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SURFACE RESPONSE OF ONIONS TO CULTURAL TREATMENTS

The University of Arizona M.S. 1986

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SURFACE RESPONSE OF ONIONS TO CULTURAL TREATMENTS

by

Curtis Lee Peters

A Thesis Submitted to the Faculty of the

DEPARTMENT OF PLANT SCIENCES

In Partial Fulfillment of the Requirements
For the Degree

MASTER OF SCIENCE
WITH A MAJOR IN HORTICULTURE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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ACKNOWLEDGMENTS

The author would like to express is sincere gratitude and thanks to his major professor, Dr. Paul M. Bessey, for his continual support, help, and encouragement throughout this project. Without his input and advice this project could not have been completed.

The author would also like to express his gratitude to Dr. Norman Oebker and E. Gregory McPherson for their input and ideas for serving on my committee.

A special thanks to the following for their help and support with this project: to the University of Arizona Cooperative Extension Service for allowing me the time to complete this degree; to the Hort Club for the use of their greenouse and equipment; to Marcia White for her help in planting and preparation of solutions; to Paul and Mary Ellen Brown for their help at harvest time; and to Bob Simons for his invaluable help with the statistical analysis.

A special and sincere thank you to my wife, Lee, for all her support, encouragement, and help with planting, harvesting, recording, and typing. Without her help this project would not have been possible. Lastly, a thank you to my "kids", Bart and Angela, for their good cheer and enthusiasm throughout the project.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF FIGURES

LIST OF FIGURES--Continued

LIST OF TABLES

ABSTRACT

The effects of irrigation, seedling size, in-row spacing, harvest date, fertilizer and seedling conditioning on the total yield and percent large bulb yield of transplanted onions (variety: Texas Grano 502) were studied during the 1986 growing season at the University of Arizona Campus Agricultural Center in Tucson, Arizona.

Irrigation levels from 115.1 to 437.9 ha-mm water and seedling size from 3.2 to 12.3 mm diameter had a positive linear effect on total yield and percent large bulb yield.

Harvest dates from June 1 to June 29 had a slight positive effect on total yield and percent large bulb yield.

Seedling conditioning with a root stimulating solution ranging in concentration from 0 ml/liter to 94 ml/liter showed a slight effect on total yield and no effect on percent large bulb yield.

Fertilizer treatments did not have an effect on total yield or percent large bulb yield at any level.

Interactions between irrigation and in-row spacing, irrigation and harvest date, and seedling size and in-row spacing, irrigation and seedling size, irrigation and harvest date, and seedling size and in-row spacing total yield.

Interactions between seedling size and irrigation, seedling size and in-row spacing, seedling size and harvest date, and in-row spacing and irrigation effected the percent large bulb yield.

CHAPTER 1

INTRODUCTION

The onion (Allium cepa L.) is a biennial of the Amaryllidaceae family thought to have originated in the Asia minor region of the world. It has been an important food item since ancient times. Onions were a staple food of the working class of ancient Egypt, but most importantly, they gave onions to their gods as an offering. Alexander the Great gave onions to his troops to build courage. At various other times, onions have been thought of as a cure for the bite of mad dogs, remedy for baldness and a cure for dysentery. An Arizona Cooperative Extension Service Bulletin (no date) indicates that as a nutritional source, onions are high in vitamin C and potassium and very low in calories.

Onions are grown for a variety of uses. They are grown for market as green bunching, sets and seed, dry bulbs and dehydrators. When one looks at current uses from flakes to onion rings, condiment to soup base, few food sources are so widely used.

Onions thrive in semi-arid regions with high solar incidence and low humidity. These conditions are widely found in Arizona. According to Agricultural Statistics for

1985 published by the United States Department of Agriculture and the University of Arizona (1986) 1200 acres were devoted to dry bulb onions yielding 564,000 hundredweight with an approximate value of $5.4 million. This represented about three percent of the total value of production of vegetable crops in Arizona.

For the Arizona onion grower, the task is to produce the highest yield, at the lowest cost, as early as possible. The Arizona crop competes with a very much larger crop in Texas which influences the price dramatically later in the season. This was best seen in 1984 when the price in April was $14.40 per hundredweight, $9.54 in May, and $8.57 in June. This also means if the Texas crop failed, the price would go up as in 1983 when the price in June was $7.71 per hundredweight and $10.20 in July. With an average yield of 440 hundredweight per acre, price differences significantly effect cash returns.

To be successful in the task of being an onion producer, the grower must manage a complex series of factors and interactions. By studying the factors and their interactions, various combinations can be uncovered which can produce equivalent and predictable crops.

The purpose of this study was to increase the total yield of dry bulb onions and the percent of large bulb (> 7.6 cm diameter) onions. The study was conducted on the Campus Agricultural Center of the University of Arizona using 'Texas Grano 502' onions. Each of the factors included in the study were thought to have a significant impact on the yield. They were: volume of irrigation water applied, size of the seedling transplant, in-row spacing, harvest, amount of N fertilizer applied, and conditioning of the seedling by soaking the roots in a root stimulating solution. These factors were each evaluated at 5 different levels using a response surface design. The response surface design was selected because it offered insight into the effect of interactions as well as individual treatments on the final product.

CHAPTER 2

REVIEW OF THE LITERATURE

Effect of Irrigation on Yield

Irrigation is an important aspect of the development of any arid land plant. Efficient and effective use of water was the focus of many studies, most of which showed that adequate irrigation was very important for proper onion development.

MacGillivray (1950) used six varieties of onions at three irrigation levels to study the effect of irrigation on yield. In his review of literature he found that most studies showed an increase in yield with an increase in irrigation. The irrigation levels he chose to study were 0, 6.6, and 11.2 inches (0, 16.8, and 28.4 cm) of water. He found that with every variety the highest irrigation treatment produced a significant yield over the lowest irrigation treatment. Only about half of the cases showed a significant yield difference between medium irrigation treatment and highest irrigation treatment. Additionally, he found a proportional increase in the size of the bulb when irrigation was increased. Those plots receiving the least irrigation matured earlier and were generally smaller in size. MacGillivray cited the shallow root system of the onion as the item responsible for these responses.

Drinkwater and Janes (1955) distributed their irrigation treatments into combinations of quantity and frequency. They had no irrigation, light/frequent irrigation {0.25 in. (0.64 cm) water every 4-5 rainless days}, heavy/ infrequent irrigation {1.0 in. (2.5 cm) water every 10-12 rainless days}, heavy/frequent {0.5 in (1.3 cm) water every 4-5 rainless days}. The yields of Number 1 bulbs was highest with heavy/frequent irrigation, but this treatment also produced the largest numbers of defects. The light/frequent and heavy/infrequent treatments produced similar yields with the light/frequent producing a slightly lower amount of defects. All irrigation treatments produced significantly greater yields of Number 1 bulbs than the non-irrigated control. They attributed much of the differences to the shallow root system where most of the roots were found in the top seven inches (17.8 cm) of soil.

Jones and Johnson (1958) used soil moisture tension to dictate their irrigation schedule. They irrigated when the soil moisture tension was 0.3, 0.6, 1.2, 2.4, and 4.8 atm. Irrigation at the 0.3 level gave the best yield with irrigation at the 0.6 level giving the second best. The 0.3 level meant an irrigation of 0.41 inches (1.1 cm) every three to four days and 0.6 level 0.57 inches (1.45 cm) every nine days. Jones and Johnson felt that the 0.3-0.6 level would be most economically feasible. They also withheld irrigation 2, 4, and 6 week periods throughout the season and found that yield was decreased more by late season drought than by early season drought.

deLis, et al, (1967) examined how irrigation affected yield in relation to certain growth periods. They caused drought situations at seedling stage, beginning of bulb formation, one-third of maximum bulb weight, one-half of maximum bulb weight, and at maximum bulb weight and without drought (check). Drought during the seedling stage accelerated bulb formation by fifteen days and had significant increase in yield over the check. When drought occurred at the beginning of bulb formation, there was a significant decrease in bulb weight as compared to the check. In the other stages of growth, drought did not cause significant damage to the plant's growth.

Nassar and Waly (1977) studied the yield of onions in relation to irrigation frequency and quantity in Egypt. They applied water at 1, 2, 5, and 9 times during the season and varied in quantity from 350 to 2300 m^3/feddan of total water. They found that they had the largest number of exportable bulbs from the plots receiving nine irrigations every fifteen days with a total of 2520 m^3/feddan applied.

Bottcher, Dreibrodt and Hohne (1977) found that increasing the water supply from 30 to 90 mm during mid-June to mid-July considerably increased the onion crop without having a negative impact on quality or storage ability.

In Egypt, El-Tabbakh, Behairy and Behairy (1979) irrigated cultivar 'Behairy' at 2, 3, 4, or 5 week intervals over twelve weeks for a total of 1000 m^3/feddan. The highest total yield, single bulb yields and average bulb weights were obtained with irrigation every three weeks. They saw a decrease in cull bulb yields with widening irrigation intervals.

In Hungary, Barnoczki (1982) conducted irrigation trials with six cultivars of onions. Onions were grown with no irrigation or with irrigation six to eight times over the season. Irrigation increased yield, mean bulb weight, and reduced the number of undersized bulbs.

In trials over two years Hassan (1984) found than an irrigation interval of ten days combined with 90 kg N/ha gave the best yields with high quality. He found that bolting was reduced by shortening the irrigation interval, but that this also increased the number of doubles.

Bailey (1984) studied effect of irrigation frequency on the yields of onions in Arizona. He found a positive linear response of large bulb yield to irrigation frequency. He also found that the irrigation rate of 35.4 acre inch (393.9 mm-ha) of water maximized yields and that additional irrigation decreased the total yield.

Effect of Seedling Size on Yield

Various studies have shown that the size of the seedling transplanted can have an effect on total yield and large bulb yield of onions. The degree of the effect has been varied.

Jones (1929) used selections 21.6 and 21.29 to study the effect of seedling size on the yield. The seedlings were divided into two general sizes, large and small with the very smallest seedlings discarded. They were planted 4 inches (10.2 cm) apart in rows 18 inches (45.7 cm) apart. He found that the larger seedlings gave higher yields and higher average weight per bulb in every case. He also found that the size did not significantly effect the date of maturity as long as the seedlings were transplanted at the same time.

Purewal and Dargan (1961) conducted experiments to show that the use of larger seedlings can increase onion yields. They found that small seedlings yielded 146.5 maunds/acre and large seedlings yielded 231.8 maunds/acre. They attribute the difference to the larger seedlings ability to root faster and make an early start.

Strydom (1965) studied how the transplant size would effect yield and the occurrence of bolters and split bulbs. The small size had a diameter of 0.13 inches (0.33 cm), the medium of 0.22 inches (0.56 cm) and the large of 0.31 inches (0.79 cm). He found that small transplants produced a smaller percentage of bolters and splitters than the large transplants. He also claimed that within certain limits, yield was not affected by plant size.

Silva, Silva and Rodriquez (1971) looked at transplant size and its effect on yield. The yield of first class bulbs with a diameter of 45 mm or more and average bulbs weight rose linearly with transplant size. The percentage of undeveloped bulbs less than 30 mm in diameter fell linearly with transplant size.

Sabota and Downes (1981) used three sizes of transplants classified as small (< 0.48 cm), medium (0.48-0.63cm), and large (> 0.63 cm). The large and medium transplants produced significantly more medium size bulbs. Large transplants produced 58 percent more yield than the small transplants, and 11 percent more than the medium transplants.

Effect of Spacing on Yield

Plants need a certain amount of space for proper development. The amount of space available will influence yield, bulb size, maturation, and nutrient utilization.

The first consideration in spacing is the distance between plants in a row. Jones (1929) planted California Early Red onions in rows 18 inches (45.7 cm) apart with plants 3, 4, 6, 8, and 12 inches (7.6, 10.2, 15.2, 20.4, 30.5 cm) apart in the rows. He found that at a 3 inch

(7.6 cm) spacing the average weight per bulb was 0.395 pounds (0.18 kg) and the total yield was 45,612 pound/acre (51,085.4 kg/ha) while at 12 inch (30.5 cm) spacing the weight per bulb increased to 0.78 pounds (0.35 kg) and the total yield was 21,796 pound/acre (24,411.5 kg/ha). In succeeding years he found that as spacing was increased from 3 inches (7.6 cm) to 12 inches (30.5 cm), the size of the bulb increased and the total yield decreased. He also noted that as spacing increased there was a delay in the time of maturity.

Eunus, Kamal and Shahudzzaman (1974) found that a spacing of 5 cm gave the highest total yield although there was an excessive number of misshapen bulbs that had to be culled. They also noted that at wider spacings there were more large bulbs, but the larger size did not compensate weight wise for the fewer number of bulbs found at wider spreadings. They felt that a spacing of 10 cm gave the best yield of saleable onions.

The findings of Randhawa and Singh (1974) concurred with the earlier works. Rows spacing was consistent at 15 cm and the spacing between plants varied at 10, 15, and 20 cm. They found that at the closer spacing the total yield was higher. They determined that there was not a significant difference between the 10 and 15 cm spacings, but there was between the 10 cm and 20 cm spacing.

In 1982 Villagran and Escaff planted onions with a distance of 50 cm between rows. At various planting densities, they found that as the plant density decreased, the weight per bulb decreased but that total yield for the row increased. They felt that the optimum spacing for total yield was 7 cm.

Maeso and Villamil (1981) planted 'Valencia' type onions at various spacings. Plants in rows that were 40 cm apart and spaced 6-8 cm apart within the row yielded the highest percentage of 5-7.5 cm diameter bulbs.

Bailey (1984) examined the effects of in-row spacing on onions. He varied the in-row spacing from 0.5 inches (1.3 cm) to 4.5 inches (11.4 cm). He found that total yield had a positive linear correlation.

Along with in-row spacing, there are many that have studied the ratio width to mean linear spacing within the row. This concept is known as rectangularity.

Rickard and Wickens (1979) found that ware bulb yields were influenced by plant population densities. They concluded that if the rectangularity ratio was more than 5:1, the yield could be reduced by fifteen percent. They also felt that the space between rows should not be more than 25 cm.

Frappell (1973) did an extensive study on how the spacing and rectangularity effect yield. His study showed that a rectangularity of 8:1 reduced yield up to ten percent and a 15:1 rectangularity reduced yield up to fifteen percent as compared to a 1:1 rectangularity. The study also showed that rectangularity was most important at the higher densities. Frappell felt that one must expect a reduction in total yield when producing large bulb onions, since large bulbs require more space. He also concluded that plant spacing could not be used as a means of producing a whole crop of a certain bulb size, but that spacing could be used to influence the range of bulb sizes produced.

Hatridge-esh and Bennett (1980) also used density as a measure instead of strictly in-row spacing. They varied densities from 7-100 plants/m^2 and rectangularity from 1:1.8 to 1:7. They found that an increased density increased the total yield but decreased the average dry bulb weight. Concurrently they found that as the rectangularity decreased, the total yield increased. This indicates that the square arrangement gives higher total yields. They felt that spacing shifts the proportions of the sizes of bulbs and therefore can be used to influence the field.

Brewster and Salter (1980) found that total and large bulb yields increased linearly as the density increased from 43 to 129 plants/m^2 and as the rectangularity was reduced from 8:1 to 1:1. In fact the ware bulb increased by twenty percent with the 1:1 arrangement over the 8:1 arrangement. They found that there was not an interaction between density and rectangularity.

Another way used to describe spacing is by using density of the planting as the scale.

Cornejo-Aizperrutia (1956) found that by planting three rows per ridge instead of two rows (363,000 plants/ha instead of 242,000 plants/ha) the yield increased by 23.4 percent but that the bulbs were smaller. In 1966 Bleasdale found that the total yield increased as the total plant population density increased, up to a point. He noted that by decreasing the between row spacing from 18 inches (45.7 cm) to 9-12 inches (22.9-30.5 cm) and keeping the population density consistent at 7 plants/ft^2 the yield was increased by ten to thirty percent. He also noted that at optimum total yield, the bulbs were so small that they were suitable for pickling only. Bleasdale additionally found that there was no variation with varieties of onions. When he ranked varieties based on yield, the ranking did not change when different densities were used. Lastly, he found that with narrower row spacing, the weed problem was reduced.

Vik (1972) used planting densities from 24.6 plants/m^2 to 64.2 plants/m^2. He found that 60 plants/m^2 gave the highest number of marketable bulbs. He also found that double rows 70 cm apart gave similar results to single rows 35 cm apart, whereas single rows 70 cm apart gave lower total yields.

In a different way at looking at space, Hassan (1978) used spacing of rows and number of rows per ridge along with in-row spacing as his indicator of density. He used ridge spacings of 50, 60, and 70 cm; 1, 2, and 3 rows per ridge and 5, 10, and 15 cm in-row spacings. He found that the spacing of the ridges had no effect on the yield. He did find that increasing the rows per ridge increased total yield but decreased bulb weight, the percent of large bulbs, the number of doubles and the number of those bolting. He also noted that increased in-row spacing, the total yield decreased but that there was an increased average bulb weight in percent large bulbs, in doubles, and in those bolting.

Rogers (1977) used the cultivar 'Creamgold' to show that plant density allowed the grower to manipulate the size range over which bulbs would be produced. He varied both the between row spacing and the in-row spacing. He found that to optimize the production of onions over 50 mm, the optimum plant density should be 75-80/m^2

McGeary (1985) used a square arrangement with densities of 178, 625, 816, 1111, and 1600 onion plants/m^2. He found that as plant density increased, the plant size, mean bulb weight, plant fresh and dry weights all decreased. He noted that plant densities did not have a significant impact on uniformity but that density could be used to influence the range of sizes within a crop.

Effect of Harvest Date on Yield

Harvest date is closely associated with the date of bulb maturity. As the harvest date departs from the date of bulb maturity, effects are apparent in relation to total yield, large bulb yield and storage ability.

Drinkwater and Janes (1955) studied the effects of irrigation on maturity and yield of two onion hybrids. They found a paradox. Heavy irrigation produced the highest yield. But, heavy irrigation also delayed maturity, which lead to significant storage problems.

Romanowski (1962) looked at how time of harvest affected yield, scale retention, storage losses, firmness of the onion, and color development. He found that there was increased yield with a delay of harvest. If he delayed harvest from 80-90 percent die down when only a few green leaves remained, the yield was increased by 15-20 percent. Delay in harvest also decreased the percent of bulbs with neck rot and bacterial soft rot.

deLis, et al, (1967) examined the effect of irrigation timing on bulb development. They felt that a majority of the bulb development took place at the beginning of the bulb formation cycle. Therefore since most of the growth is done early, the yield change will be minimal when harvest dates are changed.

Kepka, Sypien and Smolinska-Stepien (1971) found that a delay in harvest did have a significant effect on yield. If the harvest was delayed until all the tops were bent over, not just 25-30 percent, they expect a 30-40 percent increase in yield. The delay in the harvest until complete leaf bend did impair the storage quality of the bulbs harvested.

Randhawa and Singh (1974) looked at how fertilization and spacing affected the maturity of the onion. They found that an increase in the spacing of the plants did not effect the maturity of the crop. Conversely, they found that increasing the N applied did delay maturity. This delay in maturity impacted the optimum harvest date.

In 1976 Steen reported that both yield and storage quality were influenced by the harvest date. He reported that if harvest was delayed from ten percent bend over to 100% top bend over, there was a small (4%) increase in yield and that the percent of large bulbs increased. He also found that the delay in harvest made for poor storage ability due to an increase in splits.

K"Kam"kova (1976) found that yield was not affected whether the bulbs were harvested in mid-July or mid-August. The different harvest dates did not effect the storability and the percentage of bolters.

Nassar and Waly (1978) conducted experiments that examined the effect on yield and grade under different irrigation frequency and stage of maturity. The stage of maturity ranged from tops upright and green to tops bent and brown. The later harvests with greater bulb maturity gave a greater yield of exportable bulbs.

Hatridge-esh and Bennett (1980) examined the effects of spacing on harvest date. They found that a decrease in the density of the planting caused a delay in the maturity of the bulbs, which affected the optimum harvest date.

Again yield quality and storability was looked at in relation to harvest date by Mustafa and Chzhao (1983). In six harvest dates, they found a positive linear relationship between yield and a delayed harvest date. In contrast to other researchers, they found that the bulbs from third and fourth harvests had the highest quality and stored the best.

Bailey (1984) harvested onions in Arizona over a range of dates from May 27 to June 16. Both total yield and large bulb yield showed a positive linear response to the harvest date.

Effect of Fertilization on Yield

Proper nutrition is important for proper growth of a plant. Availability of nutrients becomes a factor of amount, timing, application method, and the elements applied and in what form. Various combinations of these factors has been important in elucidating the nutritional needs of onions.

