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The influence of drip irrigation on cotton petiole nitrates and yield

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THE INFLUENCE OF DRIP IRRIGATION ON COTTON PETIOLE NITRATES AND YIELD

by

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APPROVAL BY THESIS DIRECTOR

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24 July 87
Date

DEDICATION

This work is dedicated to my wife, Valerie K. Dahlberg, for her patience and encouragement throughout this whole learning experience.

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ABSTRACT

Three cotton (*Gossypium hirsutum* L.) cultivars were grown under field conditions at Eloy, AZ in 1985 and 1986 to investigate the effects of five drip irrigation treatments on yield, petiole nitrate concentrations, and fruiting characteristics.

Irrigation treatments ranged from 59 to 86 cm applied during the growing season. Petiole samples were collected once a week and analyzed for nitrate content. Flower and boll numbers and yield data were recorded throughout both years.

Results indicated that irrigation treatments had significant effects on yield with lower amounts of irrigation producing significantly lower lint yields. Significantly lower nitrate concentrations were also observed among the lower irrigation treatments. Irrigation treatments affected flower and boll production with lower irrigation treatments producing fewer flowers and bolls. Irrigation treatments did not significantly influence percent boll set, however, percent boll set was lower in the higher irrigation treatments. The higher irrigation treatments also produced heavier bolls.

INTRODUCTION

As Arizona moves closer to the 21st century, water conservation and the economics of obtaining water are becoming critical issues. Roughly 85 to 90% of all water consumed in Arizona is for irrigation of agricultural lands (Wilson et al., 1976). If Arizona agriculture is to continue, new and improved methods for efficient water use need to be developed.

Drip irrigation is one relatively new method that shows promise for conserving water. Drip irrigation is defined by Bucks et al. (1982) as the "precise, slow application of water in the form of discrete drops, tiny streams, or miniature sprays through mechanical devices called emitters or applicators located at selected points along water delivery lines." Substantial water savings and higher yields can be achieved with drip irrigation as compared to traditional slope-furrow irrigation.(Bucks et al., 1982; Davis, 1975; Goldberg et al., 1976).

Many obstacles hinder the use of drip irrigation as an economically viable tool for Arizona farmers. One of the greatest drawbacks is the initial cost of installation with estimates in 1984 running between $2000 and $3400 per ha (Wilson et al. 1984). Another serious problem is the management of cotton under drip irrigation. Drip is a new and more efficient irrigation technology where management of the system and of the crop plays a critical role in terms of maximizing yield. New and improved cotton management practices need to be developed in order to make drip irrigation economically feasible for the farmer.

LITERATURE REVIEW

Cotton is the most important crop in Arizona, making up nearly 50% of total harvested acreage since 1977 (Ayer, 1985). It requires, however, full season irrigation consuming up to 152 cm of water ha^{-1} (Hathorn, 1986; Kobriger and Oebker, 1985). Irrigated agriculture consumes roughly 85 to 90% of all water used in Arizona (Wilson et al., 1984, 1976). With many Southwestern States facing problems of water scarcity, rising energy prices, and deeper wells, drip irrigation, also known as trickle or micro-irrigation, is an alternative that can conserve water and improve farm profits (Wilson et al., 1984). The greatest potential for drip irrigation lies in areas where water is expensive or scarce, soils are sandy, rocky, or difficult to level, and high-value crops are produced (Bucks et al., 1982).

The history of drip irrigation has been well documented (Bucks et al., 1982; Davis, 1975; Davis and Bucks, 1983). The first experiments began in Germany in 1860, while the first work done in the United States was a study by House in 1913 that concluded that drip was too expensive for practical use (Davis, 1975). An Israeli, S. Blass, patented the first trickle irrigation system in the early 1960's and from Israel the trickle irrigation concept spread to other areas of the world (Davis, 1975). Drip irrigation of cotton in Arizona has been a recent phenomenon which started with a 0.4 ha experimental plot planted in 1979 (Wilson et al., 1984). Since then, cotton acreage under drip irrigation has increased to a high of 8930 ha in 1985 to approximately 4400 ha in 1987 (E.N. Biggs, 1987, personal communication).

