cultivars the number of branches increased with wide rows and low populations. The lowest pod height of Nebsoy increased with narrow rows and high population, but it was not affected in Harcor.

Table 13. Effect of irrigation, water type, row width and plant population on agronomic characteristics averaged over other factors in 1980.

	NEBSOY					HARCOR				
TREATMENT	NODES PLANT	PODS PLANT	PODS NODE	LOW POD HIEGHT	BRANCHES PLANT	NODES PLANT	PODS PLANT	PODS NODE	LOW POD HEIGHT	BRANCHES PLANT
				cm					cm	
Water Type										
No Water	14.1	26.6	1.9	7.2	0.8	13.6	33.6	2.5	8.8	1.9
Well Water	14.0	27.0	1.9	7.9	0.9	13.1	30.9	2.3	10.0	1.8
Wastewater	14.4	29.7	2.0	6.4	0.9	13.3	30.9	2.3	8.3	1.9
LSD .05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row Width(cm)										
51	13.7	23.2	1.7	8.7	0.7	13.5	30.2	2.2	8.6	1.7
76	14.6	32.3	2.2	5.7	1.1	13.2	33.4	2.5	9.4	2.1
LSD .05	NS	5.5	0.3	1.5	NS	NS	NS	0.3	NS	NS
Population (plants/m)										
20	14.8	32.4	2.2	6.4	1.3	13.6	35.6	2.6	8.3	2.2
32	13.5	23.1	1.7	7.9	0.4	13.1	27.9	2.1	9.7	1.6
LSD .05	1.0	5.5	0.3	1.5	0.5	NS	5.5	0.3	NS	0.5

Dry Matter Production

For Nebsoy, the wastewater treatment resulted in the greatest production of stem DM, leaf DM and petiole DM with not much difference between the well water and no water treatments (Table 14). All these also tended to be higher in narrow rows and low populations. Pod DM of Nebsoy was about the same for no water and wastewater with well water being the lowest and row widths and population did not have any effect. The highest LAI was recorded for the well water treatment.

Harcor exhibited its highest levels of dry weights and LAI under the wastewater treatment, although the differences were insignificant. Generally, the narrow rows and lower populations had the highest levels of these parameters.

Even though few of the dry weights were increased, the general pattern of dry weight production and how it was affected by the treatments, is similar to reports of other irrigation experiments performed during wetter than normal years (82). Scott (82) reported that 6 cm of water applied during two irrigations on a silt loam soil resulted in significant dry weight increases late in the growing season even though it was a very wet year. The results reported herein agree with those of Scott (82) in that the increases in dry weights were not translated into increased seed yield during wet years. Nebsoy's performance under the wastewater treatment was different in 1980 compared to 1979. In 1979 Nebsoy's dry matter production was adversely affected by wastewater, whereas in 1980 it responded favorably. One possible explanation for this reaction is the fact that the pH of the field in 1979 was approximately 5.5 and the wastewater lowered it even further to 5.3, which may be near Nebsoy's lowest tolerance

Table 14. Effect of irrigation, water type, row width and plant population on dry matter accumulation and leaf area index (LAI) for two soybean cultivars in 1980.

	NEBSOY					HARCOR				
TREATMENTS	POD WT.	STEM WT.	LEAF WT.	PETIOLE WT.	LAI	POD WT.	STEM WT.	LEAF WT.	PETIOLE WT.	LAI
	kg/ha					kg/ha				
Water Type										
No Water	2405	1510	1550	622	2.8	1841	1689	1598	792	2.9
Well Water	1909	1569	1522	602	3.7	1928	1815	1671	782	3.2
Wastewater	2382	1829	1674	728	3.3	2418	1954	1740	899	3.5
LSD .05	NS	NS	NS	NS	0.77	NS	NS	NS	NS	NS
Row Width(cm)										
51	2219	1718	1584	674	3.2	2023	1930	1683	884	3.4
76	2246	1553	1581	626	3.3	2102	1709	1656	765	2.9
LSD .05	NS	NS	NS	NS	NS	NS	NS	NS	114	NS
Population (plants/m)										
20	2162	1662	1642	667	3.2	2302	1898	1774	839	3.3
32	2094	1609	1522	634	3.3	2031	1741	1566	810	3.1
LSD .05	NS	NS	NS	NS	NS	NS	NS	190	NS	NS

level. In 1980 the field was limed and the pH stayed around 6.0, thus avoiding this lower limit.