Kunkel (1947) studied the effect of N and K applications on the yield of onions. He had treatment of 0, 40, 80 pound/acre (0, 44.8, 89.6 kg/ha) applied pre-plant and a treatment of 40 pound/acre (44.8 kg/ha) pre-plant 20 pound/acre (50.8 kg/ha) side dressed later in the season. Half of the N was $(NH_4)_2SO_4$ and the other half was split between Na_2NO_3 and urea. Superphosphate was used for the P treatment and KCl as the source of K. His results showed that the significant difference was due to N application when N application rose from 0 pound/acre to 80 pound/acre (89.6 kg/ha). Potassium levels did not have a significant impact if the N and P levels were held constant. He also found that if the N was applied late, the storage life of the onions was reduced, especially when K was not applied when the N was applied.

Singh and Singh (1969) found that onions did not react to a N fertilizer lacking in P. They applied N at 0, 84, 168, and 252 kg/ha. While the 15 plots that had N applied had slightly better yields than the control, the 84 kg/ha had the best yield overall. When P was also applied, yields increased with increased N. They concluded there was a significant interaction between N and P. When K was applied, there was no significant decrease in the yield when K was high and concluded that high levels of K may be harmful since it appeared to interfere with the absorption of P.

Lazo, Queddeng and Caliwag (1971) studied the effect of fertilizers on the yield of 'Granex' onions in the Philippines. They found that increased levels of N alone or in combination with P gave the best yields. Unfortunately, the highest N levels which gave the highest yields produced onions with poor storage qualities.

Lazic (1971) found that N had the most favorable effect on yield. The singular effect of P was less strong and K did not significantly influence the yield. When a complete fertilizer was used, the best results were obtained from the combination of moderate amounts of N, P, and K and the combination with high amounts of N, P, and K produced the lowest yields.

Pande and Mundra (1972) looked at the response of onions to various levels of N, P, and K. They found that the application of N increased the bulb diameter and total yield. Similar results were obtained with the addition of P. The application of K did not effect yield or bulb diameter. The combination of N and P gave the best yields. There was no interaction of nutrients to influence yield when K was added.

Randhawa and Singh (1974) found that N was the only nutrient that influenced yield, that P and K did not. They recorded the lowest number of bulbs where N was not applied, but that the highest yield was recorded with an application of 150 kg N/ha.

Khashmelmous (1979) studied 3 cultivars of onions in Mesa, Arizona. He applied at rates 0, 100, and 200 kg/ha on three different dates after a pre-plant application of ammonium phosphate at a rate of 640 kg/ha. He found that onions in Arizona responded to increased N. Both total yield and bulb width were increased at higher N rates. He also found that onions did not necessarily respond to late applications of N.

Bottcher, Dreibrodt and Hohne (1977) examined how the time of N application influenced the crop. They found that a higher rate of N applied in a single treatment in late season after an adequate pre-plant N application was more effective than evenly spaced multiple applications of an equal amount of N.

Hassan and Ayoub (1978) examined the effect of N, P, and K on clay soils in the Sudan. In their study, applications of N consistently increased total yields. Phosphorus showed significant effect on yield in two out of three years and K applications had no effect. Increased N and P also increased the occurrence of doubles and splits but did not increase bolting.

Fertilizer experiments conducted by Flones (1977) showed that increased levels of N consistently increased yields, increased P had some effect but increased K had no effect. Increased N did have the negative side effect of decreased storage quality.

El-Tabbakh, Behairy, and Behairy (1979) looked at the effect of soil moisture and N levels on yield. They found that increased N levels increased the yield. The highest yield and bulb weights were obtained by a combination of high N level with a moderate irrigation level.

Villigran and Escaff (1982) studied the effects of spacing and N levels on yield of 'Valencia' onions. They found a linear response of increased yield to increase N levels and that bulb weights increased as N was increased. They did not feel that there was an interaction between N levels and plant densities.

In their work on 'Bellary' onions, Belasundaram, et al, (1983) found what they felt was a significant N-K interaction when the P was held constant. They found that 51 kg N/ha and 64 kg K/ha in combination with 30 kg P/ha was the optimum dose in relation to economics appraisal.

Patil, Mahorkar and Patil (1983) looked at the effect of N, P, and K on growth and yield of onions. They found that increased amounts of N and increased amounts of P increased the total yield, but that the increased amounts of K had no effect.

In studying the timing of N application on vegetable crops, Iwata (1984) classified onions as a crop that needed less N before harvest. This contrasted to lettuce which needed N right up to harvest for best yield.

Gaafer and Hafer (1979) looked at how fertilization affected yields in a direct seed versus transplant experiment. They found that fertilization had no effect on yields.

Bailey (1984) found that N application gave a positive linear response in relation to total yield and large bulb yield. The N levels ranged from 0 to 594 pound N/acre (665.3 kg N/ha).

Asiegbu and Uzo (1984) studied farm yard manure and its relationship with inorganic fertilizers. They found that bulb diameter and large bulb percent increased with increased application of farm yard manure. They also found that total yield increased with increased applications of farm year manure.

In 1984 Smittle examined the response of onions to both N and S. He found that N applications ranging from 45-180 pound/acre (50.4-201.6 kg/ha) of NH_4NO_3 did not significantly effect yields, size distribution or bulb decay.

Hassan (1984) working in the arid tropics found that an application of 90 kg N/ha gave optimum yields. Increasing N also tended to increase bulb doubling.

Effect of Seedling Conditioning on Yield

Numerous different treatments have been made to seedlings to condition them for transplanting. The treatments have ranged from growth regulators to microelements to mechanical pruning. Results of these treatments have been variable.

Levine and Lein (1941) studied the effects of indole acetic acid (IAA), vitamin B_1, and colchicine on root growth.

They found that immersion in 10^{-8} IAA aqueous solution accelerated the growth of roots. Immersion in vitamin B_1 produced a retardation of root growth when used alone but accelerated growth if first submerged in 10^{-8} IAA. Exposure to 10^{-8} colchicine increased root growth only after initial exposure to 10^{-8} IAA.

Garcia (1949) found that untrimmed seedlings produced significantly heavier yields (in both number and weight of the bulb) than seedlings with roots trimmed. Seedlings with roots trimmed had significantly higher yields than transplants that had both roots and tops trimmed.

McManus (1960) treated onion roots with 1 ppm and 10 ppm kinetin, gibberellic acid (GA), IAA and maleic hydrazide (MH) and combinations of these. McManus found that GA and IAA gave an initial growth depression followed by a growth stimulation. GA and IAA together gave no response.

Jauhari and Singh (1960) treated seedlings with a 4 h soak in 10 or 20 ppm IAA solution before transplanting or watered the seedlings after transplanting with a solution of cow-dung with $(NH_4)_2SO_4$ plus KH_2PO_4 or with $NaNO_3$. All treatments significantly increased the yield with the solution with $(NH_4)SO_4$ and KH_2PO_4 giving the largest increase.

Samimbhi, Arora and Padda (1970) applied ascorbic acid to seedlings of 4 cultivars, Number 2, Number 4, B-32, and S-48. They were immersed in 0, 100, 200, or 400 ppm of ascorbic acid for 1, 2, or 4 hours. The 1 and 2 hour treatments with all concentrations increased bulb size and yield. The 4 hour treatment was mildly toxic and reduced size and yield. There was some variation as to which variety responded to which length best. B-32 and Number 4 responded best to 2 hour treatments at 200 and 400 ppm and the S-48 and Number 2 responded better to the 1 hour treatment at the 200 and 400 ppm level.

Levy, Kedar, and Karacinque (1973) studied the effect of ethephon on the bulbing of long day onions. They used four treatments: immersion of seedlings in various concentrations of ethephon for 28 days; foliar application of ethephon; ethephon injected directly into the root zone; and ethephon used as a soil drench. In the seedling immersion trial, bulb swelling could be seen seven days after treatment. A solution of 48 ppm gave the most bulb enhancement but also reduced leaf numbers. Even a solution of 1.5 ppm had an impact. They felt that the effect of such low concentration was due to direct contact of the roots to the ethephon solution.

Saimbhi, Thakur, and Singh (1974) applied ethephon to seedlings in concentrations ranging from 0 to 2000 ppm for 30 minutes. They found no beneficial effect on plant growth or bulb yield.

Rathore and Kumar (1974) studied combinations of top pruning and withholding irrigation after transplanting. Top pruning was at 0, 25 percent, and 50 percent levels and irrigation was withheld from zero to nine days. They found bulb size and yields highest with 25 percent of the top removed and irrigation withheld for three days.

Maurya and Lal (1975) looked at the effects of plant regulators on the growth and development of onion transplants. They soaked seedlings for 12 hours in solutions of water, 20, 40, and 60 ppm of naphthaleneacetic acid (NAA), IAA and GA before transplanting. Leaf, root and bulb growth were improved by all of the treatments at the 20 ppm level, with NAA being the most effective. They also found that the higher rates were generally less effective and sometimes harmful.

Joi and Shinde (1978) dipped seedling in an *Azobacter* slurry for 30 minutes before transplanting. *Azobacter* inoculum and/or N at 100 kg/ha were applied to the field. The highest bulb yield was obtained from plots receiving the treatment of additional *Azobacter* and N.

Ibrahim, Mahmoud and Ashoub (1980) conducted field trials in which 45 day old transplants were soaked in 0.2 percent solution of Zn or Mn, or Zn+Mn for 1.5, 3, or 4.5 hours. Zn+Mn for 3 hours gave the highest yield, 5838 kg/feddan while the control produced 4284 kg/feddan.

Ibrahim, Mahmoud and Ashoub (1980) also used salt solutions with microelements to pre-treat the seedlings. Seedlings were soaked for 1.5, 3.0, and 4.5 hours in 0.2

percent $MnSO_4$ or 0.1 percent $CuSO_4$ or in combination solutions as well as control seedlings in water. The highest bulb yields were achieved with the seedlings soaked in Cu+Mn for three hours, or on Mn alone. Yield was greater in seedlings soaked in Mn than in Cu.

Badawi and Khalaf (1981) soaked 45 day old transplants for 30-90 minutes in solution containing Mn, or Cu, or Mn+Cu. Treatments with Cu or Mn or Cu+Mn for 60 minutes resulted in highest yield.

Jasimuddin and Hossain (1982) top and root pruned transplants before putting them in the soil. They found that top and root pruning of seedlings had a negative effect on the yield.

As did Maurya and Lal (1973), Singh, Pankag, and Singh (1983) used growth regulators on seedlings before transplanting. Roots were dipped in solutions of 20, 30, or 40 ppm of IAA, NAA and GA for 24 hours. They found that the best plant growth, bulb quality and yield was obtained with the treatment of 40 ppm GA. 40 ppm of NAA gave the next best results.

Response of Surface Methodology

According to Hill and Hunter (1966) the response surface methodology (RSM) was first developed by Box and Wilson in 1951. Mead and Pike (1975) did not necessarily agree that RSM was developed by Box and Wilson, but they conceded that the large numbers of papers by Box and his associates did generate numerous fundamental ideas in the investigation of response surfaces. Mead and Pike (1975) noted that response curves were being used for the growth curves of animals and plants before Box and Wilson published in 1951. While RSM has some of its principle foundations in agriculture, it has been used more extensively in chemical engineering, food science, and dye stuff industries but not necessarily in agriculture. In fact, Mead and Pike (1975) claimed that it was used mostly in agriculture for single experiments, instead of a sequence of experiments such as Box and Wilson originally conceived. Box (1954) noted that the experimenter should use the concept of steepest ascent in a sequence of experiments until there was no further gain. Here second order equations can be readily fitted.

Researchers often discussed the experimental designs whose purpose it was to find the point on a response surface at which the maximum output was achieved while using the smallest possible number of observations. Hader, et al, (1957) felt that the search for other designs was motivated by the need to reduce the numbers of treatment combinations required for factorials using more than two to three treatments. They felt constrained by traditional approaches to experimentation in which one factor at a time was manipulated while the others were held constant. This single factor experimentation ignored the concept of factor dependency and inter-relatedness. Hader, et al, (1957) felt that information of wider generality would be obtained when several factors were investigated simultaneously and the effect of each factor at different levels could interact on the other factors. Box (1954) had previously stated that any method which attempted to avoid the multifactor problem by varying only one factor at a time is almost valueless. In the past, Box claimed that the interpretation of such dependency and interactions was piece meal and not as a whole. For this same reason, Henicka (1982) felt RSM was a valuable tool since it did not test several variables at one time and he used the special designs to cut costs and measure special effects by objective tests.

Hill and Hunter (1966) thought RSM would be used to answer such questions as "What operating conditions should be maintained so that maximum yield is achieved?" and "Are there any settings of the variables that will give a product satisfying all desirable specifications?" Box (1954) emphasized that the response surface gave identification to a whole range of alternative optimum processes which would be available to choose from. This took into account what Box referred to as compensating factors in which departure from the maximum response of one factor due to the change in one variable can be compensated by a suitable change in another variable. Examples of this were in processes where cost or convenience was a factor.

RSM has not been used as extensively in the agricultural/biological sciences as in other fields. Henicka (1982) reported that RSM was first described in Food Technology in 1966 and was being used extensively in food science. This was not surprising where a final response such as flavor consist of the taste of all the ingredients together and where factors can not necessarily be treated as independent variables. Hill and Hunter (1966) found that work done by people such as Ferrante in 1962 gave a good example of how RSM can be used in the textile industry. Mead and Pike (1975) also noted that work of Stone, Luu, and Tiemann in 1965 in extraction of silica from quartz, of Roth and Switzlyk in 1957 on their study of textile resin finishes, and of Shewell in 1956 in an investigation of catalytic cracking.

Mead and Pike (1975) reviewed various biological journals to examine the extent that RSM was used. They looked at fifteen journals covering a range of topics from agronomy to biology, to ecology, to poultry, and to weeds. Out of the 412 papers they examine, 103 had some connection to response surfaces. Most of these papers were concerned with finding maximum response though some looked at estimating the maximum non-toxic level or estimating a rate of increase or decrease of response.

There are some notable examples of RSM being used in agriculture. Hermansen (1965) used RSM in trying to maximize the yield of potatoes. He found that RSM left an excessive amount of unexplained error. Miller and Ashton (1960) looked at the effect of P and N levels on yield in oats. They felt that RSM was effective in showing relationships and reduced significantly the number of plots needed. Robinson and Nielsen (1960) studied the effect of N, P, and K on the growth of tomatoes. They found that RSM was effective only when the number of factors exceeded 5. Bailey (1984) used RSM to study the effects of spacing, herbicide, pesticide, fertilization, irrigation, and harvest date treatments on onion yield.

Box (1954) stated that no matter what the methodology, the ultimate success of the experiment as a whole must necessarily depend on the skill of the experimenter. No amount of artistry in statistical design can compensate for the omission of the most important factor. Hill and Hunter (1966) felt the experimenter had a role in the success of an experiment. They felt that the experimenter must be able to appreciate the results of an RSM study. There have been cases where rather elaborate mathematical models have been proposed, the appropriate data collected, the models fitted and the results presented in the form of mathematical equations, only to have the practical implications of the results remain unappreciated and therefore unexploited.

CHAPTER 3

MATERIALS AND METHODS

Production of Transplants

Originally, for this particular study an estimated 6,000 seedlings were needed for transplanting. Onion seed of 'Texas Grano 502' was obtained from Asgrow Seed Company to grow plants. Seed was planted at a depth of 3 mm in metal flats filled with a peat/perlite mix on December 10, 1985. Each flat had 10 rows 30.5 cm long and 3.8 cm apart with approximately 30 seeds per row. The flats were placed in a temperature controlled greenhouse on a wire mesh table. Water was applied every 2-3 days to maintain even soil moisture.

Germination began eight days after planting and continued for the following ten days. Irrigation continued on a 2-5 day schedule depending on the soil moisture in the flats. The seedlings were fertilized on January 23 and February 25 with a nutrient solution made from "Schultz Instant" with an N-P-K composition of 20-30-20. The concentration of the solution was 30 ml/liter.

The seedlings were pulled out of flats March 1, and placed in plastic bags and stored in a household refrigerator. Moisture was added to prevent dehydration. On March 2, the seedlings were sorted into five size groups. The seedlings were then put into small plastic bags with sufficient number for the spacing of each particular row. These bags were refrigerated (with moisture added) in a household refrigerator until they were taken into the field for transplanting.

Experimental Design

This experiment consisted of 53 randomly assigned plots put in a central composite response surface design. There was not a repetition of the design due to the limitations of available space. This design evaluated the response of six cultural factors at five different treatment levels. This design also allowed for the examination of interactions. Central or "optimum" levels for each treatment in this study were set utilizing currently available cultural information available for growing onions in Southern Arizona. In some cases the optimums were biased from the recognized successful level due to experimental conditions of this study. The factors and levels are shown in Table 1.

Cultural Practices

Irrigation

In the Southwest desert, irrigation is an important and increasingly more costly component of the cultural practices for onions.

Table 1. Factors and treatment levels used on 'Texas Grano 502' onions.

	Coded Levels				
	+2	+1	0	-1	-2
Irrigation					
Interval (days)	2	5,3	9,5	13,7	16,8
Total Applied (ha-mm)	437.9	261.1	198.4	135.4	5.2
Seedling Size Mean Diameter (mm)	12.8	9.3	7.3	5.2	3.2
In-Row Spacing (cm)	13.3	11.4	8.3	5.1	3.2
Harvest Date	6/29	6/22	6/15	6/8	6/1
Fertilizer (kg N/ha)	656	492	328	164	0
Root Stimulation Solution Conc. (ml/liter)	94.0	62.7	47.0	31.3	0

The test irrigation system was set up with a drip line running for 6.1 m on the east side of each row. Emitters at 20.3 cm intervals dispensed water at a rate of 94 ml/h. The drip lines were connected to 1.9 cm main lines with 5 mm tubing. The main lines attached to separate valves and meters so that one, two, three, four, or all five main lines could be used independently (see Figure 1). The source of water was a hose bib connected to the Research Center water line that utilized well water.

Two uniform irrigations were applied after planting in order to insure seedling survival. From March 20 to May 18 the most frequent irrigation treatment (+2) was used every two days, the optimum was every nine days, and the least frequent (-2) was every sixteen days. In response to increased temperatures, the schedule was modified on May 18 such that the most frequent treatment was every other day, the optimum was every five days and the least frequent every eight days. At each irrigation the water remained on for approximately seven hours dispensing approximate 71.9 liters of water of the 6.1 m drip line length. This rate was randomly checked throughout the study and remained essentially constant. Slight variations were noted when there was significant pressure drop due to high water use on the research facility. The effect of rainfall during this period was insignificant. Less than 0.25 cm of rain fell in that geographical region during the duration of the study.

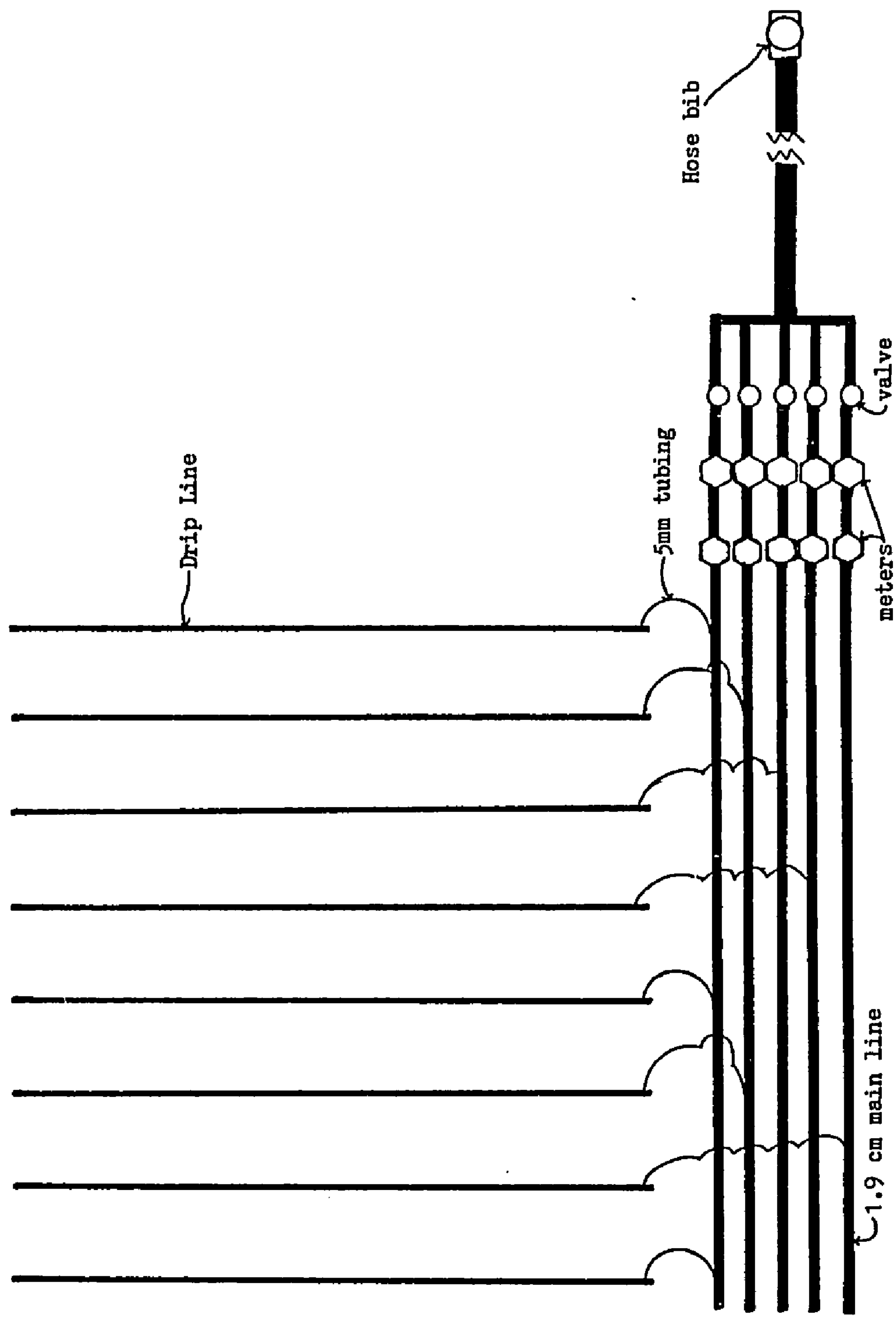

Figure 1. Irrigation system for the study.