Drip Irrigation

There are basically two types of drip systems; subsurface drip and surface drip (Bucks et al., 1982). Both systems use main lines, lateral lines, emitters, and the control station which may include flow meters, filters and screens, injection equipment, pressure regulators, and timers (Bucks et al., 1982; Davis, 1975; Davis and Bucks, 1983). Main lines carry water from the control station to the lateral lines. They are usually made of polyvinyl chloride (PVC) plastic pipe and may be buried or left on the soil surface (Davis, 1975; Davis and Bucks, 1983).

Lateral lines are generally flexible PVC, rigid polyethylene tubing or collapsible tape 9 to 19 mm in diameter (Davis and Bucks, 1983; Wilson et al., 1984). These lines carry water down plant rows and may run up to 300 m in length (Davis and Bucks, 1983).

Emitters, which are installed in lateral lines, are available in a wide range of designs (Bucks et al., 1982; Davis and Bucks, 1983). Their designs are classified into two general categories; line-source systems and point-source systems (Bucks et al., 1982).

Line-source systems discharge water at close spacings (less than 1 m) or continuously along a lateral line and are made up of perforations, porous walls, or holes in the lateral lines (Keller and Karmeli, 1975). Typically, line-source systems are used on small fruit trees, vegetables, or other closely spaced row crops (Bucks et al., 1982).

Point-source systems emit water from individual or multiple emitters placed in the lateral line and are spaced at least 1 m apart. These are typically used for tree crops, vines, ornamentals, and shrubs (Bucks et al., 1982).

Emitters are designed to deliver a predetermined flow rate (Davis, 1975; Davis and Bucks, 1983; Vaughn et al., 1980). This is normally achieved by small holes, long passage ways, vortex chambers, or other mechanical means which decrease the water pressure from the lateral to the soil (Davis, 1975).

Systems with lateral lines laid on the soil surface are the most widely used (Davis and Bucks, 1983). Typically, these systems are removed at the end of the growing season and may be installed in the same or a different field the following year. Advantages of these systems include ease of installing, inspecting and repairing main and lateral lines, and changing clogged emitters (Bucks et al., 1982). Disadvantages include interference with cultivation, harvesting, and other cultural practices (Bucks et al., 1982). Subsurface systems have gained wider acceptance in small fruit and vegetable crops. Advantages include freedom from anchoring main and lateral lines at the beginning of the growing season, little interference with cultivation, and a longer economical life (Davis and Bucks, 1983).

The control station is where irrigation water is pumped, filtered or screened, and measured. It also regulates the pressure and timing of applications (Davis, 1975; Davis and Bucks, 1983). Water quality determines the type and number of filters required for each station. In Arizona, three types of filtration are used; cyclone separators which operate as prefilters, screen filters which are used primarily to remove suspended inorganic matter, and sand-media filters which can remove some algae, inorganic matter, sand, silt, and other organic contaminants (Wilson et al., 1984).

Scheduling and applications of water and chemicals can be controlled with electrical or mechanical time clocks that activate pumps or solenoid valves

(Davis and Nelson, 1970). Paldi (1974) discussed the use of more sophisticated equipment such as soil moisture devices, microcomputers, and remote controllers in the full automation of drip irrigated systems in Israel.

The advantages and disadvantages of drip irrigation have been well documented (Bucks et al., 1982; Davis, 1975; Davis and Bucks, 1983; Marsh and Gustafson, 1971). In general, when compared to traditional irrigation techniques such as slope-furrow and sprinkler irrigation, drip irrigation has the potential to save water, by up to 50%, and increase yields at the same time. Irrigation efficiency has been defined by Israelsen (1950) as the ratio of water consumed by the crop to the water delivered to the project. With good furrow irrigation practices, irrigation efficiency can be as high as 60% (D.D. Fangmeier, 1987, personal communication), while poor irrigation practices can lower that figure to 12% (Israelsen, 1950). Under sprinkler irrigation, efficiency may reach 75%, while drip irrigation can by as high as 90% (Goldberg et al., 1976).