Leaf Analyses

In the leaves from Nebsoy plants, iron was the only element whose amounts were significantly affected by the water type (Table 15). The well water treated plants had iron levels nearly twice those of the other treatments and the levels increased as the sample time progressed. This is the same pattern exhibited in 1979. The only other element that showed a tendency to increase under irrigation was phosphorus.

Harcor plants seemed to accumulate more nutrient elements in their leaves than Nebsoy plants under both clean water and wastewater irrigations. Nitrogen and phosphorus had significant increases with their highest levels resulting from well water and wastewater, respectively.

Chloride levels were not affected by the wastewater treatment, whereas in 1979 chloride levels were four times higher in the wastewater irrigated plants compared to the other two treatments. This may be due to the fact that the same site was used both years, and residual amounts of the chloride applied in 1979 (95 kg/ha) may have been taken up by plants that were in the non-wastewater treatments in 1980. Whenever the irrigation was turned off in 1979, the remaining water in the pipes leaked out to the pipe joints, forming small pools, and some of the high chloride levels in the non-wastewater treatments in 1980 may have been situated on the site of these pools. Similar reasoning might also be used to explain the non-significance of the sodium levels. Another possible explanation may be that the excessive rainfall recorded in August 1980 (15.3 cm) may have carried these elements below the rooting zone of the plants.

Table 15. Analysis of leaves collected from the upper canopy one week after each irrigation averaged over other factors in 1980.

		CONSTITUENT								
CULTIVAR	WATER TYPE	N	P	MG	ZN	MN	CU	FE	CL	NA
		%			ppm					
Nebsoy	No Water	5.45	0.338	0.20	44.9	84.8	10.1	89.3	284	304
	Well Water	5.35	0.354	0.20	42.7	75.6	10.0	147.3	217	303
	Wastewater	5.44	0.353	0.19	43.6	77.5	10.8	87.8	263	304
	LSD .05	NS	NS	NS	NS	NS	NS	13.6	NS	NS
Harcor	No Water	5.42	0.344	0.21	58.8	88.8	9.5	90.0	205	312
	Well Water	5.94	0.365	0.22	51.4	74.3	9.3	161.4	221	301
	Wastewater	5.69	0.377	0.21	60.1	93.0	9.8	84.6	235	305
	LSD .05	0.49	0.023	NS	7.5	16.8	NS	13.6	NS	NS

Once again the cultivars responded in a similar fashion as they did in 1979. Harcor seems to respond much better to the irrigation than Nebsoy with increased levels of plant nutrients in the leaves. Major nutrient levels in the leaves were generally higher in 1980 compared to 1979. This may have been due to the higher pH levels in 1980 and the greater precipitation which enabled more extensive root growth and mineral uptake.

Photosynthesis and Leaf Water Potentials

Photosynthetic readings taken on 29 August 1980 revealed rates of 56,700 and 54,700 dpm for irrigated and nonirrigated plants, respectively. There was no difference in photosynthetic rates between well water and wastewater irrigated plants. Leaf water potentials taken on the previous day were 8.0 and 8.7 bars for irrigated and nonirrigated plants, respectively. The leaf water potential readings indicate that both irrigated and nonirrigated plants were well below the stress level of -11 bars, above which the photosynthetic rate begins to drop (14). Harcor's photosynthetic rate was slightly above that of Nebsoy and neither row spacing nor plant population had an effect on the photosynthetic rate.

Only during a brief one-week period in early August were the nonirrigated plants approaching a stress situation based on soil irrometer readings (Figure 4). Heavy rains in mid-August tended to equalize the soil moisture levels of both irrigated and nonirrigated plots. This abundant supply of moisture throughout most of the reproductive period is the primary cause of the lack of response to irrigation found in 1980.

Soil Analyses

There were no significant differences for any of the elements on which analyses were performed except chloride (Table 16). Although most of the elements were found in small quantities in the irrigation water, not enough water was added to make any significant change in the levels found in the soil.

Chloride was added in the largest amount (93.5 kg/ha) and the soil in the wastewater treated plots had significantly higher levels of chloride. There was a tendency for increased soluble salt levels (mmho) in the wastewater irrigated soil.

pH Study

This experiment was set up to explain the positive-negative response to wastewater found in 1979. The objective was to test the hypothesis that pH has a significant influence on dry matter production of soybeans.

The general trend was that the most dry matter was produced at the mid-pH range (5.75-6.25), although these trends were not significant. The yields, as grams per container, significantly increased as the pH increased up to pH 6.5, after which they dropped somewhat (Figure 10).

The results of this experiment do not support the original hypothesis of pH significantly affecting dry matter production. Therefore, Nebsoy's adverse reaction to wastewater in 1979 probably should not be attributed to the fact that wastewater tended to lower the soil pH.