Seedling Size

The size of seedlings transplanted is important when trying to get a head start on the growing season.

After the seedlings were pulled from the growing flats they were sorted by size into six categories - the five sizes for the study and a discard pile. Due to the large number of seedlings to be sorted, sorting was done by the "eye" as opposed to individual measurement. After sorting, each category was resorted at least two additional times in an effort to eliminate inconsistencies.

Seedlings were placed into plastic bags by row number with the count needed for the spacing treatment for that row. After all the seedlings were bagged, a random sample of five seedlings were taken from each bag for diameter measurement. The mean seedling size of the treatment were: (+2) the largest, 12.8mm (range: 12-15 cm), the optimum, 7.3 mm (range: 6-9 cm), and (-2) the smallest, 3.2 mm (range: 3-4 cm). While the 7.3 mm size of the "optimum" group may not in actuality be the optimum, it represented the mid-size group of the seedlings available for this study.

In-Row Plant Spacing

In-row spacing is an important factor in determining the diameter size of the onion bulbs. Depending on the final end use of the onions, spacing does play an important role in final yield.

Due to many different inter-row and in-row spacing combinations cited in the literature, a compromise was chosen in selecting an optimum for the row spacing treatments. Inter-row spacing was maintained constant at 45.7 cm center to center, a wide spacing that was dictated by the need to prevent an overlap of irrigation water. The in-row spacing most frequently mentioned in the literature was in the 6.35-10.6 cm range, so an optimum was selected at 8.3 cm between plants. The low treatment (-2) had spacing between plants of 3.2 cm, the high treatment (+2) had spacing of 13.3 cm.

In-row spacing in the field was determined with the aid of marked cords. Inelastic cotton cords were marked at appropriate intervals for each spacing. The cord was looped over the row marker and pulled tight about 5 cm above the soil level and secured on the other end. Seedlings were then planted to line up with the marks on the cord. This procedure resulted in consistent in-row spacing over the entire experiment.

Harvest Date

The date of harvest is influenced in two ways. First, the earlier the harvest, generally the better the market price. Second, plant maturity can influence post-harvest storage condition of the bulbs.

Dry onions are generally harvested in June in Southern Arizona. June 15 was set as the optimum harvest date based on the fact that it occurred in the middle of the normal harvest period. It would have been more precise to study the condition of the plants to select an optimum date, but the need for two harvests before the optimum did not allow for selection on that basis. The harvest started with the -2 treatment on June 1 and continued at one week intervals for the following four weeks.

In each 4.5 m row the first 30.5 cm was eliminated as a buffer. The next 3.8 m were harvested which left at least 45 cm for a buffer on the south end of each row. Bulbs were loosened with a shovel and then hand pulled and put into a metal bucket for weighing. Subsequently, they were cured in burlap for six days.

Fertilization

The fertilization factor was designed to look at the effect of various levels of nitrogen applied late in the season. No fertilizer was applied at pre-plant or shortly after planting as would be under normal cultural practices. This omission was made in an effort to maximize the impact of a late nitrogen application.

The fertilizer selected was ammonium nitrate distributed by Capital Nursery Supply of Phoenix, Arizona. The guaranteed analysis was 33.5-0-0 without micronutrients.

The recommended level of N for a crop grown in this manner, according to Lorenz and Maynard (1980), is 164 kg N/ha (converted from pound/acre). Since side banding application of N was not thought to be the most efficient, and since N in an ammonium form leaches readily, the recommended rate was doubled for an optimum rate of 328 kg N/ha. The -2 level was set with no N applied and the other extreme (+2) had the N applied at 656 kg N/ha. The designated amounts were applied in two applications, one made on April 22 and the other on May 17.

Ideally the fertilizer would have been applied through the irrigation lines. This method would have insured that the fertilizer was applied to the same region as the water which would provide the highest level of root uptake. Due to the design of the irrigation system to deliver different levels of water to each individual row but not fertilizer, the preferred method was not available for use. Another preferred method would have been to place the fertilizer in the soil directly under the drip lines. This would require moving the drip lines out of the way which was not practical in a commercial situation. Since the fertilizer was in granular form with the granules being about 1.6 mm in diameter, a Plant Junior brand seeder was used to side dress the fertilizer. The seeder was set up to dig a shallow, 6 mm trench and then cover the trench after the fertilizer was applied. The designated amount of fertilizer granules was loaded into the hopper. The seeder was the pushed the length of the row on the west side of the row opposite the drip lines. After all rows were fertilized, the whole field was irrigated so that the fertilizer would be available to the plants in each row at the same time.

Seedling Conditioning

Given the shock of uprooting and eventual transplanting, efforts were made to condition the seedlings to stimulate root growth to help shorten the period of shock and hasten new growth. Shortening the shock period by even a few days may be important in hastening maturity.

The product selected for use was Green Light Root Stimulator and Starter Solution manufactured by Green Light Company of San Antonio, Texas. The guaranteed analysis was 5-20-10 for N-P-K and also contained .0004 percent indole butyric acid (IBA) and .015 percent thiamine hydrochloride. This is a commercially available product, readily found in horticulture supply stores.

The product was mixed at a rate of 47 ml/liter of water for the optimum. This was triple the recommended rate, but due to the short duration of the treatment (10 minutes) it was felt that the higher rate was justified. The low treatment (-2) was plain water and the high treatment (+2) was a concentration of 94 ml/liter of water.

For each row, 0.5 liter of the designated concentration of solution was made and placed in a high sided 1.9 liter container. The onion seedlings were placed in the solution and mildly agitated to insure that all roots were in contact with the solution. After ten minutes, the seedlings were removed from the solution, shaken mildly, and planted directly into the row at the proper spacing and immediately covered with soil. The root stimulator solutions were not reused.

Pest Control

While pest control was not a treatment in the study, various pests did play an aggravating role in the study. First and foremost were rabbits. During early stages of onion growth, the rabbits ate young tops, either killing plants or providing a major setback. Fortunately, most of the severe damage was done on the border rows and at the ends of the plot. Damage caused by rabbits was a major factor in determining ultimate length of harvested row.

Additionally, rabbits caused considerable damage to drip lines by chewing into the plastic and causing leaks. A barrier fence was set up on one side and end that reduced the frequency of damage to some extent. Damage to drip lines was repaired on a daily basis.

At the east end of the plot, harvester ants ate 1/3 of a border row to the ground in a 24 hour period. An application of diazinon granules eliminated the ants from that area.

Thrips injury rose to unacceptable levels by mid-May. A survey of all rows showed a relatively equal level of infestation across the field. A single application of malathion at a concentration of 7.9 ml/liter applied May 23 reduced the population to acceptable levels.

Weeds, especially London rocket, Palmer's amaranth, Russian thistle, and Bermudagrass were present. The plot was cultivated with a wheel hoe prior to the first fertilizer application. After this time, the weeds were hand pulled in rows after irrigations. This was a major labor effort due to the number of weed seeds that had collected on the plot which had been left fallow for almost two years prior to the study.

Data Collection

At harvest, the plant material from each row (roots, bulbs, shoot) was placed in a container and weighed in the field with a dairy scale. After weighing, all the plant material was deposited in large burlap bags, one bag per row. The bags were shaded in an evaporatively cooled greenhouse on wire mesh tables to provide air circulation. Six days later tops and roots were trimmed and the bulbs were the reweighed and graded.

The data recorded for each row was the total fresh weight, total dry weight of the trimmed bulbs, the total number of bulbs, and the number of bulbs over 7.6 cm. The total dry weight on a row basis was then converted to total dry weight on a hectare basis. The percent large bulb was calculated by dividing the number of large bulbs by the total number of bulbs in the row.

CHAPTER 4

RESULTS AND DISCUSSION

Factor Effects on Total Yield

Effect of Irrigation on Total Yield

The irrigation treatments had a substantial impact on yield in this study. Multiple regression (see Table 2) showed that irrigation was significant at less than the one percent level.

Table 2. Stepwise multiple regression of total yield

Source	SS	df	MS	F	P	
Total	9787617958	52				
Regression	6806459987	6	1134409998	17.50	.0000	***
Water	2012408179	1	2012408179	31.05	.0000	***
Root Stim.	291628153	1	291628153	4.50	.0393	*
Fertilizer	41322771	1	41322771	0.64	.4287	
Size	2714789865	1	2714789865	41.89	.0000	***
Space	1311239941	1	1311239941	20.23	.0000	***
Date	435071077	1	435071077	6.71	.0128	*
Error	2981157971	46	64807781			

Irrigation as a singular treatment, produced dramatic differences in yields with different irrigation levels as shown in Figure 2. In the -2 treatment (irrigation at 16 and later 8 day intervals) approximately 15.1 ha-mm of water were applied and yielded 18,313 kg/ha of onions. Contrast the +2 treatment (irrigation at 2 day intervals) which had approximately 437.9 ha-mm of water applied and yielded 70,738 kg/ha of onions. The 0 treatment (irrigation at 9 and later 5 day intervals) had approximately 198.4 ha-mm applied with yields ranging from 38.181 kg/ha to 20,347 kg/ha, and an average yield from the nine 0 level rows being 28.114 kg/ha.

The results agree with the literature on onion irrigation. MacGillivray (1950), Drinkwater and Janes (1955), Jones and Johnson (1958), Nasser and Waly (1977), and Barnoczki (1982), all reported that the highest irrigation levels gave the highest. Bailey (1984) showed a decrease in total yield at the highest irrigation levels, but the irrigation levels in his study were considerably higher. Many of these authors also credited optimum irrigation levels resulting in the highest yields. They also gave optimum irrigation frequency results. While the frequency schedules of Drinkwater and Janes (1955) and Jones and Johnson (1958) coincide with the optimum frequency used in this study, there are many other factors such as soil type and

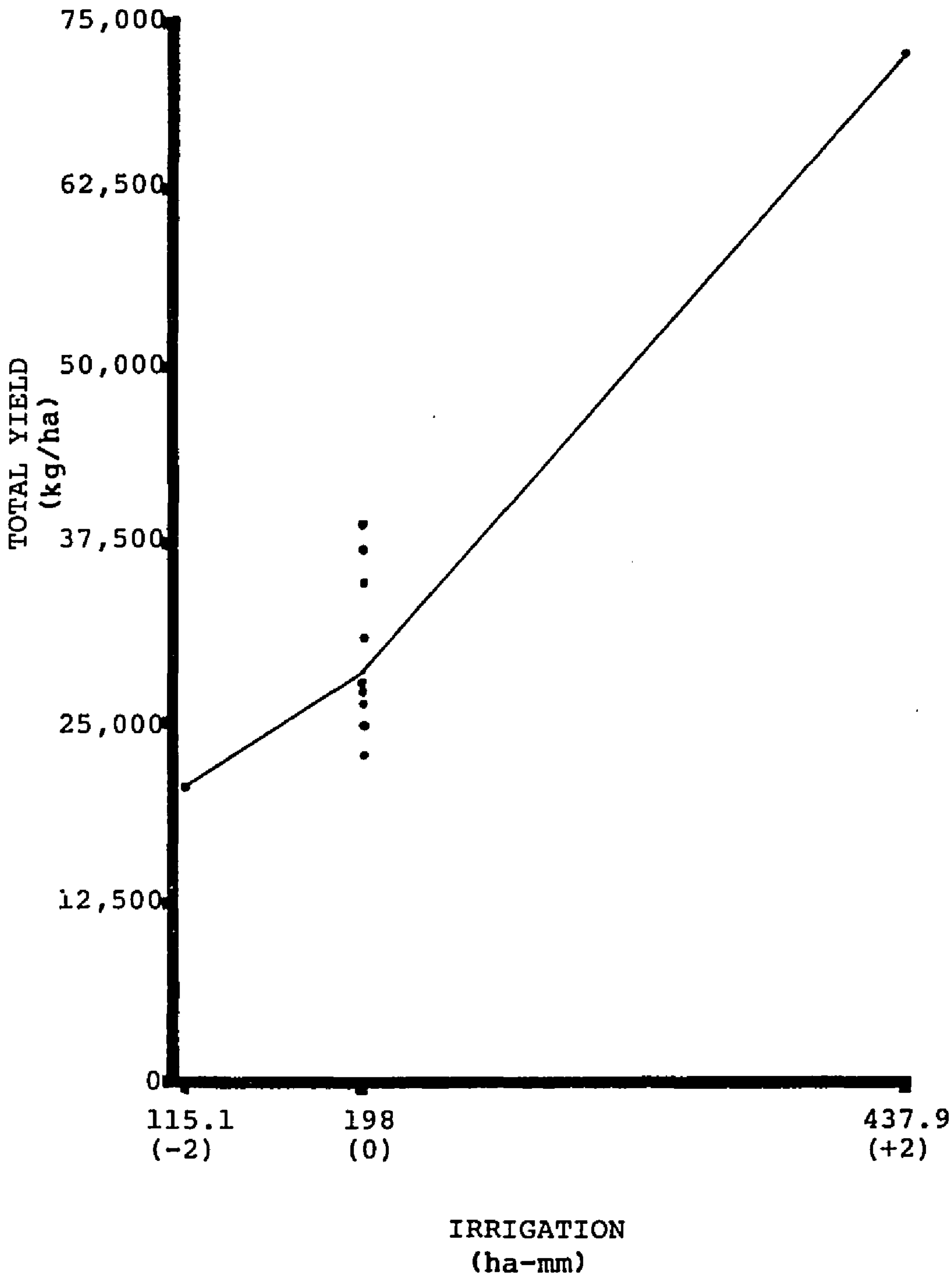

Figure 2. Effect of irrigation on total yield.

temperature that would need to be taken into account before it could be a valid comparison.

According to Erie, et al, (1969) the average consumptive use of water for growing an onion crop in Arizona was 301.2 ha-mm, and according to USDA and the University of Arizona (1986) the average yield of onions in Arizona from 1981-1985 was 49,667 kg/ha. Both the water needs and the yield are well above the water applied and average yield of the 0 treatment. The consumptive use of water for onions actually fell between the +1 (261.1 ha-mm) and the +2 (437.9 ha-mm) treatments. Using the irrigation system as it was set up would require irrigation approximately every four days in the late season to meet the consumptive use of the crop.

Increased water application above the consumption use level increased the total yield. Since the highest irrigation level also had the highest yield, it was impossible to determine from this study if the yield was maximized in relation to irrigation. Increasing irrigation levels to maximize yield would be one of the next steps in a sequence of studies to maximize the advantages of this experimental design.

The inadequate level of irrigation at the 0 treatment level surely had an impact on the rest of the study. Results found here were skewed together reporting results based on a low irrigation study, which this was not. In respectively when the irrigation schedule was adjusted in mid-May. Not only would the 0 treatment have been closer to the consumptive use of the onion, but the +2 and +1 treatments might have been high enough to maximize yields.

Effect of Seedling Size on Total Yield

The size of the seedling at transplanting had an important impact in yield, significant beyond the one percent level. The +2 treatment was used seedlings that averaged 12.8 mm in diameter and yielded 45,004 kg/ha of onions. The -2 treatment used seedlings that averaged 3.2 mm in diameter and yielded 13,046 kg/ha of onions. The two extreme treatments are well outside the 0 treatment yield range. In fact the relationship between yield and size of the seedlings is almost linear as shown in Figure 3.

The findings of Jones (1929), Sabota and Downes (1981), and Purewal and Dargan (1961) indicated that the size of seedlings did effect yield. By contrast, Strydom (1965) claimed that within certain limits, the size of seedlings did not effect the yield.

Purewal and Dargan (1961) offered the explanation that larger seedlings had an ability to root faster and made an early start. This may be due to the fact that larger seedlings would have more roots and more leaf area at the time of transplanting. The greater number of roots would be able to absorb more water and nutrients, and the greater

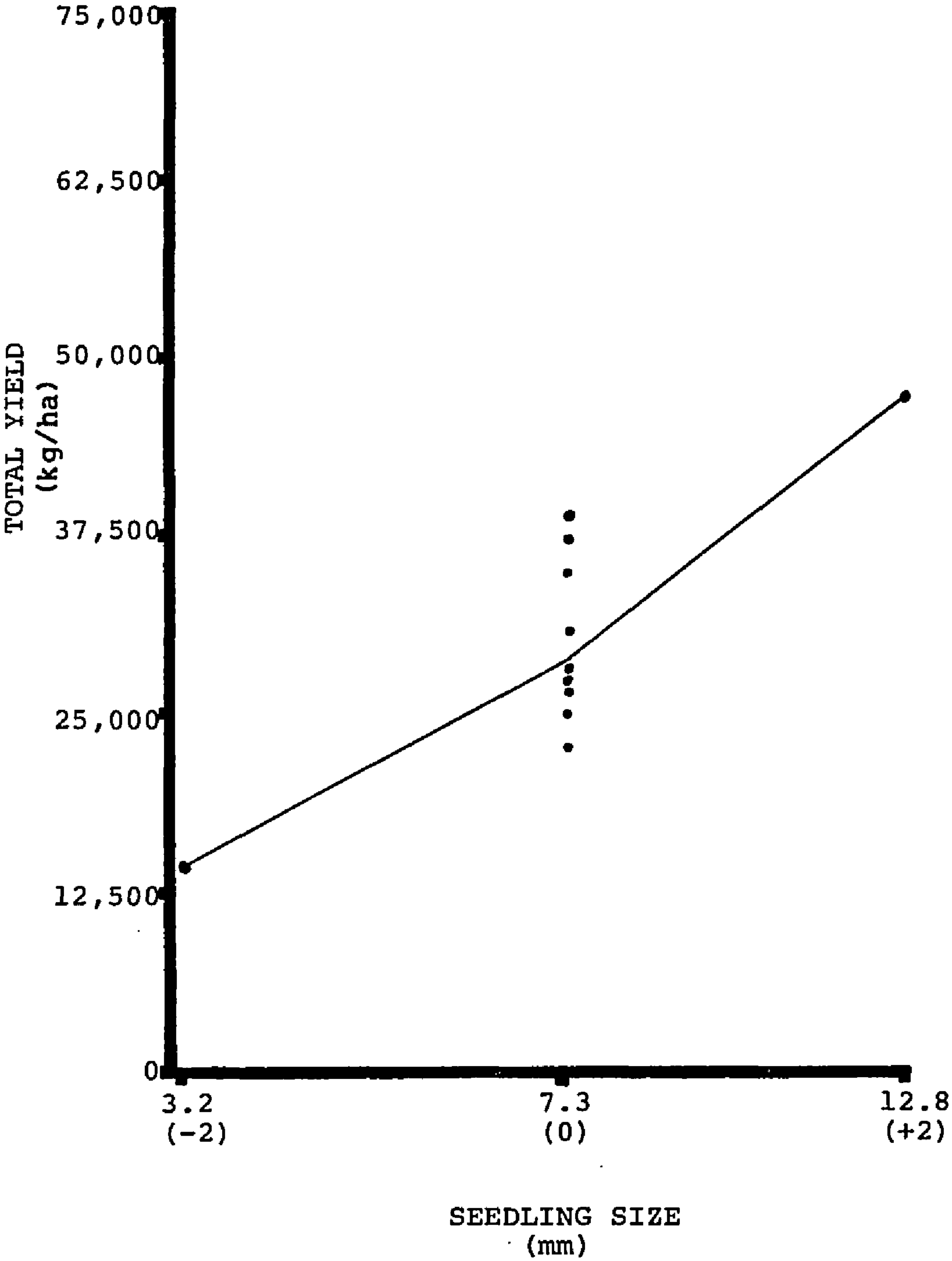

Figure 3. Effect of seedling size on total yield.

time of transplanting. The greater number of roots would be able to absorb more water and nutrients, and the greater leaf area would allow the conversion of this water and nutrients to photosynthates.