With conventional irrigation methods, water flow in the soil profile is in a vertical direction with negligible horizontal flow. With drip irrigation, only a small portion of the total soil surface is wetted and the flow patterns vary vertically as well as laterally (Bucks et al., 1982). The surface of the soil is wetted in a circular pattern and the wetted soil volume becomes onion shaped, meeting to form an elongated strip parallel to the cultivated rows (Goldberg et al., 1976). Water use decreases for many reasons; a smaller proportion of the soil volume is wetted, there is a decrease in surface evaporation because crop foliage covers much of the wetted area, there is reduction in runoff, and deep percolation losses below the crop root zone are controlled (Aljibury et al., 1974; Davis, 1975; Goldberg et al., 1976; Shoji, 1977).

Howell et al. (1981) reported that in 50 research papers reviewed, yields were equal or better in each case where drip irrigation was compared with either no irrigation or other water applications. They also reported that water use was equal or less with drip irrigation in all but two of the experiments. Bucks et al. (1973) reported, however, that cotton grown on fine-textured clay loam soil for 3 years yielded the same under both furrow and drip irrigation. Soil-moisture measurements of furrow irrigated cotton showed that consumptive water use was 103 cm or nearly the same as the consumptive water use of the various drip irrigation treatments. Soil type, therefore, plays a role in whether or not drip irrigation is more advantageous than furrow irrigation.

There are some distinct disadvantages to drip irrigation. One of the major drawbacks to this system is the high initial cost of installation with estimates ranging from \$2000 to \$3400 ha^{-1} (Wilson et al., 1984). Persistent maintenance requirements such as replacing clogged emitters are also a major disadvantage. Emitter blockage is a serious problem unless preventative measures are taken (Bucks et al., 1982; Davis 1975; Davis and Bucks, 1983). Blockages are caused by several factors. Particulate matter in the irrigation water, such as sand, rust, and algae, or smaller particles which adhere together to form large masses may interfere with water flow from the emitters (Pelleg et al., 1974).

Since drip irrigation normally wets only part of the soil-root volume, crop root development is restricted to a limited area (Davis, 1975). Three factors are responsible for determining the area wetted by the emitter; soil properties, discharge rates, and the amount of water applied (Goldberg et al., 1976).

Goldberg et al. (1971) reported that root density of carnations (*Dianthus*

Caryophyllus L. cv Red Sim) grown under drip irrigation was greatest near the emitter and became sparse as the distance from the emitter increased. Goldberg et al. (1976) also reported similar findings in peppers (*Capsicum annuum* L.) and tomatoes (*Lycopersicon esculentum* L.). In field studies carried out in the Arava and Sinai deserts, root systems grown under drip irrigation developed to only about 50% of their normal size (Goldberg et al., 1976).

Under temporary water stress, cotton's ability to carry on physiological activities with relatively little damage may be related to the presence or absence of available moisture in the soil layers below 1 m (Shimshi and Marani, 1971). Since only a small portion of the soil is wetted under drip irrigation, there is little or no deep percolation. This and the assumption that cotton root development under drip irrigation follows patterns reported on other crops (Davis, 1975; Goldberg et al., 1976, 1971) makes maintenance of emitters, lines, and the control station essential to prevent water stress during critical growth stages.

Role of Nitrogen in Cotton

Nitrogen is a constituent of all plant parts including the nucleus, chlorophyll, amino acids, proteins, and protoplasm. Ammonium and nitrate ions are the principal forms of nitrogen taken up by plants (Gardner et al., 1985).