One very interesting aspect of this study is the apparent difference in water requirements between the two cultivars. This was discovered about mid-July when, after several very hot and windy days, half of the

Table 16. Nutrient element contents (ppm) of soil samples taken prior to initiation of irrigation (sample time 0), one week after each irrigation (sample times 1-4) and prior to harvest (sample time 5).

WATER TYPE	SAMPLE TIME	CONSTITUENT										
		PH	P	K	CA	MG	ZN	MN	CU	FE	CL	SOUBLE SALTS
		ppm										mmho
No Water	0	5.9	28.3	168	1820	224	2.0	35.3	1.3	29.3	1.04	0.09
	1	6.0	34.3	176	1789	199	2.3	33.0	1.7	32.0	1.26	0.14
	2	5.8	36.7	165	1720	178	3.7	31.0	1.0	32.0	1.05	0.08
	3	6.0	17.7	168	1935	189	7.0	25.7	2.3	36.0	1.41	0.08
	4	6.0	30.7	165	2142	192	3.3	21.7	1.3	32.0	2.06	0.13
	5	5.9	26.0	157	2033	192	4.0	21.3	1.7	29.3	1.51	0.11
	Mean	5.9	28.9	167	1906	196	3.7	28.0	1.6	31.8	1.39	0.11
Well Water	0	6.3	46.7	155	1789	203	2.0	26.7	1.7	29.3	1.42	0.12
	1	5.9	51.7	168	1544	174	2.0	23.3	1.7	33.3	1.31	0.12
	2	6.0	45.0	133	1584	170	3.0	22.3	1.7	33.3	1.53	0.09
	3	6.2	38.0	136	1653	178	5.3	18.7	2.0	32.0	1.26	0.07
	4	6.1	41.3	128	1618	164	3.0	17.7	1.3	32.0	1.69	0.12
	5	6.0	37.7	128	1546	178	3.0	16.7	1.7	28.0	1.25	0.11
	Mean	6.1	43.4	141	1622	178	3.1	20.9	1.7	31.3	1.41	0.11
Wastewater	0	5.9	36.0	168	1475	164	2.3	31.3	1.3	33.3	1.04	0.09
	1	5.8	33.7	171	1611	174	2.0	28.7	1.3	30.7	2.76	0.15
	2	6.0	40.0	168	1791	178	4.0	24.0	1.7	29.3	4.44	0.10
	3	6.1	29.3	149	1826	192	2.7	21.3	1.3	29.3	4.03	0.10
	4	6.2	29.3	155	1958	181	2.7	17.3	1.0	28.0	6.24	0.15
	5	6.1	27.3	144	1857	174	3.0	17.7	1.3	28.0	3.98	0.12
	Mean	6.0	32.6	159	1753	177	2.8	23.4	1.3	29.8	3.75	0.12
LSD .05 between means		NS	NS	NS	NS	NS	NS	NS	NS	NS	2.09	NS