Additionally, larger seedlings have the advantage in the early season of being less susceptible to stress caused by temperature and other environmental factors. Under direct seeding conditions, the planting must take place early enough so that the young plants will be sufficiently mature to withstand frost but not be so large as to be susceptible to induction to bolting.

The larger seedlings also have a competitive edge. Weed control was done on a regular basis, but weeds were still found in the field. Large seedlings had a significant advantage in competing with the weeds for nutrients, water, and sunlight, whereas smaller seedlings were in direct competition and could be shaded and deprived of water and nutrients by more aggressive weeds.

This study indicated that onions did not under compensatory growth. It has been shown that in many biological systems, a undersized organism will grow faster than a larger organism of the same age. The factor of compensatory growth could be the response Strydom (1965) experienced in his experiment that showed the size of the transplant was unimportant in relation to yield.

excessively large seedling would actually decrease yield. The point of decreased yield may be reached when nearly full sized plants were transplanted. If this was found to be the case, other factors such as the cost of the seedling, maximum size of plants usable in a mechanical transplanter or availability of large transplants would determine the optimum size to use.

Effect of Spacing on Total Yield

The spacing of the plants within the plot had a very significant effect, with the significance at less than one percent level. The -1 treatment, which had an in-row spacing of 3.2 cm, the total yield was 34,658 kg/ha of onions. In the +2 treatment, the in-row spacing was 13.3 cm, the total yield was 18,185 kg/ha of onions. The total yield of the +2 treatment was below the total yield range of the 0 treatments and well below the 0 treatment average. The -2 yield was at the upper range of the 0 treatments but well above the 0 treatment average. The yield-spacing relationship was nearly linear as shown in Figure 4.

As spacing decreased, yield increased, but the size of the bulb decreased. The -2 treatment yielded 34,658 kg/ha and had an average bulb weight of 55 g. The +2 treatment yielded 18,185 kg/ha the average bulb weight was 120.5 g. Additionally, the -2 treatment produced 0 percent large

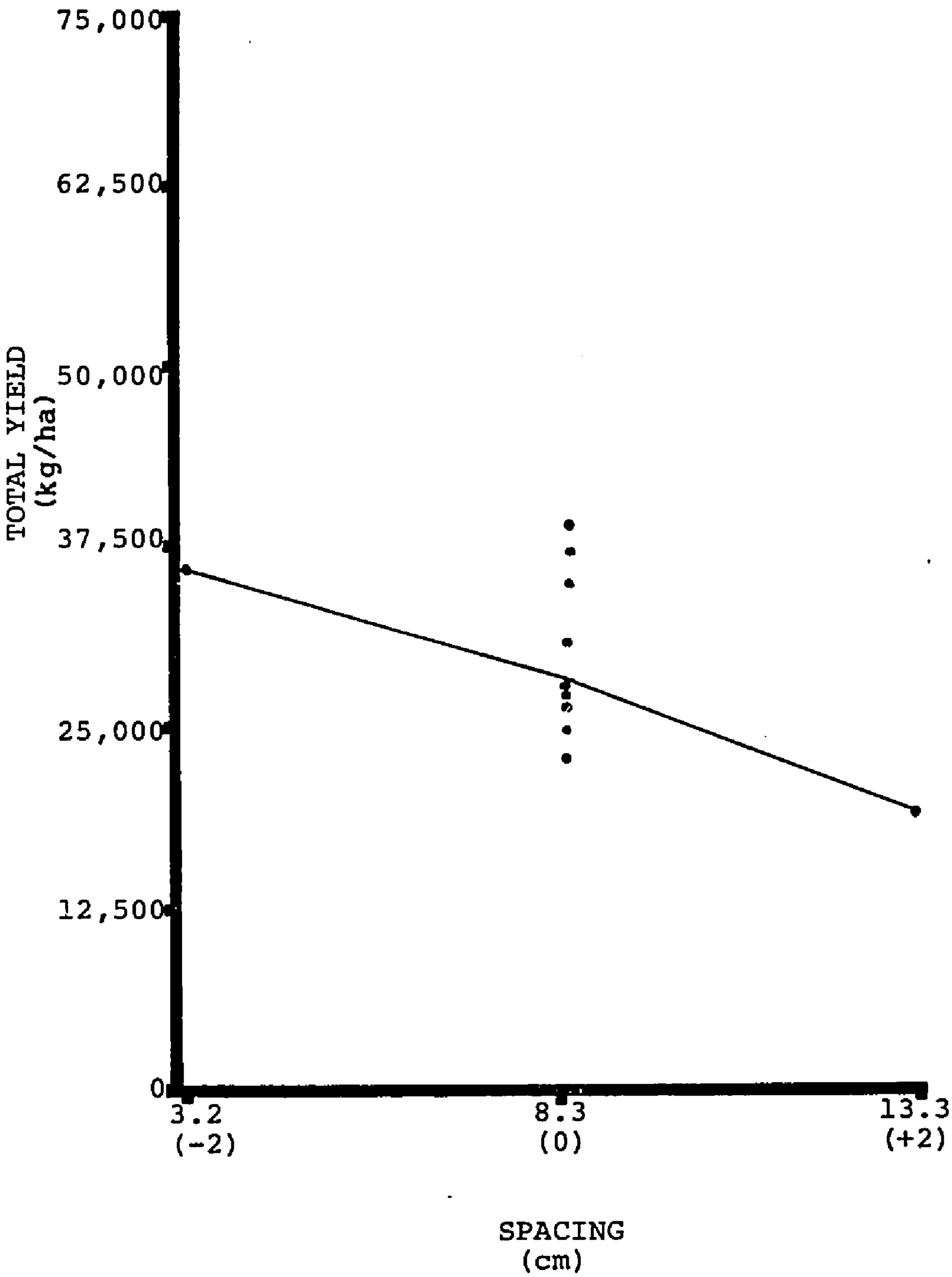

Figure 4. Effect of spacing on total yeild.

bulbs (> 7.6 cm) while the +2 treatment produced ten percent large bulbs.

The results follow the results recorded in the literature by Jones (1929), Eunus, Kamal, and Shahuduzzaman (1974). They reasoned that the increased bulb size did not compensate for the reduced population. This reasoning was substantiated in this study. The bulb weight increased 219 percent, the population decreased by 423 percent such that the bulb size did not compensate for the population reduction.

The rectangularity aspect of this experiment did not follow the literature. Rickard and Wickens (1979), Frappel (1973), Hatridge-esh and Bennett (1980) and Brewster and Salter (1980) all found that as rectangularity decreased toward a square arrangement, the yield increased. In this study the highest yielding treatment had the highest rectangularity (14.4:1) and the lowest yielding treatment had the lowest rectangularity (3.5:1). While it is an apparent conflict, in reality it is a case of inappropriate comparison. The previous studies used rectangularity on multiple row ridges, or a narrower row spacing than in this experiment. Richard and Wickens (1979) felt the row spacing should be no more than 25 cm, considerably closer than the 45.7 cm used in this experiment. At this wide spacing the effects of rectangularity were minimized due to the effect of lower plant density.

The factor of plant density followed the results in the literature. Row spacing was standard and closer in-row spacing increased density. Therefore density is simply another way of expressing the in-row spacing and the results would not be different than in-row spacing which has already been discussed.

In this study, the yield was not maximized in relation to spacing. The data indicates that smaller spacing would continue to increase total yield. This would continue until the plants were so close that they would not bulb at all. Optimum total yield then becomes a factor of other considerations, not simply maximum yield.

Size of the bulb is one factor to consider. Bleasdale (1966) found that at the maximum yield with the closest spacing, the bulbs where so small they could only be used for pickling.

Frappell (1973) and Hatridge-esh and Bennett (1980) both suggested that spacing would influence the proportion of certain sized bulbs. It was shown in this study that the percent of large bulb onions was influenced by spacing.

In most cases the total yield would not be the major consideration; the bulb size is of more importance. Large bulbs are more market acceptable and usually carry a higher price. Therefore, within limits, spacing would be used to determine the size of the bulb, not the size of the total yield.

determine the size of the bulb, not the size of the total yield.

Effect of Harvest Date on Total Yield

The date of harvest had an effect on the total yield statistically at the five percent level but not at the one percent level. The -2 treatment harvest date was on June 1 and yielded 22,741 kg/ha of onions. The +2 treatment harvest date was on June 29 and yielded 29,324 kg/ha. Both of these extreme treatments yields were within the range of the 0 treatment yields with the +2 treatment yield of 29,324 kg/ha barely exceeding the 0 treatment average of 28,114 kg/ha as shown in Figure 5.

A majority of the literature indicated that delaying harvest increased yield. The results of this study were inconclusive in this respect. While the data appears to show an increase in the total yield when there was a delay in harvest, the +2 and -2 treatments have only one replication. A single replication leaves doubt as to the reliability of the measurement.

Some of the literature also indicated that the delay affected the storage quality of the bulbs. Drinkwater and Janes (1955) and Steen (1976) found that delaying harvest increased yield but decreased storage quality due to splits. Romanowski (1963) found that delay in harvest increased yield and decreased the percent of bulbs with neck rot and

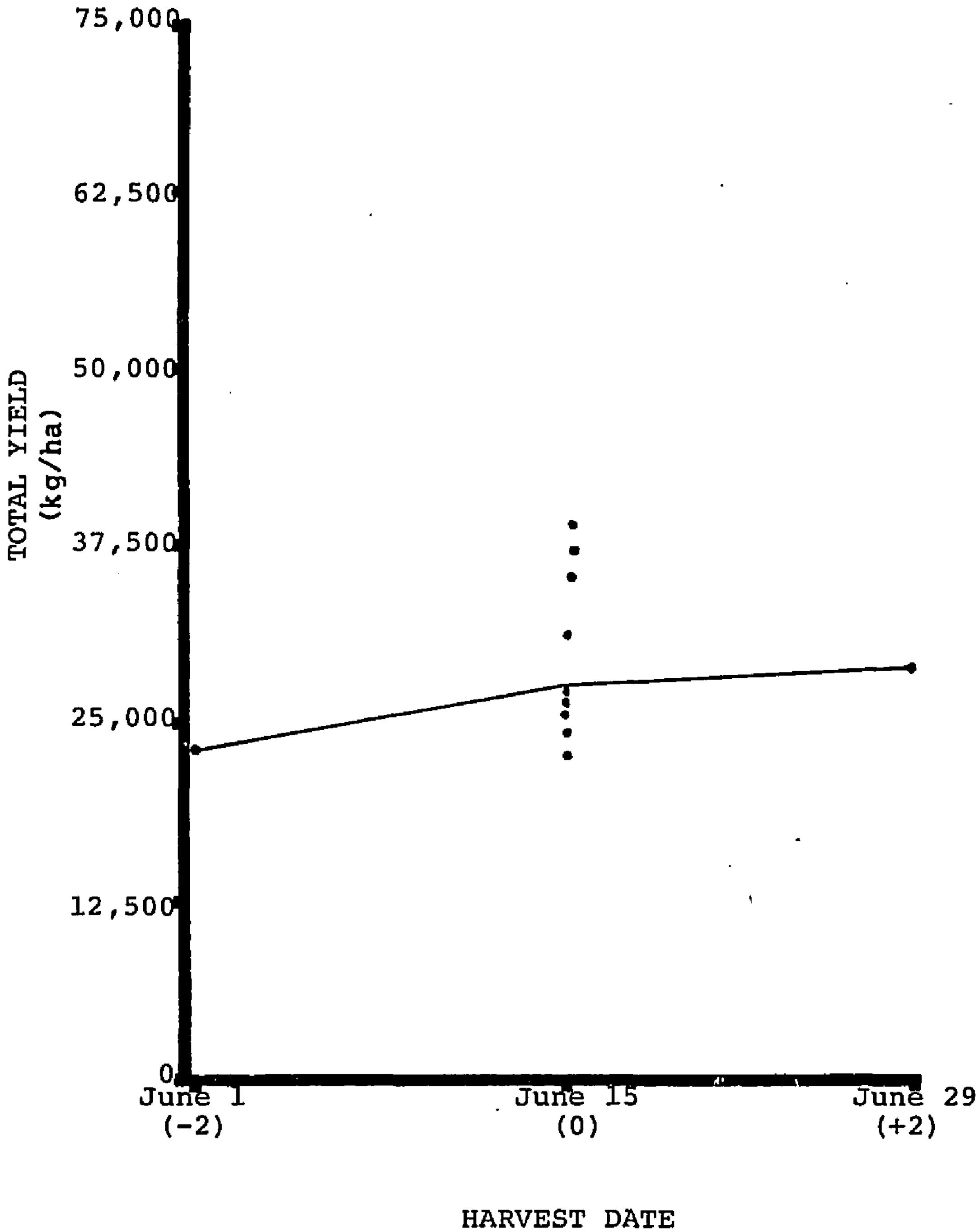

Figure 5. Effect of harvest date on total yield.

bacterial soft rot. deLis, et al, (1967) felt that since most of the bulb formation occurred early, the effects of harvest date would be minimal.

In determining the harvest date, there are two considerations that are usually opposed to each other. One consideration is the maturity of the bulb. The bulb will continue to grow until it matures and the top bends over and browns. As the bulb approaches maturity and continues to grow, the likelihood of cracking or splitting increases. When the bulb cracks or splits, it desiccates quickly and is susceptible to numerous diseases. If the bulb is left in the field past maturity, the quality decreases as the bulb desiccates. In this study, only the +2 harvest contained a large proportion of plants that were at maturity when harvested. Ideally, one wants to allow bulbs to grow toward or up to maturity with harvest coming before bulbs crack or split.

The opposing consideration is usually economics. The price offered for dry onions is generally highest early in the harvest season and declines as the harvest proceeds. The longer a crop is growing in the field, the more likely that additional irrigations will be necessary for maintenance and that the market price will fall.

In this light, the date of harvest is actually a balancing of two factors, market price and plant maturity. While factors affecting this balance change each year, knowing how much the yield can be affected by the harvest date is a very important information for making the decision on when to harvest.

Effect of Fertilization on Total Yield

Fertilization with NH_4NO_3 late in the growing cycle was shown to not be significant at any level. The +2 treatment of 656 kg N/ha yielded 21,425 kg/ha. The -2 treatment of 0 kg N/ha yielded 29,324 kg/ha and the nine 0 check plots yielded an average of 28.114 kg/ha, ranging from 38,181 kg/ha to 20,347 kg/ha. Statistically, fertilizer was the only treatment that was not significant at a five percent level. The yields of both the -2 and +2 treatments fell well into the range of the 0 treatment as shown in Figure 6.

The results shown here conflict with most of the results reported in the literature. Kunkel (1947) reported an increase in yield when 80 pound/acre (44.8) kg/ha N was applied. Lazo, Queddeng, and Caliwag (1971) that the highest N application had a favorable effect on yield. Randhawa and Singh (1974) found that N application was the only nutrient that influenced yield. Flones (1977) consistently increased yield with increased levels of N. Villigran and Escaff (1982) had a linear response of yield to N applied. Bailey (1984) found a linear response of total yield to N

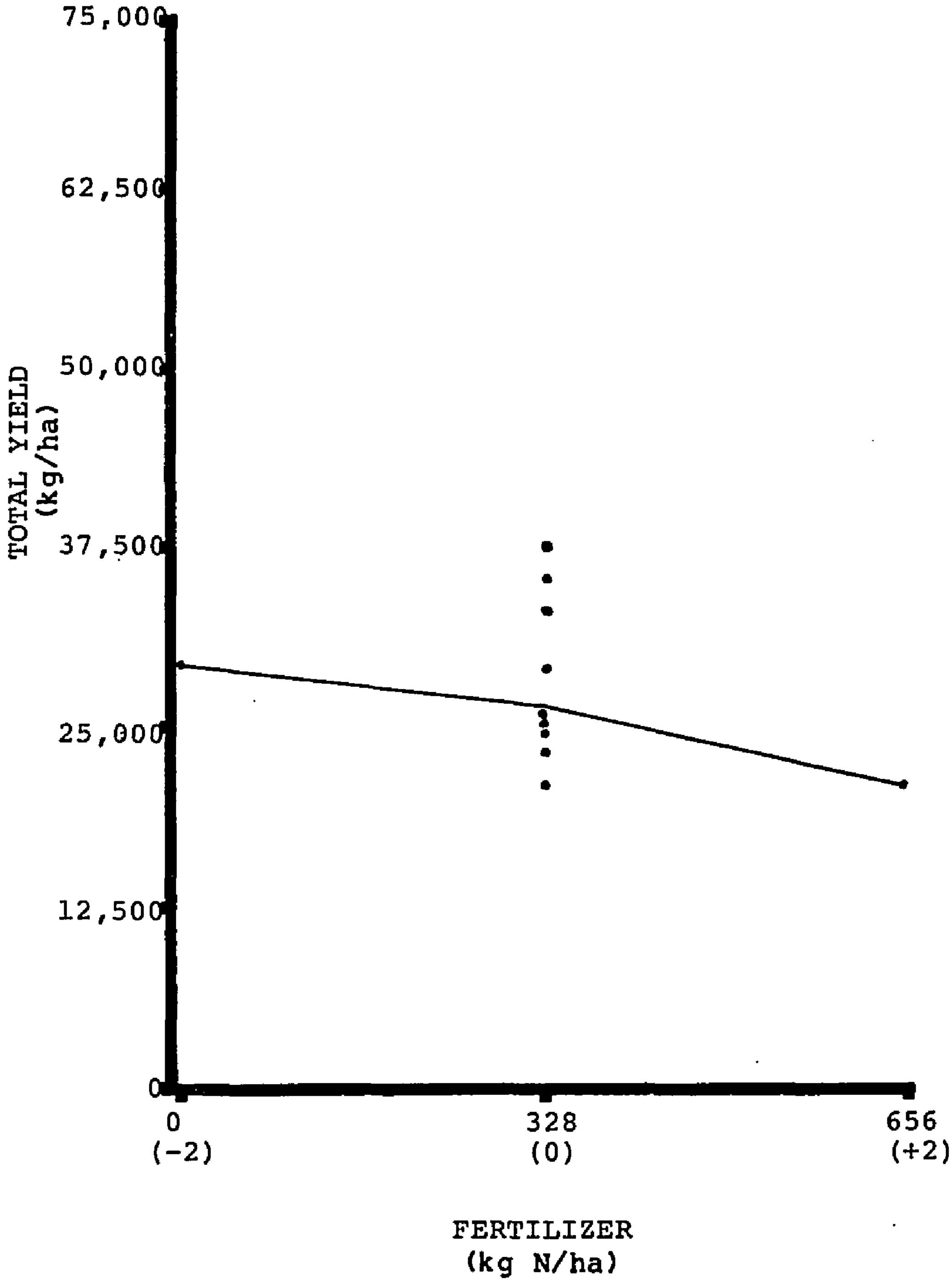

Figure 6. Effect of fertilizer on total yield.

application. Only Gaafer and Hafer (1982) and Smittle (1984) found that N did not increase yields.

A number of hypothesis can be assessed as possible explanations of why the fertilizer treatment was not significant when the literature indicates that it should be significant. Davis (1956) found that proper placement of fertilizer increased yield by 103 percent. He recommended that the fertilizer be placed two inches (5 cm) below the seed or in a one inch (2.54 cm) band to the side of the seed two inches (5 cm) deep. Shickluna, Davis and Lawton (1958) found that yield would be increased by 30-40 percent by banding two inches (5 cm) below the seed. In this study the fertilizer was sidebanded approximately 1.6 mm deep on the west side of the row with the drip irrigation lines located on the east side of the row. With this arrangement it is very likely that the fertilizer reaching the roots was limited. The pattern of water movement in the soil had the water moving laterally at a depth of 1.6 mm at a distance of 10 cm from the point of water penetration. As water dissolved the fertilizer, the fertilizer was probably carried laterally toward the next row, not vertically to the roots. Ideally, the fertilizer should have been applied through the drip lines. Unfortunately, since the drip lines were set up to vary irrigation levels and not the fertilizer levels, proper fertilizer treatments in each line would have required separate fertilizer injection ports on each row. Equipment needed was not available for this study.

An alternate application would have been to drill the fertilizer into the soil under the drip line at a 5 cm depth. This was not a practical solution since it would have required removing the drip lines. This application would also have done extensive damage to the roots.

Timing of application was probably also a factor. In the studies cited as reporting that N increased yield, the N was applied as a pre-plant application. Both Kunkel (1947) and Bottcher, Dreibrodt and Hohne (1977) found that late applications of N increased yield only if there was a pre-plant treatment of N. Khashmelmous (1979) found that his onions responded to early season N application but did not necessarily respond to late season N. In this study, N was applied 49 and 74 days after planting to determine whether late applications of N would effect yield. The late applications may have been well after the onion could effectively absorb any additional N as was suggested by Iwata (1984).

Nutrients available in the field may also have played a role. The soil in the field was not analyzed during the crop year for nutrient content. Based on a history of that plot it was assumed that after a heavy crop of onions in 1984 and extensive weed populations in 1985 that the nutrient supply would be low. While not likely, it is possible that the field contained adequate N and that the N applied was above the level that would make an impact on yield.