All axillary primordia begin development as vegetative meristems. Fruiting branches arise from the transformation of these initially vegetative areas into flowering primordia (Mauney, 1984). Nitrogen has been shown to increase the number of vegetative branches in cotton and flower production may increase due to a greater number of flower initiation sites (Tucker and Tucker, 1968). It follows that with increased flowering, the potential exists for increased production of bolls and ultimately yield, provided other environmental conditions are favorable (Abbot et al., 1955). Nitrogen can also affect leaf area, vegetative growth, stem and branch length, plant weight, growth rates, earliness, boll shedding, lint and boll characteristics, and stomatal responses to water stress (Eaton and Rigler, 1945; Gardner and Tucker,1967; Hamilton et al.,1956; Radin and Ackerson, 1981; Radin et al., 1985).

The nutrient composition of the cotton plant varies throughout its development (Gardner and Tucker, 1967). Except for the seed, the percentage of total nitrogen in all tissue tends to decrease with maturity (Tucker and Tucker, 1968). Abbott et al. (1955) reported that the highest N% in both leaf blades and stalks of cotton appeared 60 days after planting regardless of the amount of fertilizer applied (0 to 110 kg ha^{-1}). After this period, there was a stepwise reduction in total N% throughout the plant. The decline in total N with time may be attributed to the development of "physiological sinks" (bolls which have a high requirement for plant nutrients and assimilates) (Mezainis, 1985). Recommended NO_3^--N levels for cotton over various stages of growth range from 15 000 to 18 000 mg kg^{-1} at first square to 4000 mg kg^{-1} at first open boll (Mackenzie et al., 1963; Ray et al., 1964).

A summary of California data indicated that 27 kg of N were required to produce 0.2 Mg of lint (Williams, 1970). Regardless of total N required by the cotton plant, it has been estimated that cotton removes 16 kg of N per 0.2 Mg of seed cotton harvested (Williams, 1970).

Symptoms of nitrogen deficiencies in cotton include chlorotic leaves which are considerably reduced in size. This change occurs first in the lower leaves as nitrogen reserves are translocated to apical meristem and fruiting forms. Lack of vigor and decreased growth are also symptoms characterized by small, short petioles and woody textured main stalks with few vegetative branches. Finally, disorganization of leaf cells occurs accompanied by formation of anthocyan. Leaves senesce, die, and eventually abscise (Guinn, 1982b; Tucker, 1984; Tucker and Tucker, 1968).

A drip system allows for fertilizer application with the irrigation water. Nitrogen can be injected into the system and becomes readily available for plant use within a short period of time (Bucks et al., 1982). Bucks and Nakayama (1980) recommend that nitrogen fertilizers be applied through drip systems if they do not corrode the system or clog emitters, are safe for field use, do not decrease yield, are soluble in water, and do not react adversely with salts and other chemicals in the irrigation water.

Stark et al. (1983) concluded that nitrogen use efficiency was improved with drip irrigated tomatoes resulting in improved economic yields. In order for any application of fertilizer to be efficient, the fertilizer must be applied and distributed uniformly throughout the field (Mezainis, 1985). Drip irrigation increases the efficiency of fertilizer applications by reducing deep percolation of water which removes nitrogen from the root zone (Goldberg et al., 1976). The ability of a drip system to move fertilizers into the region where most of the feeder roots develop also increases the efficiency of fertilizer applications (Goldberg et al., 1976).

With drip irrigation, it is possible to control nutrient supply in the soil in accordance with changing plant needs during the growing season (Bucks et al., 1982; Goldberg et al., 1971). Goldberg et al. (1976) research on carnations showed that N moves readily with water and the concentration of N in the soil near emitters becomes relatively low as the N is moved away from the emitters with the water front. Furthermore, root density in the vicinity of the emitters may also reduce N concentration. Since drip irrigation encourages the development of a shallow root system, the need for uniform distribution of water and nutrients becomes essential for improved yields (Goldberg et al., 1971).