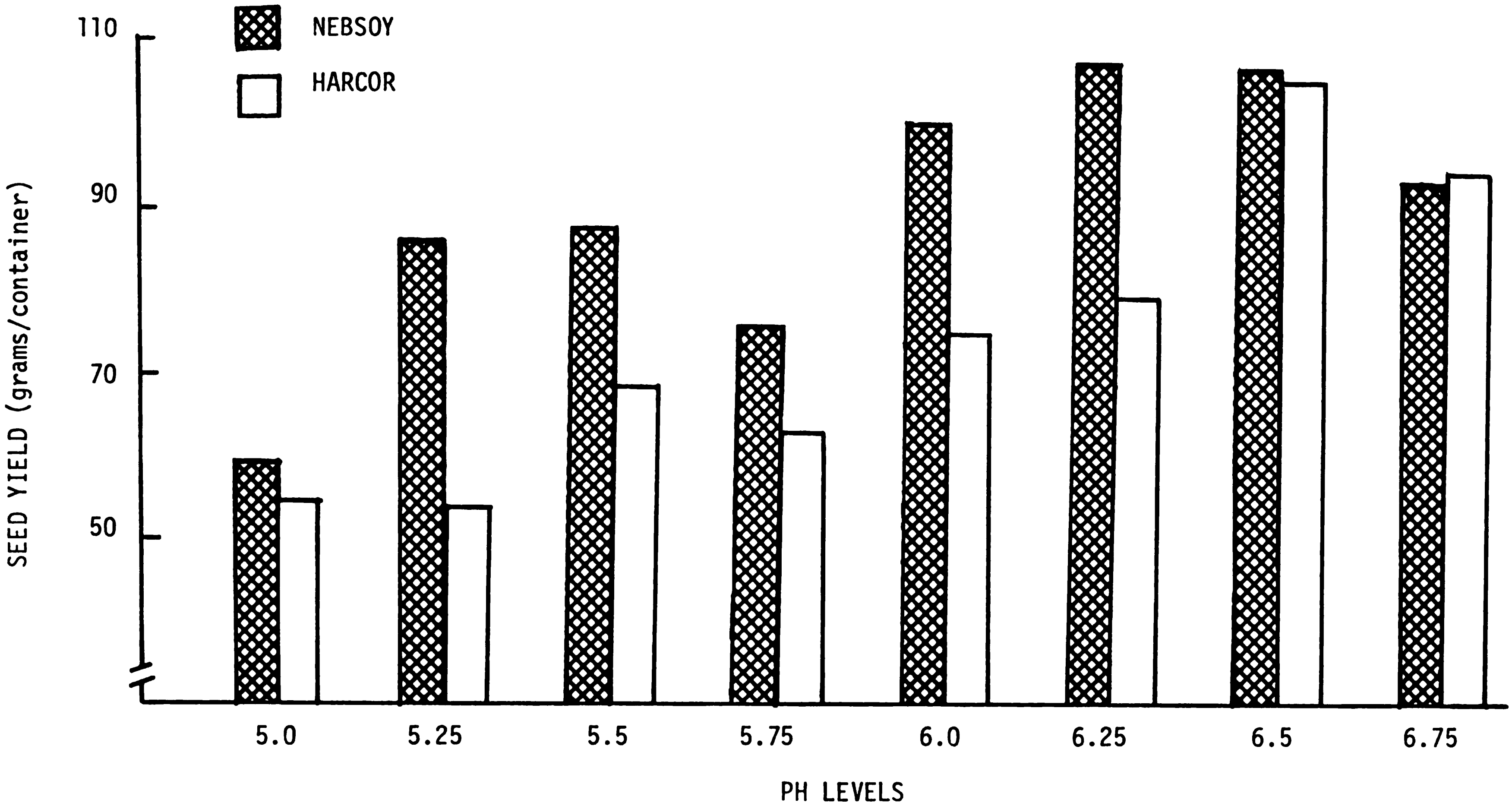

Figure 10. Effect of eight pH levels on seed yield of two soybean cultivars grown in sand culture.

plants were severely wilted. Only the Harcor plants had wilted and nearly all the Nebsoy plants had remained fully turgid. This same pattern occurred several weeks later but on a much milder scale. The conditions were the same for all the pots and they all had received identical water amounts. Additionally, at the time the wilting occurred, there were no differences in plant size between the two cultivars.

A logical explanation may be that Harcor uses more water than Nebsoy during vegetative development. This may stem from the fact that Harcor was developed in a more humid environment than Nebsoy. If Harcor has this additional water use potential, it may explain why Harcor responded much better to the additional water applied during irrigations.

SUMMARY AND CONCLUSIONS

Results from this study indicate that a yield response by soybeans to supplemental irrigation may be expected under normal weather conditions in Michigan. However the magnitude of the response will depend upon the rainfall distribution during reproductive development. With irrigation, yields generally increased as row spacing decreased and plant population increased. A second and important factor affecting the response to irrigation is the cultivar grown. Results reported herein show that Harcor responds much better than Nebsoy to the additional water. Various studies have also shown differences in cultivar response to irrigation (30,32,42).

Municipal wastewater irrigation was satisfactory under the conditions of soil, climate, and wastewater quality found during this experiment. The two cultivars responded differently to the wastewater, with Nebsoy often displaying an adverse reaction to the wastewater, whereas Harcor generally responded favorably to the wastewater.

The following conclusions were drawn from this study:

1. Soybean yields in Michigan can be increased with supplemental irrigation during the reproductive phase in a normal growing season.
2. As far as yields were concerned, the best cultural practice combination in this experiment was narrow rows and high plant populations.
3. Harcor responded much better than Nebsoy to both well water and wastewater and to the spatial arrangement of the plants.

4. Wastewater was generally superior to well water in increasing yields, and wastewater seemed to adversely affect the performance of Nebsoy even though no visible symptoms were noted.
5. Harcor appeared to have a higher water requirement than Nebsoy.
6. Nebsoy probably should not be used under wastewater irrigation due to its adverse reactions to wastewater.
7. During a wetter than normal year, there was little or no yield response of soybeans to irrigation.

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