Lastly, the composition of the fertilizer itself may have been inadequate. While Lazic (1971) and Randhawa and Singh (1974) found that increased N by itself increased yield, Singh and Singh (1969) found that increased N did not increase yield unless there was increased P. Lazo, Queddeng and Caliwag (1971) and Pande and Mundra (1972) found higher yields when N and P were applied in combination than when applied separately. A soil test in 1984 showed moderate amount of P in the field, but if this level was inadequate, it could be that the N applied could not be utilized.

While the preponderance of the literature indicated that onions do respond to N, it is apparent that under the circumstances of this study yield was not increased due to applications N. In future work, the experimenter would need to change the circumstances in order to explain any response to N.

Effect of Seedling Conditioning on Total Yield

The conditioning of seedlings by soaking them in a root stimulating solution was just barely significant at the five percent level. The -2 treatment which had seedlings soaked in water only yielded 22,481 kg/ha of onions. The +2 treatment which had seedlings soaked in a solution of 94 ml root stimulator/liter of water yielded 23,459 kg/ha of onions. As with the harvest date, the yield of the extremes fell within the range of the 0 treatment yields and below the average of the 0 treatment yields as shown in Figure 7.

The literature identifies numerous treatments that have been given to seedlings before they were planted. Levine and Lein (1941), McManus (1960), Jauhari and Singh 1960), and Maurya and Lal (1975) used growth hormones to stimulate root growth. Garcia (1949) and Rathore and Kumar (1974) trimmed tops to reduce transpiration. Ibrahim, Mahmoud and Ashoub (1980), Badawi and Khalaf (1981) subjects the roots to microelements. While some varied the length of treatment, most looked at varying the concentration of the solution. The results were varied, even for the same factor used under similar conditions.

In this study, the seedlings were subjected to varying concentrations of a solution of root stimulator for 10 minutes. The root stimulating solution was a composite product made up of five components: N, P, K, IBA, and thiamine hydrochloride. The original intent of the treatment was to show the effect of the product as a whole. It was soon discovered that treatments of the individual components would also need to be made. Due to the fact that this study did not include testing of the five components, a separate, concurrent study was established to examine the

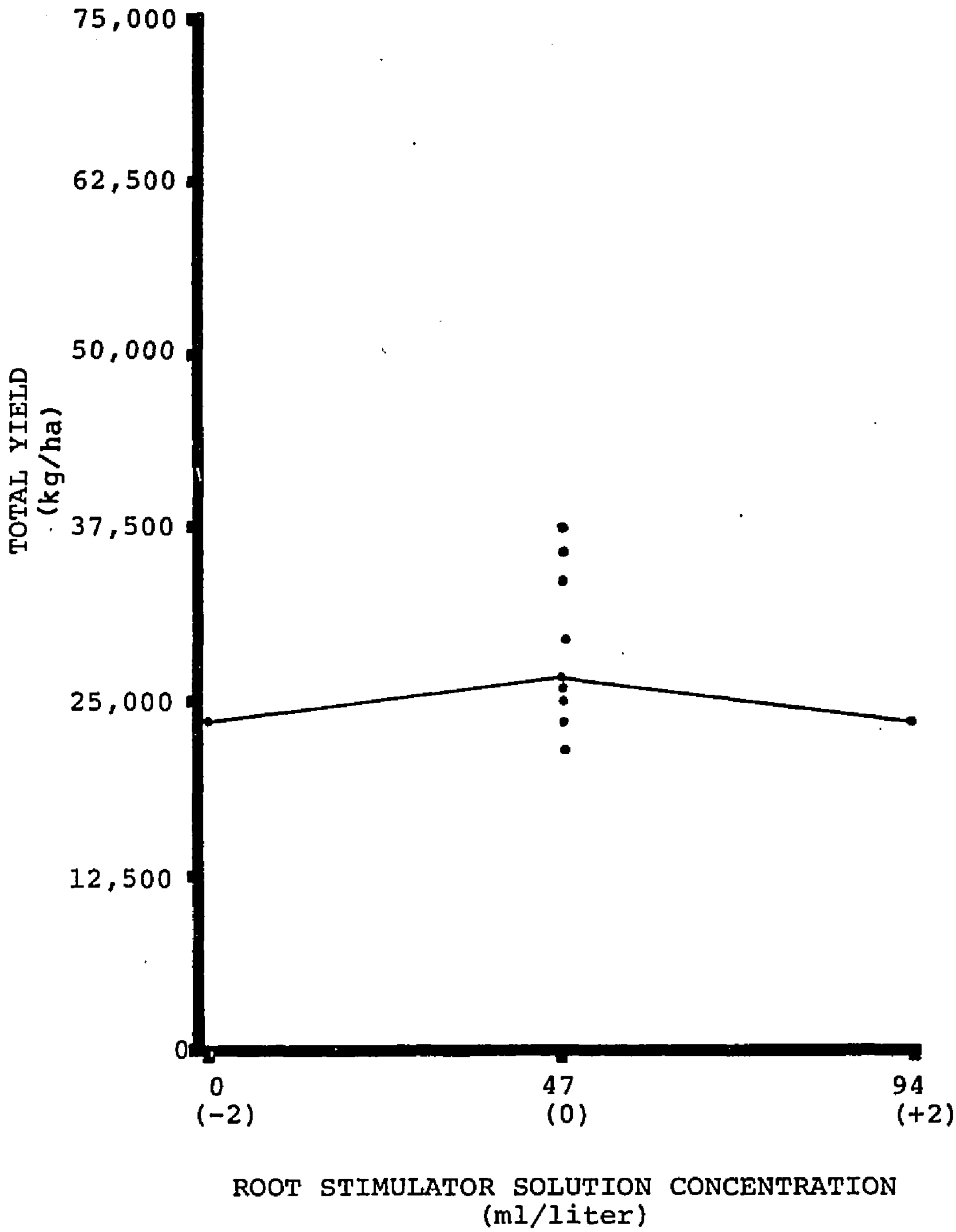

Figure 7. Effect of seedling conditioning on total yield.

components individually. The methods and results of this experiment are found in Appendix A.

The results of the root conditioning treatment do not appear to be conclusive. The statistics show that the treatment is significant at the five percent for total yield level, yet if the dry weight/bulb characteristic is examined, the treatment is not significant. In the concurrent study, none of the components were significant at the five percent level, and while not shown statistically, the K component appeared to have a negative effect. Since none of the individual components were significant, it would suggest that there is a synergestic effect in the composite product which caused a significant effect on the total yield in this study.

In the plotting of the extremes and the optimum yields, it appeared that there was an increase between the -2 and 0 treatment and a decrease between the 0 and +2 treatment. A single repetition of the extremes casts some doubt as to whether this was indeed the relationship. Additional plots would have produced more reliable information.

Aside from studies that would look at the effects of the individual components of the compound and various combinations thereof, further studies could take a number of different angles. One would be to vary the duration of the treatment; ten minutes was shorter than any duration in the cited literature. Vary the time from removal of the seedlings from the flats until treatment time; freshly wounded roots might react differently than roots that have had time to "heal" over.

Factor on Large Bulb Yield

Large bulb yield is very important in commercial production due to the higher market price. For the purpose of this study though, a shortcoming in any factor would be accentuated more with large bulb yields than with total yield. The method for recording a large bulb yield is absolute, the bulb either had more than a 7.6 cm diameter or it did not. In total yield an onion with a low response still provides some weight to record for the plant. In large bulb yield, a plant with a low response (less than 7.6 cm diameter) is not recorded. Therefore, responses that do not yield 7.6 cm diameter bulbs will stand out.

Effect of Irrigation on Large Bulb Yield

The effect of irrigation on large bulb yield was statistically significant at the one percent level (see Table 3). The -2 treatment, which received irrigation every sixteen days, later every eight days, for a total of 115.1 ha-mm of water yielded 2.3 percent large bulbs. The +2 treatment, which received irrigation every two days throughout the study for a total of 437.9 ha-mm yielded 81 percent large bulbs. The 0 treatments, which received irrigation

Table 3. Stepwise multiple regression of percent large bulb yield.

Source	SS	df	MS	F	P
Total	.88	52			
Regression	1.63	6	0.27	10.04	.000 ***
Size	0.69	1	0.69	25.33	.000 ***
Water	0.37	1	0.37	14.25	.001 ***
Space	0.39	1	0.39	14.39	.000 ***
Date	0.13	1	0.13	4.66	.037 *
Root Stim.	0.04	1	0.04	1.53	.223
Fertilizer	1.28	1	1.28	0.05	.829
Error	1.25	46	0.03		

every nine days and later every five days for a total of 198.4 ha-mm, yielded an average of 9.3 percent large bulbs. The +2 treatment went far above the range of the 0 treatments and in fact yielded the highest percentage of large bulbs in the study as shown in Figure 8.

In the literature, Drinkwater and Janes (1955) and Bailey (1984) studied the effect of irrigation on large bulb yield. Drinkwater and Janes found that frequent and heavy irrigation yielded the most Number One onions. Bailey found a positive linear response of large bulb yield to irrigation frequency. The large bulb yield data from this study concurred with their findings.

As was discussed in the section on effects of irrigation to total yield, it should be noted here that the 0 treatment for irrigation was below the consumptive use of onions and created an element of "dryness" not intended for this study. Due to the lack of irrigation it is quite possible that many of the other treatments were not fully expressed in the extreme treatments. In future work, a shifting of irrigation frequency to insure that the appropriate amounts of water are delivered is a must.

Effect of Seedling Size on Large Bulb Yield

Size of the transplanted seedlings was statistically significant beyond the one percent level. The -2 treatment used seedlings 3.2 mm in diameter and yielded no large

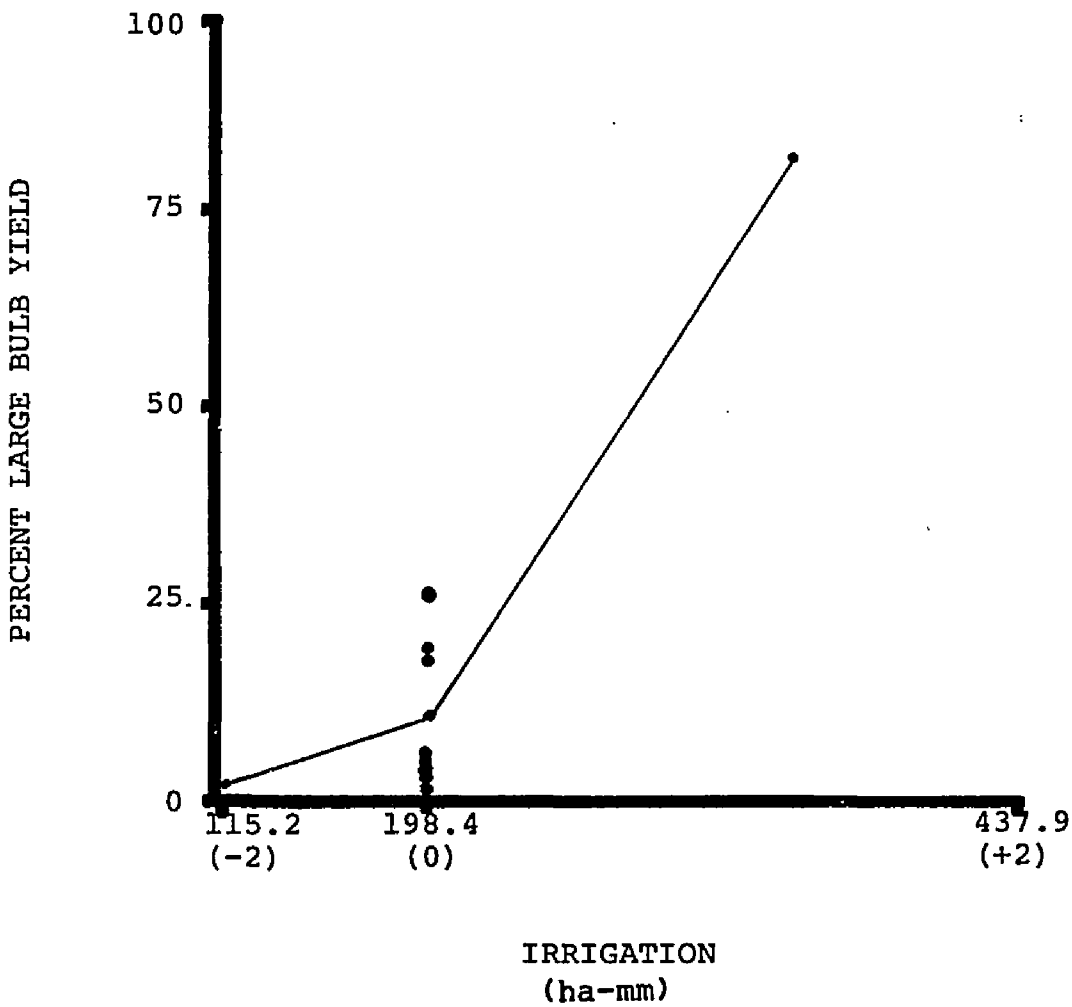

Figure 8. Effect of irrigation on percent large bulb yield.

bulbs. The +2 treatment used seedlings 12.8 mm in diameter and yielded 43.1 percent large bulbs. This +2 treatment is substantially above the 0 treatment mean and range yield of 9.4 percent large bulbs as shown in Figure 9.

Silva, Silva, and Rodriquez (1971) were the only researchers in the literature that specifically addressed the yield of large bulb onions in relation to seedling size. They found a positive linear relationship between large bulb yield and transplant size.

The data from this study revealed a linear relationship of seedling size to large bulb yield. The yield of large bulbs was not maximized, so additional study would be needed to reveal the size that maximized yields of large bulbs. The use of larger seedlings has a built in advantage - a higher percent of the 7.6 cm necessary to constitute a large bulb would already be part of the bulb at transplant time. At the -2 treatment level the seedling represented only four percent of the final large bulb size. At the +2 treatment level, the seedling represented seventeen percent of the large bulb size. The smaller seedling required an additional thirteen percent to grow to the large bulb size. With this initial size advantage, larger seedlings should produce a higher percentage of large bulbs, even with a lower growth rate.

It is difficult to establish if increasing the size of the seedling would dictate the optimum size of seedling

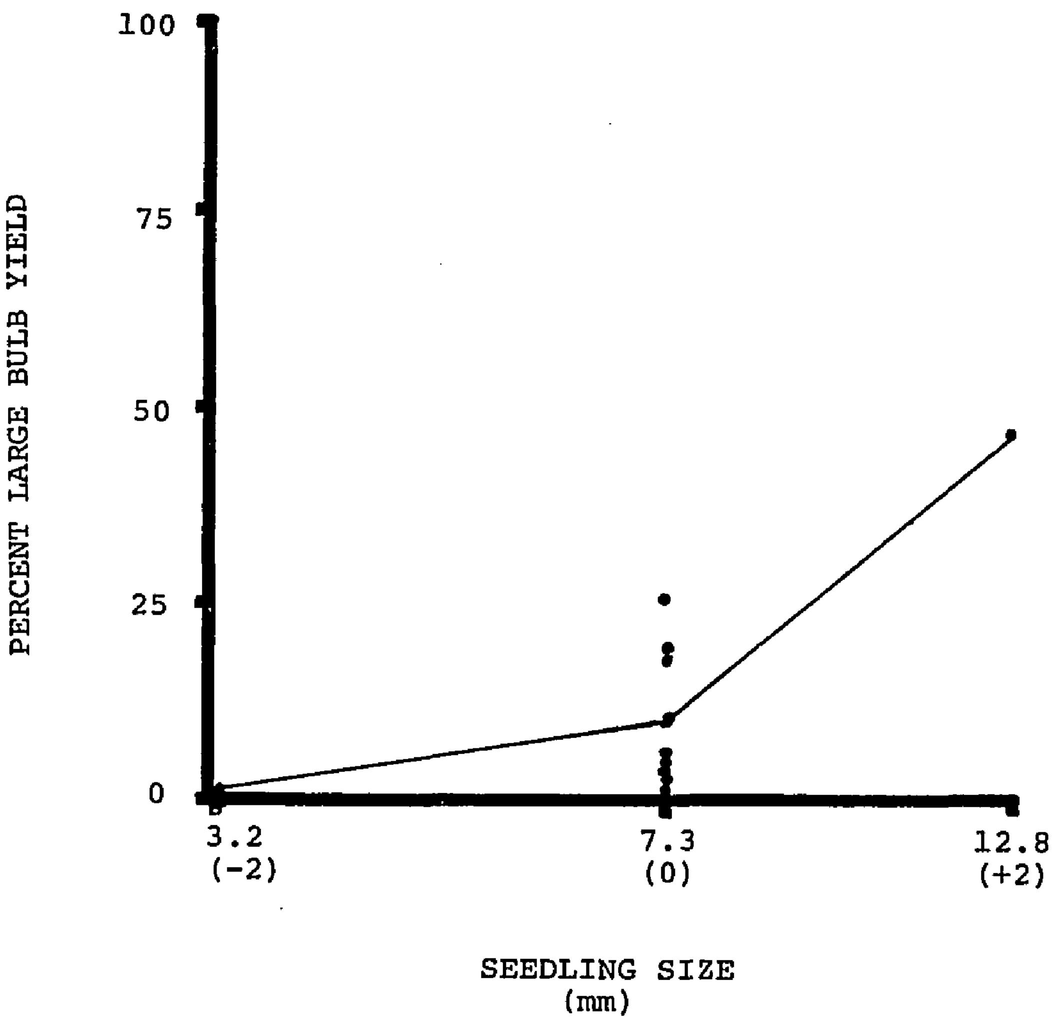

Figure 9. Effect of seedling size on percent large bulb yield.

to use for a commercial crop. Consideration such as the cost of larger seedlings, if the larger seedling could be used in a mechanical planter, or availability of larger seedlings may dictate at the point that seedling size for transplant is established.

Effect of Spacing on Large Bulb Yield

The spacing of plants in the row had a very significant effect on the yield of large bulb onions. The -2 treatment, which had an in-row spacing of 3.2 cm, yielded no large bulb onions. The +2 treatment, which had an in-row spacing of 13.3 cm, yielded 10.3 percent large bulb onions. The 0 treatments, which had in-row spacing of 8.3 cm, yielded an average of 9.4 percent large bulbs. As shown in Figure 10, the two extreme treatment yields are well within the range of the 0 treatment yields, yet statistically the in-row spacing had a very significant effect.

The literature was very uniform in stating that increased spacing yielded increased bulb weights, but only Maeso and Villamil (1981), Frappell (1973), Hassan (1978), Rogers (1977), and Bailey (1984) specifically addressed large bulb yield. There was general agreement among these authors that large bulb yields would be increased with increasing space. The data is this study indicates agreement with the previous findings but, since the +2 treatment yield

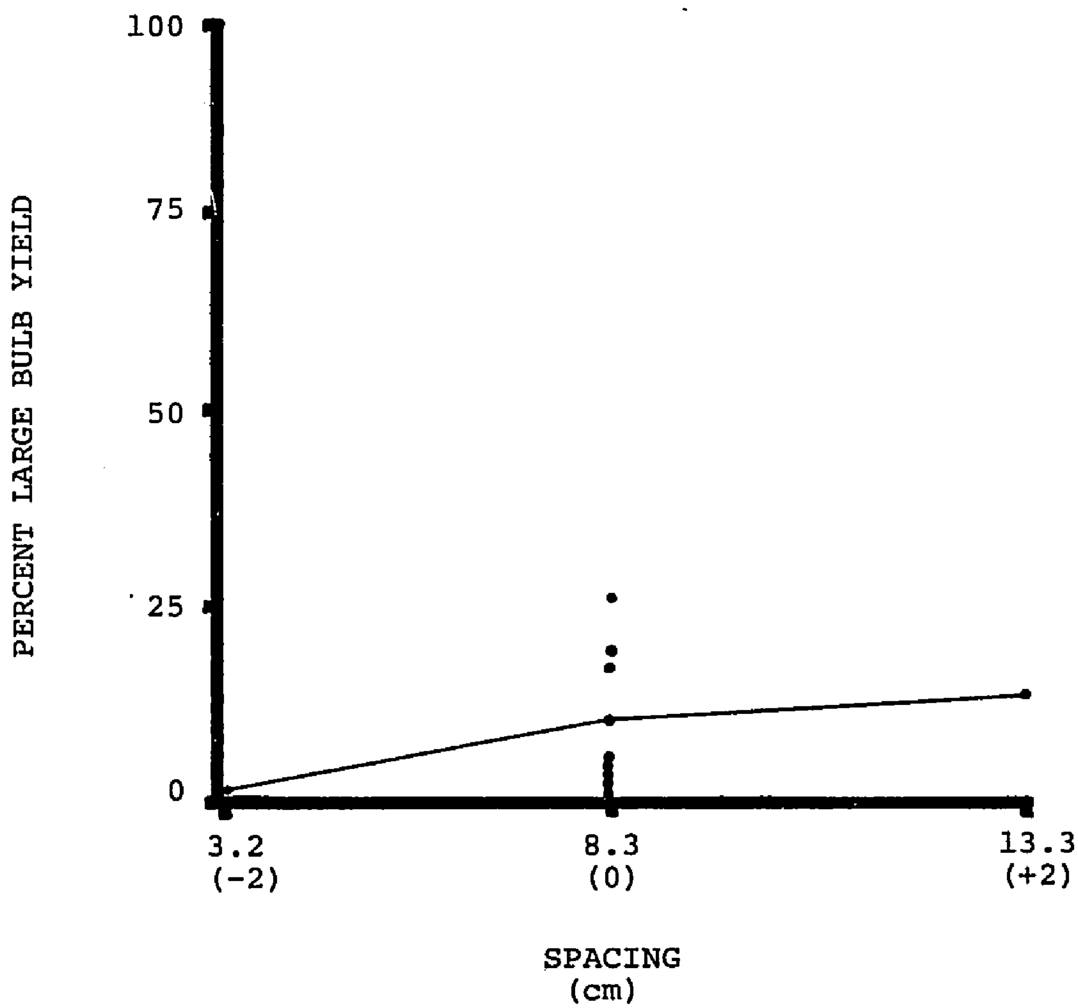

Figure 10. Effect of spacing on percent large bulb yield.

fell within the range of the 0 treatment yield, the data is not conclusive.

There is a certain amount of logic that enters into the expectations for the effect of this treatment. In order to produce 100 percent uniform, round, well shaped bulbs of at least 7.6 cm in diameter, there needs to be at least 7.6 cm between plant centers. If the standard is reduced, allowing for misshapen bulbs or allowing less than 100 percent large bulb yield, the spacing could be reduced slightly. Large bulb onions need to meet this special criteria, and meeting it may mean sacrificing on other results such as total yield. It was discussed previously that the increased size of the large bulb does not compensate for the decreased yield caused by a decreased population at the wider spacing.

Effect of Harvest Date on Large Bulb Yield

The date of harvest treatment was significantly significant at the five percent level in relation to large bulb yields. The -2 treatment, harvested on June 1, yielded none. Large bulb yield of the +2 treatment, harvested on June 29, was seventeen percent. The 0 treatment, harvested on June 15, yielded an average of 9.4 percent large bulbs over its nine rows. The extreme treatments, however, are both well within the range of 0 to 26 percent large bulbs of the 0 treatments as shown in Figure 11.

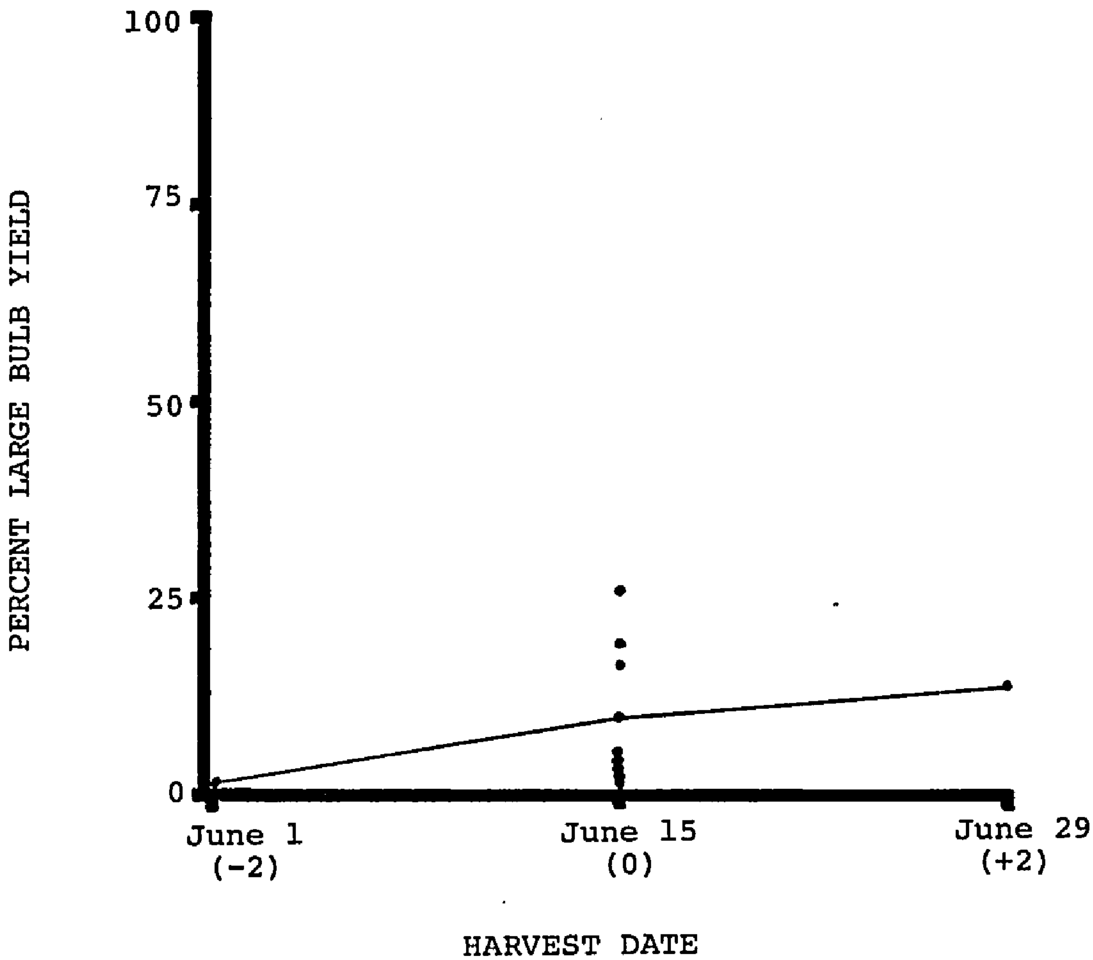

Figure 11. Effect of harvest date on percent large bulb yield.

Bailey (1984) directly addressed large bulb yields. Both researchers found that delaying the harvest date increased the yield of large bulb onions. The data from this study indicated that there was a mild significance to the date of harvest, but it was the least important of all the significant effects.

Effect of Fertilization on Large Bulb Yield

The application of fertilizer did not significantly effect large bulb yields. The -2 treatment, which did not receive fertilizer, yielded 6.3 percent large bulbs (> 7.6 cm in diameter). The +2 treatment, which received 656 kg N/ha, did not yield any large bulbs. The 0 treatment, which received 328 kg N/ha, averaged 9.4 percent large bulbs. The range on the nine 0 treatments was from 0 percent to 26 percent. Neither extreme fertilizer treatment was outside the range of the 0 treatments, and both of the extreme treatments had lower percentages of large bulbs than the check as shown in Figure 12.

As with the fertilizer effect on total yield, the effect of fertilizer on large bulb yield in this study was in conflict with the literature. Pandi and Mundra (1972), Bailey (1094), and Asiegbu and Uzo (1984) found that increased N increased the yield of large bulb onions. The reasoning that the timing of fertilizer application effected large bulb yield would be valid. Khashmelmous (1979) found

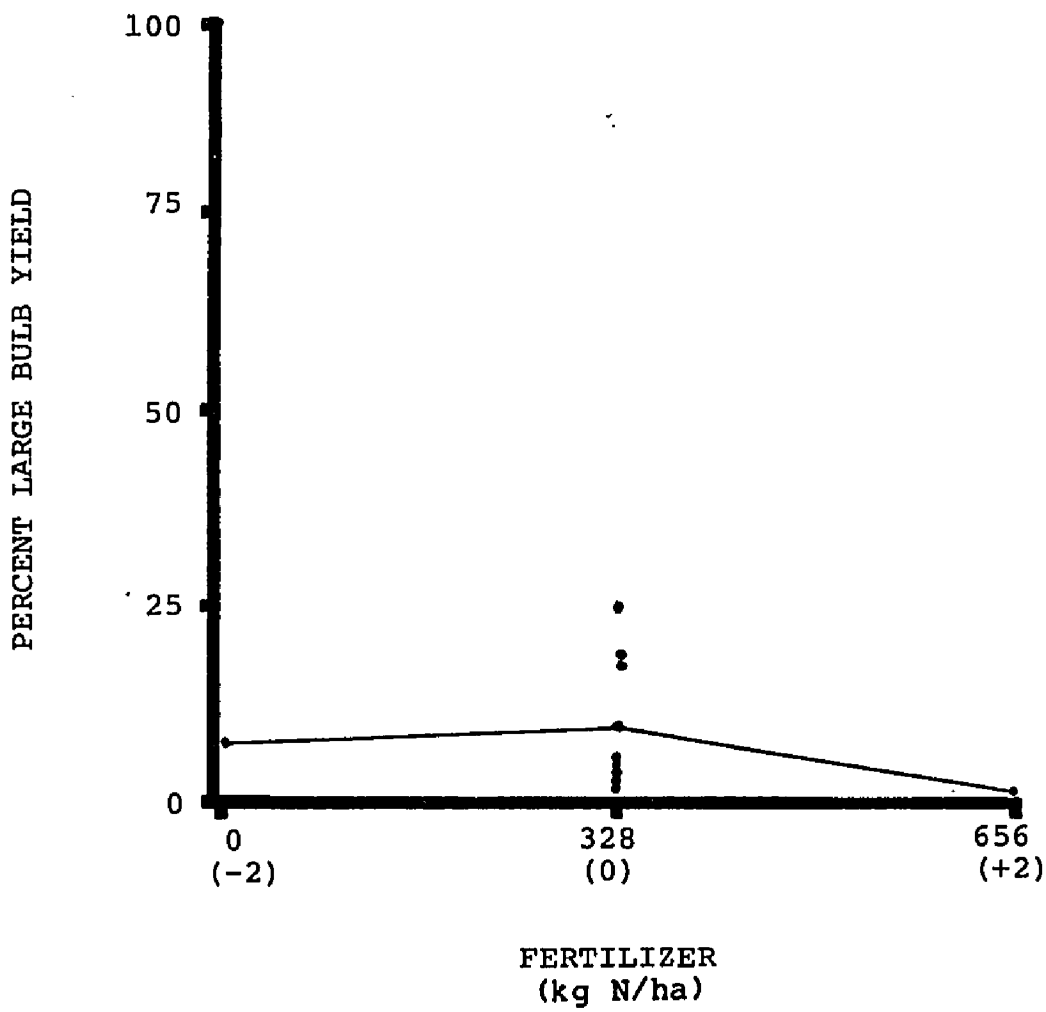

Figure 12. Effect of fertilizer on percent large bulb yield.

that late applications of N decreased large bulb yields as it did total yield.

The lack of P in the fertilizer would effect large bulb yield in the same manner that Singh and Singh (1969) felt it effected total yield. Their data indicated that there needed to be adequate P to utilize the N.

Effect of Seedling Conditioning on Large Bulb Yield

Seedling conditioning with the root stimulating solution was not statistically significant in relation to large bulb yield. Treatment extremes (-2) in which seedlings were soaked for ten minutes in water, and (+2) in which seedlings were also soaked for ten minutes in a solution of 94 ml root stimulation/liter of water, neither yielded any large bulbs. Both of these treatments were below the 0 treatment yield of 9.4 percent large bulbs as shown in Figure 13.

None of the literature cited deals with seedling conditioning in relation to large bulb yield. It is assumed that the results of this study are valid

Effect of Interactions

Effect of Interaction on Total Yield

One of the chief advantages of the RSM design is that one can examine interactions between factors. It was found that there were four major interactions between factors: seedling size x spacing, spacing x irrigation,

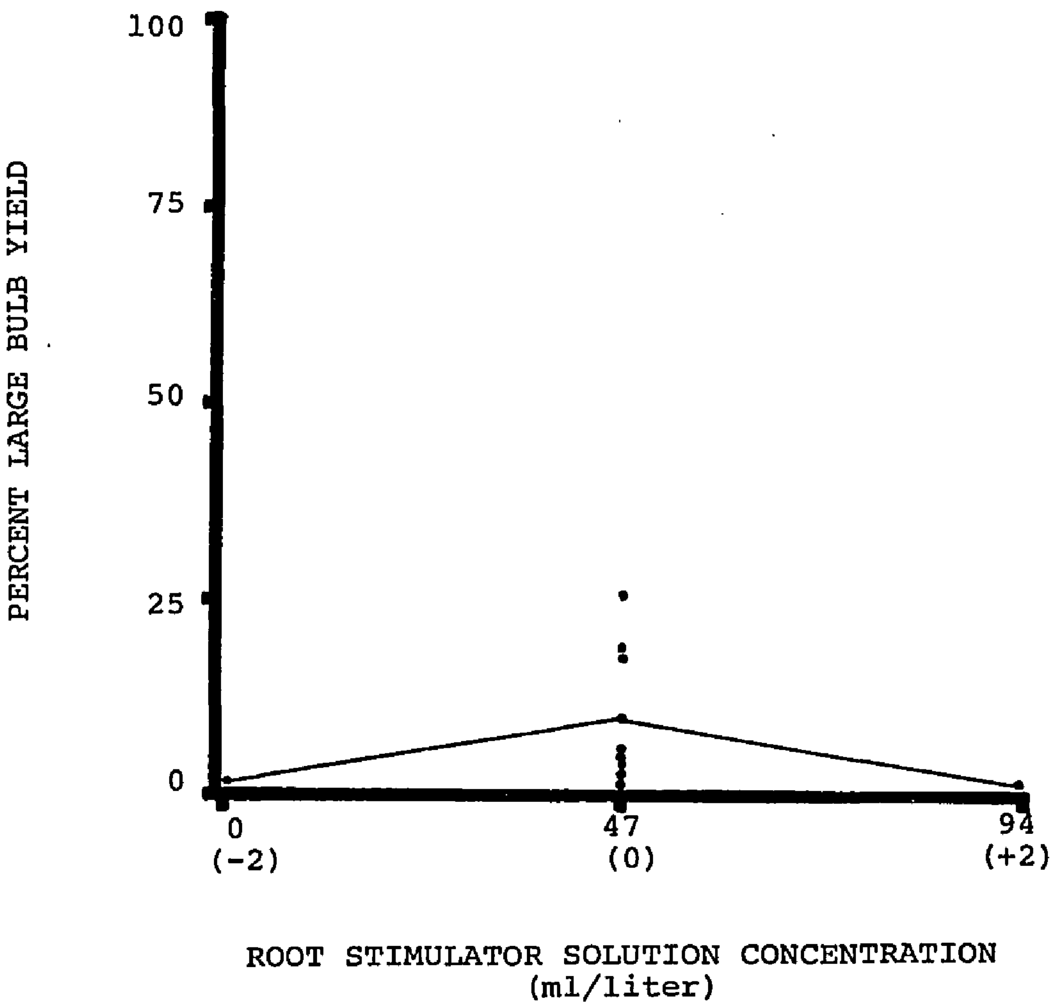

Figure 13. Effect of seedling conditioning on percent large bulb yield.

seedling size x irrigation, and date of harvest x irrigation.

Seedling Size x Spacing

Seedling size and spacing interact such that as spacing decreased and the seedling size increased the yield count progressively increased as shown in Figure 14. The yield lines showed a steepening of the ascent at an area between the 0 and the +1 seedling size treatment and between the 0 and -1 spacing treatment. This located the area of greatest change in total yield for the smallest increment in treatments. The area of the -1 to -2 spacing treatments and +1 seedling size also showed a change in the slope indicat- that the spacing became less important in increasing yield and the largest percent of the change was provided by increasing seedling size. This indicated that further decrease in the spacing did not have a significant role in increasing yield, and that the factor of seedling size should be explored to increase yield.

This interaction also indicates where "trade-offs" can be made in determining what level of inputs that are necessary to produce a certain yield. If outside considerations such as cost of seedlings or availability of sizes forces decisions, inadequacies can be compensated by adjusting spacing. Knowing how to make these adjustments based on interactions can be very important.

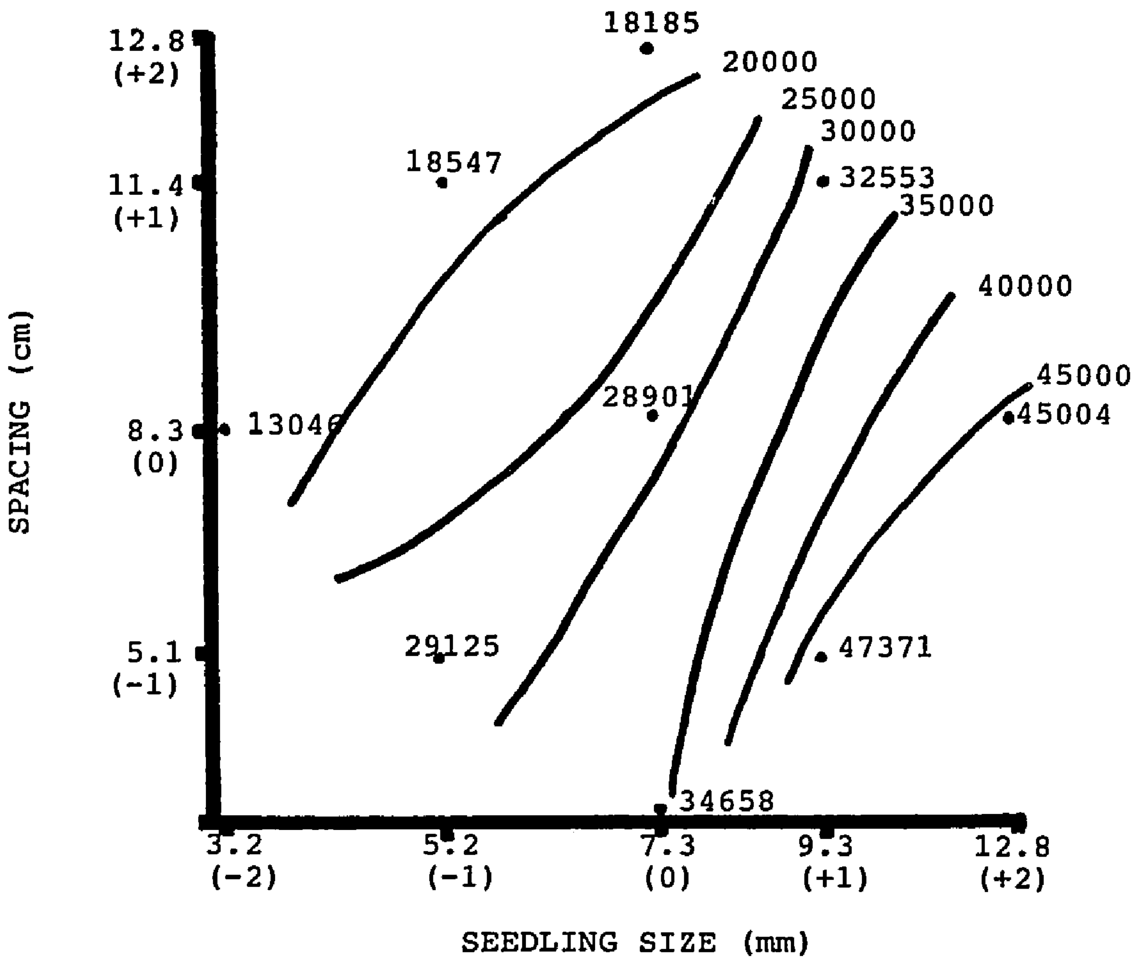

Figure 14. The interaction of spacing and seedling size on total yield (kg/ha).

Spacing x Irrigation

Spacing and irrigation had an interactive effect on total yield. Figure 15 shows that as spacing decreased and irrigation increased, the total yield increased. A number of observations can be made by analyzing the yield at lower irrigation levels (-2 to -1 treatments) and at the spacing levels of the -1 treatment, where spacing was more effective at increasing yields than irrigation.

At the +1 treatment for irrigation level, the slope of the yield line changed radically to nearly a flat slope. At treatments greater than +1 irrigation treatment level, the spacing had very little effect on the total yield. In the analysis of the singular effect of spacing on total yield, some doubt was cast on the validity of the results since the 0 irrigation treatment was less than the optimum. In analyzing the yield lines in Figure 15 at the +1 irrigation level, it appears that the +1 irrigation level, spacing would not have had an appreciable effect on the results. While the yields would have been increased, the difference in the -2 and +2 spacing treatments would have been less pronounced.

Additionally, the are of the +1 by +1 treatments had the area with the closest yield lines. While the slope of the yield lines indicated the irrigation treatment was contributing a disproportionate amount of the change in

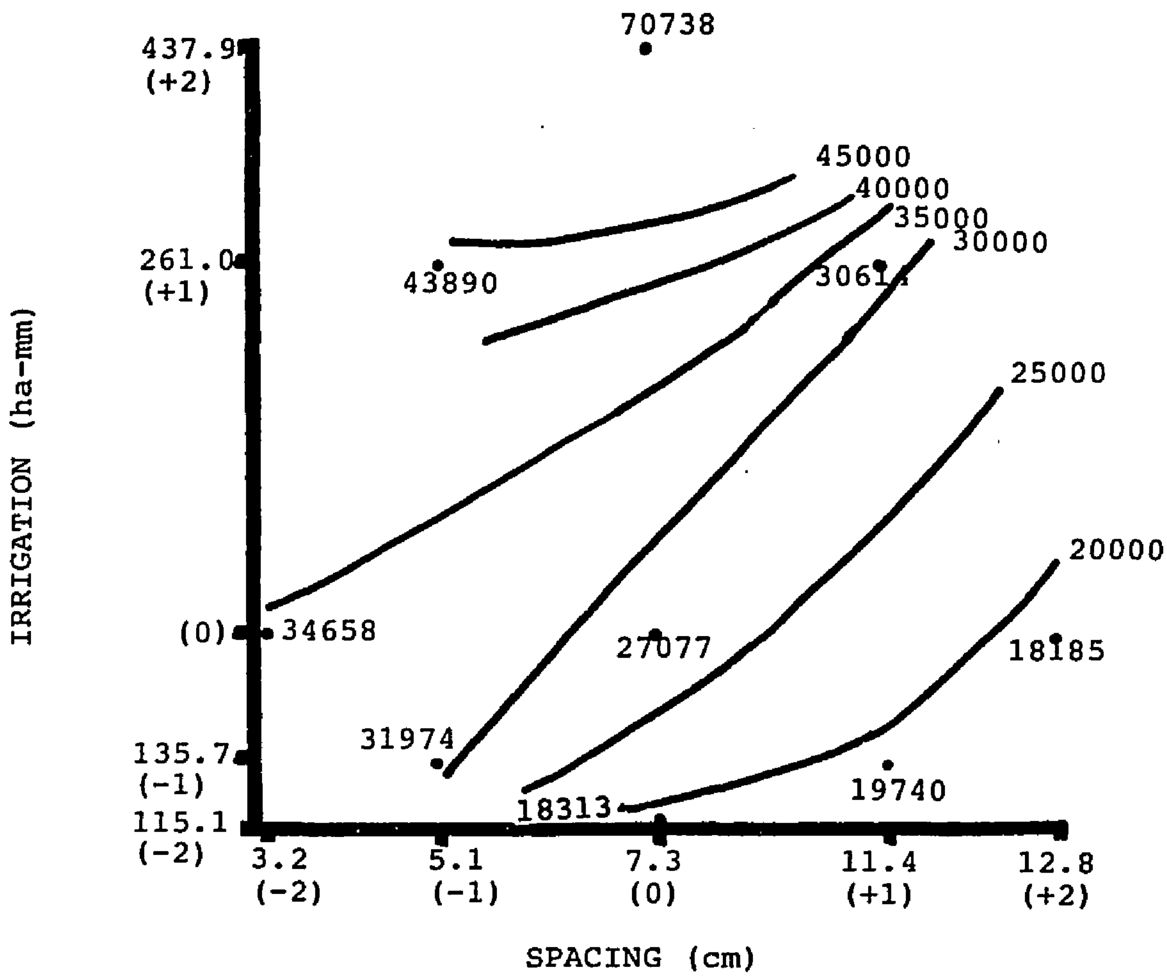

Figure 15. The interaction of irrigation and spacing on total yield (kg/ha).

yield, nevertheless this was the area of greatest change for the amount of treatment input.

Seedling Size x Irrigation

Seedling size and irrigation level treatments had an interaction that affected the total yield. Figure 16 shows an interaction that as irrigation increased and the seedling size increased, the total yield increased. The yield lines are nearly equidistant until reaching the +1 level of irrigation at the -1 seedling size level. At that point the lines are closer, indicating that additional inputs mean more substantial impact on the total yield. The data does show reasonably equidistant yield lines and an even slope throughout the heavily tested middle section which indicated that one treatment is not particularly dominant over the other in the interaction.

This interaction may have caused a difference in the singular effect of seedling size. If the 0 irrigation treatment had been at a higher level, the total yield difference between the -2 and +2 seedling size would have been more pronounced than the data shows.

Harvest Date x Irrigation

The interaction of harvest date and irrigation level is far less pronounced than the other interactions discussed. Figure 17 shows yield lines that are fairly flat, an indication of a weak interaction. The irrigation

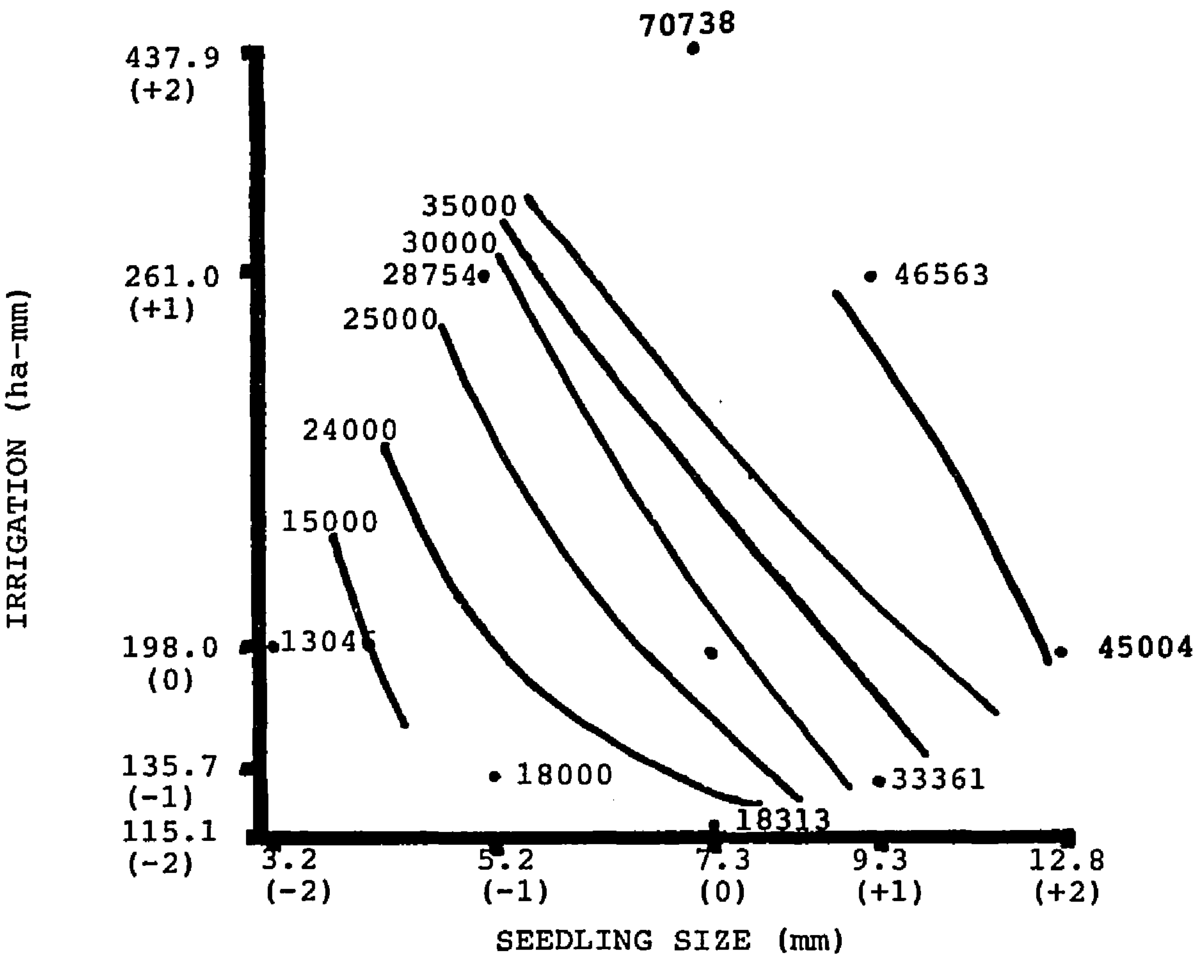

Figure 16. The interaction of irrigation and seedling size on total yield (kg/ha).

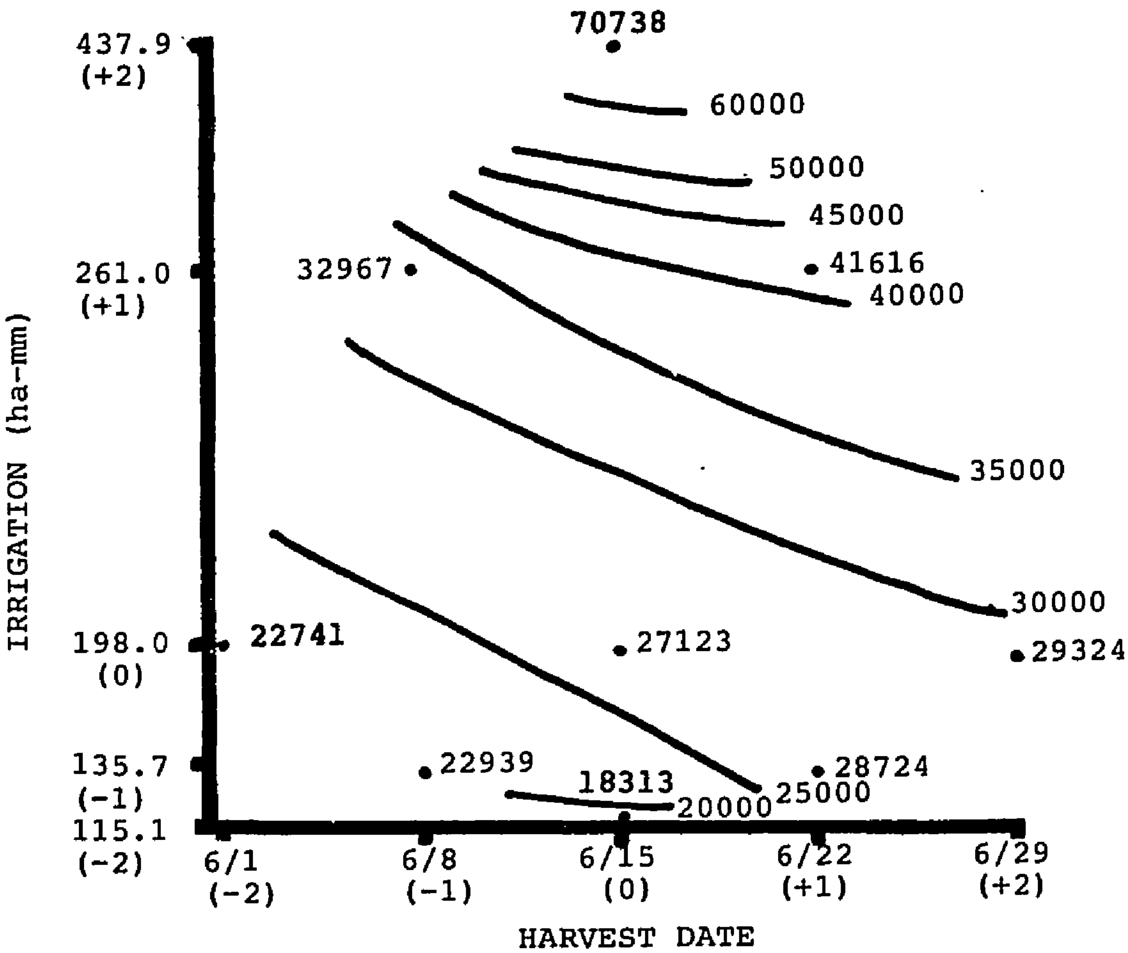

Figure 17. The interaction of irrigation and harvest date on total yield (kg/ha)

treatment provided the major part of the total yield change throughout most of the experimental range. Only in the late harvest by low irrigation area does it appear that harvest date was providing a significant amount of the total yield change. The area of the +2 harvest date and -1 irrigation level appeared to be the area where harvest date had the greatest effect on yield, but it was an area outside of the area of high reliability since there is no actual test data to plot.

As with the other treatment combinations in which there was an interaction with the irrigation level, a higher 0 irrigation level treatment may have had an influence on total yields of the two extreme harvest date treatments. In looking at the flatness of the slope, though, it is doubtful that a higher irrigation level would have made a significant difference in the singular effect of harvest date on total yield.

Effect of Interactions on the Percent Large Bulb Yield

The interactions of experimental factors and treatment levels are apparent in examining large bulb percentages. Three interactions, seedling size x irrigation, seedling size x spacing, and seedling size x harvest date are very distinct. One interaction, spacing x irrigation has an area that is suggestive.

Seedling Size x Irrigation

There was a definite interaction between seedling size and irrigation levels that affected the percent of large bulb yield. Figure 18 shows a very distinct set of percent yield lines that indicate that as irrigation levels and seedling size increase, the yield of large bulbs increased. The arrangement of the yield lines show that there is a seemingly "threshold level" to producing large bulbs. The wide distance between the one percent yield line and the ten percent yield line indicates that there is little effect of low irrigation or small seedling size on the large bulb yield. Then at the higher treatments of irrigation and larger seedling sizes a much greater impact on the yield of large bulbs is seen.

From the slopes of the lines it is apparent that seedling size is the dominant treatment in the interaction. At low irrigation levels the slope of the yield line are almost vertical indicating that irrigation level had little effect. Even at the high irrigation levels the slope was in favor of the seedling size though the slope did not approach a position of equality.

In examining the data, it is apparent that the effect of seedling size did intensify at the higher irrigation level of the +1 treatment. In looking at the singular effect of seedling size on large bulb yield, if the 0

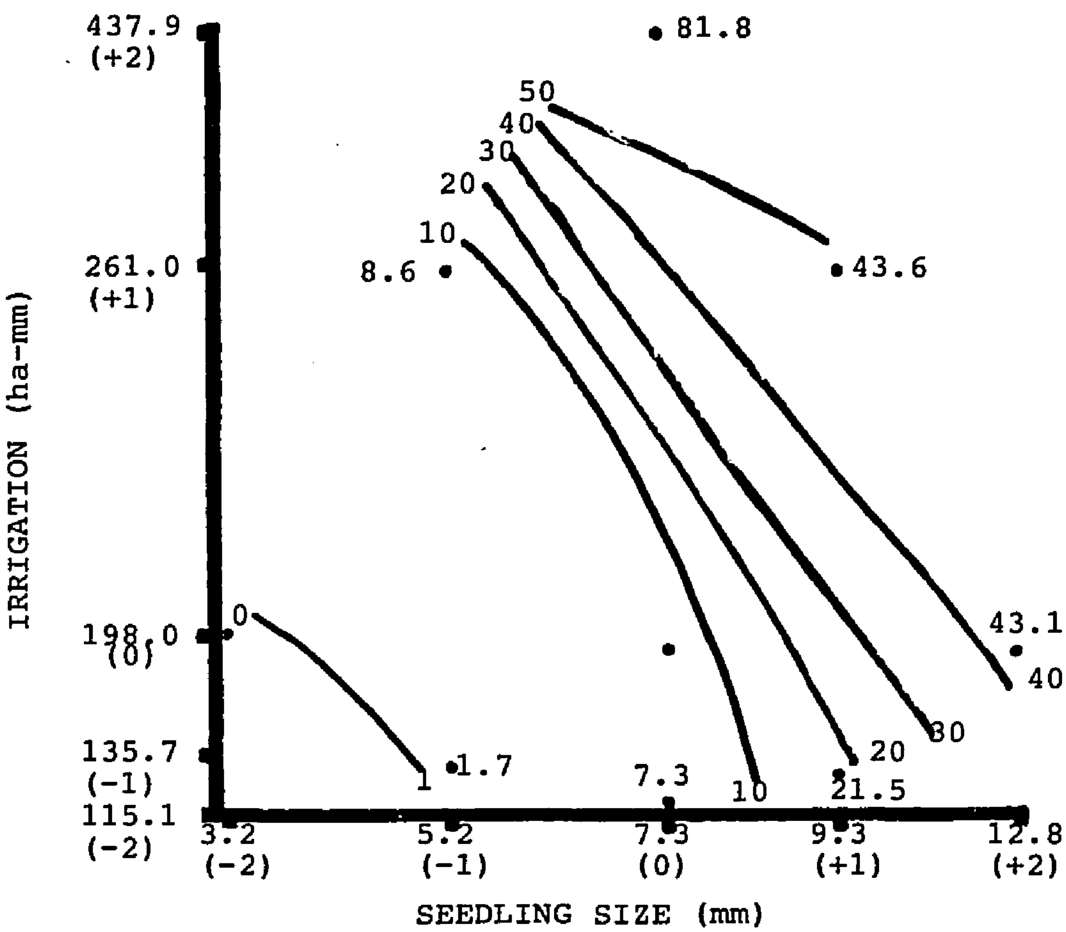

Figure 18. The interaction of irrigation and seedling size on the percentage large bulb yield.

irrigation treatment had been at a higher level, the effect of seedling would have been even more pronounced.

Seedling Size x Spacing

The percent yield lines of seedling size versus spacing resulted in an interesting pattern as shown in Figure 19. The data shows that when the spacing went above the 0 treatment, the slope flattened, indicating that seedling size was the dominant factor in producing large bulbs. This pattern is not as pronounced at the -1 spacing by -1 seedling size interaction area, where it appears that spacing has a larger role in the interaction.

This interaction provides valuable information if a decision needs to be made concerning these two factors, but there is one caution. This information is in relation to percent large bulb yield, not a yield of large bulbs. If this fact is overlooked, the results may be used to justify the use of wider spacing and smaller seedlings, a less expensive combination than narrower spacing and larger seedlings. The hazard is that the total yield of large bulbs will go down with the wider spacing even if the percent large bulbs is constant since there are fewer plants to bulb up. The economic savings at planting time must be carefully assessed against the probably decrease in total yield of large bulbs.

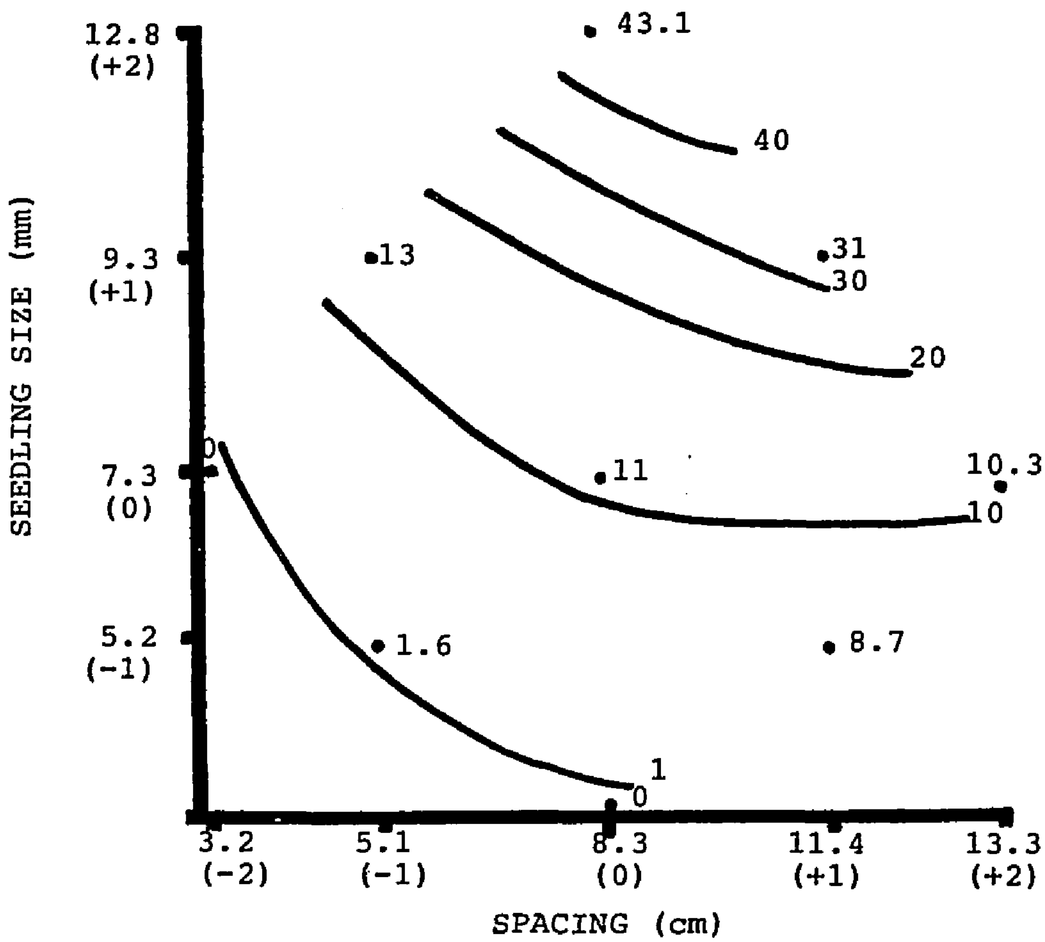

Figure 19. The interaction of seedling size and spacing on percent large bulb yield.

Seedling Size x Harvest Date

The interaction between seedling size and harvest date, as shown in Figure 20, is distinct but skewed toward increased seedling size. At the smaller seedling sizes, the harvest date appeared to have an equal impact on the percent of large bulbs. As the size of the seedling increased, the date of harvest became a less important factor. Given that the harvest date is often determined by factors such as price for the crop, it would appear that there would be little additional incentive to leave a crop in the field since the harvest date does not play a dominant role in large bulb yield.

Spacing x Irrigation

The interaction of spacing and irrigation as shown in Figure 21 has some very pronounced features, but also has an area of uncertainly in the area of the +1 to +2 spacing and 0 to -1 irrigation levels. The +1 spacing by -1 irrigation intercept and the +2 spacing by 0 irrigation intercept do not follow the pattern established by the rest of the data points. This indicates that possibly there is an area around the +2 spacing of low large bulb percent, or that the data may not be representative. The reliability of the +1, -1 point is higher than the +2, 0 point since the +1, -1 point is a mean of eight data points and the +2, 0 point is a singular data point. This is not conclusive so the area

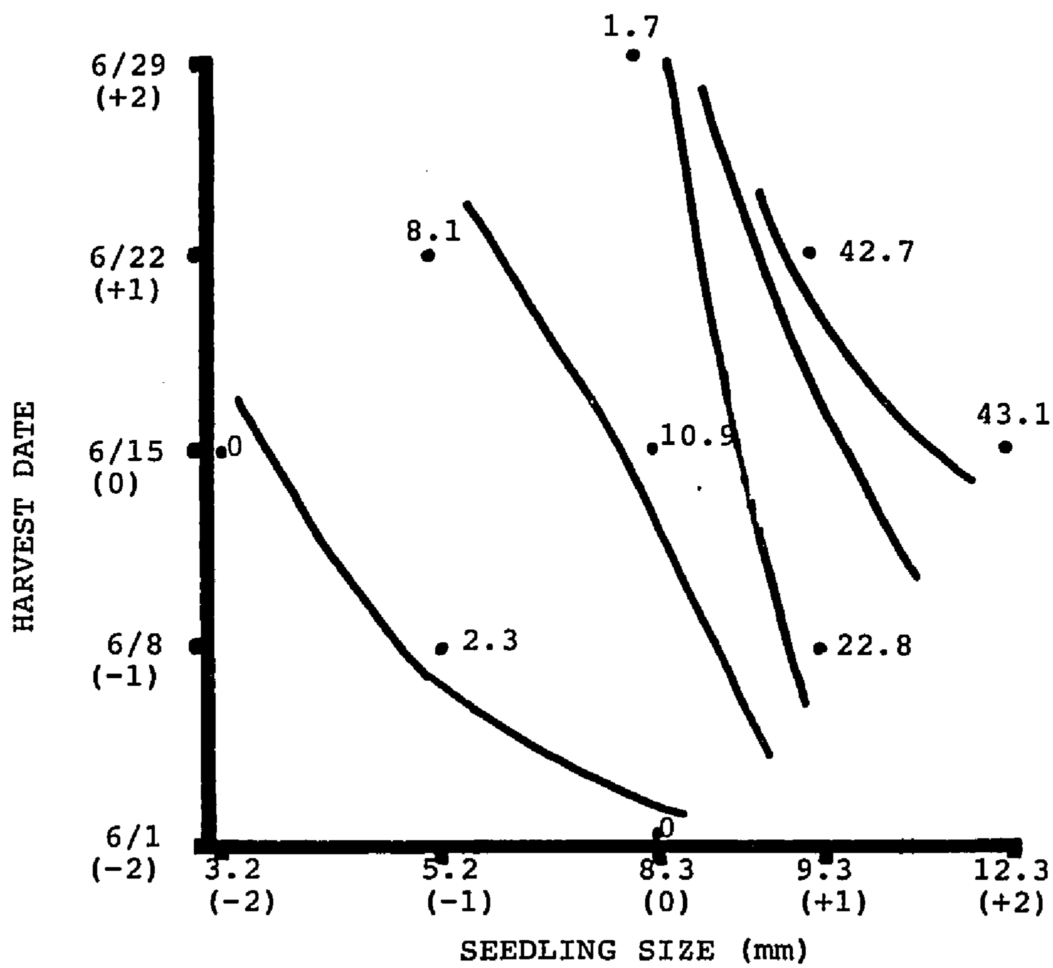

Figure 20. The interaction of harvest date and seedling size on percent large bulb yield.

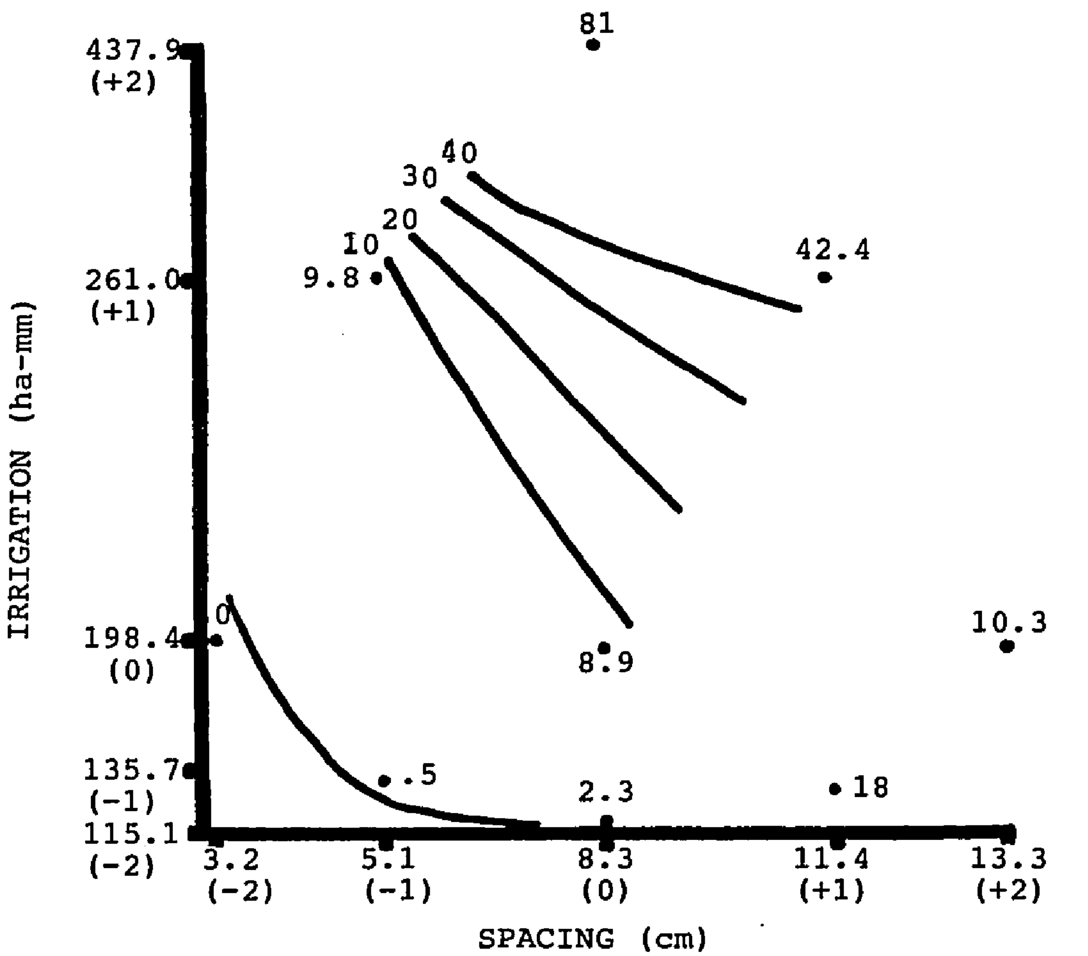

Figure 21. The interaction of irrigation and spacing on percent large bulb yield.

of the figure will not be discussed as part of the interaction.

As with the seedling size x irrigation interaction, the spacing x irrigation interaction appeared to have a threshold level that had to be met before large bulbs would be produced. The wide space between the one percent and ten percent yield lines indicated that neither irrigation nor spacing had a profound impact on increased yield of large bulbs in this range. Then above the ten percent level yield lines were much closer, indicating a very pronounced impact by the treatments. The slope remained fairly constant and equal though it did flatten at the +1 irrigation level.

This indicates that both factors roughly impacted the large bulb yield equally. It is unfortunate that it can not be determined whether this trend would continue at the wider spacings.

With irrigation having its greatest impact at the higher levels, it is very possible that the singular effect of spacing on percent large bulb would have been more dramatic if the 0 irrigation treatment would have been closer to the consumptive use point.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to determine the treatment levels necessary to increase the total yield and yield of large bulb onions. There were six cultural treatments at five levels to which the response was noted. While optimum levels of some of the cultural treatments have been established, the interaction of other treatments and possible effects on the optimum level have not been studied. Unfortunately, none of the six treatments were maximized, and therefore, specific optimums were not found.

The irrigation treatment had a very significant effect on total yield and percent of large bulbs. Due to an "optimum" irrigation that was below the consumptive use of water for onions, the full positive effect of irrigation was not seen. It was apparent that the low irrigation level had an impact on the significance of the seedling size in total yield and on seedling size in large bulb yield.

The size of the seedling had a significant effect in a positive linear relationship with both total yield and percent large bulb yield. In neither large bulb nor total yield was the response maximized and it may not be maximized until the seedlings fail due to excessive maturity or bolting. Factors such as availability of large seedlings, cost of large seedlings and ability to fit seedlings into mechanical planters would determine the maximum size of seedling to use. The seedling size also had a significant interaction with spacing for both total yield and large bulb yield.

In-row spacing of the plants was a significant treatment for total yield and for percent large bulbs. Spacing had a negative relationship with percent large bulb in both cases, though the results were somewhat misleading. With decreased spacing the total yield was increased but a majority of the bulbs were essentially too small to sell. With percent large bulbs, as the spacing increased, so did the percentage of large bulbs. What was misleading was that as the percentage of large bulbs went up, the total yield of large bulbs was decreased. The size of the bulb did not compensate for the reduction in population. From a commercial viewpoint a more useful measurement would have been the total yield of "large" bulbs (or any designated size).

The harvest date had slight significance on both percent large bulb yield and on total yield. As the harvest date was delayed, total yield and percent large bulbs increased. The harvest date also interacted with at least two other opposing parameters, plant maturity - the longer an onion grows the larger it will become until fully mature, and economics - the best prices for onions usually occur early in the season before the onions reach full maturity. Therefore, the optimum harvest date becomes a balance between economics and onion maturity.

The late application of N as a fertilizer treatment did not have a significant impact on either total yield or percent large bulbs. It was noted that in most other works fertilization did have significance. In this study it was reasoned that placement and timing along with composition of the fertilizer treatments acted to minimize fertilizer impact on yields.

The conditioning of the seedlings with a root stimulating solution had slight significance on total yield and no significance on percent large bulbs. The total yield increased slightly in a positive manner to the root stimulating solution. Graphically the response did not appear significant and when examined from a weight per bulb level, the treatment was not significant. In a related experiment the treatment was not significant. The conflict in the data concerning this response indicates that further work is needed in this area. There is little published working the area of root stimulation and the potential variations for further study are great.

The response surface design provided a number of advantages. It reduced the number of plots necessary to conduct a study of this kind. It allowed the observer to study how treatments interact. Finding an optimum level of treatment is an admirable goal in a single treatment experiment, but eventually, the single factor does interact with other factors, especially in agricultural studies where all the variables can not be controlled. These interactions also become much more important to producers of agricultural crops that have a constant fluctuation in the supply and cost of materials necessary to produce the crop and constant fluctuations in the end product desired. The knowledge of the interactions and how they effect the crop can provide invaluable flexibility to the producer that is attempting to maximize yield and profit.

Conclusions

The following conclusions can be made from this study:

1) Irrigation played a very important role in the production of onions, both in total yield and percent large bulb. Not only did irrigation have an impact as a singular factor but it also interacted with numerous other factors;

2) In-row spacing and size were also important factors, both singularly and interactively. Proper application of these factors can allow manipulation of the size of the onions at harvest;

3) Response surface methodology was very useful. It reduced the number of plots needed and allowed for examination of interactions;

4) Harvest date had a minor role in the yield and was a factor that had interaction implications with other factors.

Future studies definitely include irrigation treatments, either to maximize yields under ideal conditions or to maximize yields under dry conditions. Also important to investigate would be examining decreased spacing to the extent that total yield would be maximized. Another aspect would be to examine increased size of the seedling transplanted until the yield is maximized. The seedling conditionig with a root stimulating solution would merit additional study, focusing on both concentration and duration of the root soak. Solving the question surrounding the fertilizer ineffectiveness, whether it was timing, placement, or composition would also be a worthwhile area to pursue. Ideally one should pursue either large bulb yield or total yield. With many factors such as spacing, it will be difficult to maximize the effect on two opposite outcomes of total yield and large bulb yield. If large bulb yield is pursued, not only should the percent of large bulbs be studied but also the total yield of the large bulbs. This would be helpful in determining where the total yield of large bulbs declines even though the percent of large bulbs may remain constant. RSM should be part of any future work since it does give good insight into the interactions that can be useful and important.

APPENDIX A

APPENDIX A

Due to the fact that the root stimulating compound was a combination of five elements, a concurrent study was established to determine which, if any, of the five individual elements had an effect on total yield and percent large bulb yields.

This study was set up in a completely randomized design on a plot directly east of the main experiment and was separated by a buffer row. The seedlings of seven varieties of onions ('3237', '3238', '10304 Presidio', 'Brownsville', 'Ringer', 'Y Granex', and 'Texas Grano 502') were planted on March 16, 1986. Before planting, the roots of the seedlings were soaked in one of six solutions: five percent N, twenty percent P, ten percent K, 0.00004 percent IBA, 0.015 percent thiamine hydrochloride, or plain water. The plants were spaced at 8.3 cm, irrigated at the 261 mm-ha level, averaged 9.0 cm in diameter, and fertilized at the 328 kg N/ha level. The plants were harvested on June 15, weighed, cured, trimmed and reweighed along with the onions from the main study.

The ANOVA and Student-Newman-Keul Tests for both dry weight/bulb and percent large bulb are shown in the following tables. Since there was an equal number of bulbs/plot the conversion multiplier for dry weight/bulb to total yield would be the same, therefore, conversion is not necessary.

Table A.1 Two way ANOVA completely randomized
Variable: Dry weight/bulb

Source	SS	df	MS	F	P
Main Effects					
Root Stimulation Solutions	0.046	5	9.13E-03	1.83	.128
Varieties	0.110	6	0.01	3.68	.005**
*Interaction					
Root Stimulation x Varieties	0.099	30	3.30E-03	0.661	.880
Error	0.209	42	4.99E-03		
Total	0.4650778288	83			

Student-Newman-Keuls Test
Factor: Root Stimulating Solutions
Error mean square = 4.9973906E-03
Degrees of freedom = 42
Significance level = .05
LSD .05 = 0.05392142642

Treatment 1 = 5% N
2 = 20% P
3 = 10% K
4 = 0.015% thiamine hydrochloride
5 = 0.0004% IBA
6 = Control (plain water)

Rank	Treatment No.	Mean	n	Non-significant ranges
1	2	0.173	14	a
2	5	0.220	14	a
3	3	0.225	14	a
4	4	0.232	14	a
5	1	0.240	14	a
6	6	0.243	14	a

Student-Newman-Keuls Test
Factor: Varieties
Error mean square = 4.9973906E-03
Degrees of freedom = 42
Significance level = .05
LSD .05 = 0.05824179712

Variety Treatments
1 = 3237
2 = 3238
3 = 10304 Presidio
4 = Brownsville
5 = Ranger
6 = Y Granex
7 = Texas Grano 502

Rank	Treatment No.	Mean	n	Non-significant ranges
1	3	0.178	12	a
2	1	0.195	12	a
3	2	0.199	12	a
4	6	0.209	12	a
5	5	0.228	12	ab
6	4	0.258	12	ab
7	7	0.289	12	b

Table A.2 Two way ANOVA completely randomized
Variable: Percent large bulbs

Source	SS	df	MS	F	P
Main Effects					
Root Stimulation Solutions	0.044	5	8.76E-03	0.92	.447
Varieties	0.16	6	0.03	2.8	.022*
Interaction					
Root Stimulation x Varieties	0.263	30	8.76E-03	0.92	.582
Error	0.4	42	9.52E-03		
Total	0.87	83			

Student-Newman-Keuls Test
Factor: Root Stimulating Solutions
Error mean square = 9.5238095E-03
Degrees of freedom = 42
Significance level = .05
LSD .05 = 0.07443806501

Treatment 1 = 5% N
2 = 20% P
3 = 10% K
4 = 0.015% thiamine hydrochloride
5 = 0.0004% IBA
6 = Control (plain water)

Rank	Treatment No.	Mean	n	Non-significant ranges
1	2	0	14	a
2	6	0.014	14	a
3	5	0.028	14	a
4	4	0.042	14	a
5	1	0.042	14	a
6	3	0.071	14	a

Student-Newman-Keuls Test
Factor: Varieties
Error mean square = 9.5238095E-03
Degrees of freedom = 42
Significance level = .05
LSD .05 = 0.08040229957

Variety Treatments 1 = 3237
2 = 3238
3 = 10304 Presidio
4 = Brownsville
5 = Ranger
6 = Y Granex
7 = Texas Grano 502

Rank	Treatment No.	Mean	n	Non-significant ranges
1	1	0	12	a
2	3	0	12	a
3	4	0	12	a
4	2	0.017	12	a
5	5	0.017	12	a
6	6	0.084	12	a
7	7	0.126	12	a

Table A.3. Treatment levels, total yield, and percent large bulb yield.

Row No.	Irrigation	Root Stimulation Code	Fertilizer Code	Seedling Size	Spacing Code	Harvest Date Code	% Large Bulb Yield	Total Yield KG/HA
1	0	0	0	0	0	0	4.7	20347.
2	-1	1	-1	1	-1	-1	3.9	30053.
3	1	1	-1	-1	-1	-1	0	24979.
4	-1	-1	1	-1	-1	1	1.4	22247.
5	-2	0	0	0	0	0	2.3	18313.
6	0	0	0	0	0	2	17.0	29324.
7	1	1	1	-1	1	-1	15.2	24214.
8	-1	-1	-1	-1	1	1	2.9	17431.
9	0	0	0	0	0	0	10.9	28127.
10	-1	1	-1	-1	1	-1	0	14855.
11	1	-1	1	-1	1	1	30.3	29366.
12	1	-1	-1	-1	-1	1	4.2	42347.
13	-1	1	-1	1	1	1	23.5	20178.
14	1	1	-1	-1	1	1	15.2	25760.
15	0	0	-2	0	0	0	6.3	29324.
16	1	1	1	-1	-1	1	4.1	40005.
17	0	0	0	0	0	0	17.4	35907.
18	1	1	1	1	1	1	79.4	42675.
19	1	-1	1	1	1	-1	52.9	34604.
20	1	1	-1	1	-1	1	14.7	54837.
21	-1	1	1	1	1	-1	6.3	17602.
22	-1	1	1	1	-1	1	0	32785.
23	0	0	0	0	0	0	2.2	25853.
24	0	0	0	0	0	0	19.1	32436.
25	1	-1	1	1	-1	1	34.2	65180.
26	-1	-1	1	1	1	1	81.8	42933.
27	2	0	0	0	0	0	81.8	70738.
28	-1	-1	-1	-1	-1	-1	3.3	40591.
29	-1	-1	-1	1	-1	1	31.0	63618.
30	0	0	0	0	0	0	26.7	38181.
31	1	1	-1	1	1	-1	72.7	38811.
32	0	0	0	0	0	-2	0	22741.
33	1	-1	-1	1	-1	-1	20.3	53276.
34	-1	-1	1	1	-1	-1	1.3	34736.
35	1	-1	-1	1	1	1	73.5	38639.
36	0	0	0	-2	0	0	0	13046.
37	0	2	0	0	0	0	0	23459.
38	0	0	0	0	-2	0	0	34658.
39	-1	1	-1	-1	-1	1	0	21271.
40	1	-1	-1	-1	1	-1	0	14683.
41	-1	-1	1	-1	1	-1	0	7814.
42	0	-2	0	0	0	0	0	22981.
43	0	0	0	0	0	0	4.2	25494.
44	0	0	2	0	0	0	0	21425.
45	1	-1	1	-1	-1	-1	0	28684.
46	1	1	1	1	-1	-1	1.3	44491.
47	0	0	0	2	0	0	43.1	45004.
48	0	0	0	0	0	0	0	22502.
49	-1	1	1	-1	-1	-1	0	12880.
50	0	0	0	0	2	0	10.3	18185.
51	0	0	0	0	0	0	0	24178.
52	-1	1	1	-1	1	1	6.3	13996.
53	-1	-1	-1	1	1	-1	24.2	24987.

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