The use of petiole analysis to monitor the nutritional status of cotton has been well documented (Amer and Abuamin, 1969; Baker et al.,1972; Bock and Adam, 1980; Joham, 1951; Mackenzie et al., 1963; Sunderman et al., 1979; Tucker and Tucker, 1968). Petiole analysis can detect excessive or deficient nitrogen levels in plants (Ray et al., 1964; Tucker and Tucker, 1968). Excessive nitrogen can cause abundant vegetative growth, delays in maturity, and reduced yields (Tabor et al., 1984) On irrigated cotton, research has shown a positive relationship between petiole nitrate concentrations and yield (Amer and Abuamin, 1969; Baker et al., 1972; Gardner and Tucker, 1967; Grimes et al., 1973; Mackenzie et al., 1963; Maples et al., 1977; Sunderman et al., 1979).

Tabor et al. (1984) evaluated the variability in the collection of petioles for nitrate study and concluded that consistency can be obtained by collecting petioles from the first mature leaf. Tucker (1984) stated that when sampling petioles, the leaf age was a more important consideration than leaf location because younger leaves are stronger sinks for metabolites.

Sunderman et al. (1979) reported that cotton cultivars (Paymaster Dwarf and Dunn 56-C) did not appear to differ in petiole NO_3^--N concentration with any degree of consistency. Their evidence suggested that cultivars that perform well in narrow row spacing will yield similar petiole NO_3^--N concentrations when grown under similar cultural and environmental conditions.

Problems can occur in the use of a petiole analysis program. Beneficial responses to nitrogen application cannot be expected if factors other than nitrogen are limiting yield and this may explain why petiole analysis may not be helpful in some cases (York, 1982). York (1982) also reported "people problems" where slow turnaround time from tissue analysis labs hindered the effectiveness of corrective fertilizer applications. By the time a nitrogen deficiency is positively identified by petiole analysis it can be too late to correct (York, 1982). Accuracy in laboratory analyses may also be questionable (York, 1982).

Flowering and Boll Development

The appearance of three bracts rather than a true leaf distinguishes the first true differentiation of a flower bud on the branch axis. Flower part differentiation takes place from the broad dome meristem. Flower development takes 40 to 50 days from differentiation to anthesis (Mauney, 1984). Carpel formation occurs 35 days before anthesis, 10 to 14 days before the flower bud (square) becomes visible (Mauney, 1984). Wadleigh (1944) found that regardless of N treatments, cotton began flowering on about the same date. However, nitrogen had a marked influence on the termination of flowering with nitrogen deficient plants exhibiting a determinate flowering pattern. Plants treated with high nitrogen applications flowered over a much longer period of time and produced a flowering pattern similar to that of indeterminate cotton.

Square and boll shedding is influenced by many environmental conditions including soil moisture, insect damage, temperature, and plant nutrition (Guinn, 1985, 1982b). Guinn (1974) reported that factors which decrease photosynthesis or increase respiration may delay fruiting and decrease retention of floral buds and bolls.

Research on the effects of water stress on fruit and boll production in cotton has led to many conflicting conclusions. It was shown in the early 1900's that drought can cause severe boll shedding (Ewing, 1918; Lloyd, 1920). It has been estimated that up to 70% of the yield potential for a cotton crop can be lost to premature shedding of squares and young bolls (McMichael et al., 1973).

In general, water stress affects fruiting and boll abscission by decreasing the total number of potential fruiting points which may be caused by several factors; a general reduction in shoot growth, decreased photosynthesis, decreased leaf size, stomatal closure, decreased synthesis and activity of photosynthetic enzymes, increased production of ethylene and abscisic acid (ABA), and increased photorespiration (Guinn, 1982a, 1976; Jordan, 1986; Lipe and Morgan, 1973). Guinn and Mauney (1984a) concluded that water stress caused a severe reduction in flower production with unstressed plots producing an average of 214 as compared to 185 flowers m^{-2} within stressed plots.

Guinn (1982a) suggested that boll shedding in response to prolonged drought was basically a survival mechanism. Boll abscission increased in a linear manner as leaf water potentials dropped from -1.0 to -2.4 MPa (McMichael et al., 1973). Guinn and Mauney (1984b) reported that as leaf water potential dropped below -1.9 MPa, boll retention was significantly reduced.

Guinn (1982a), Mauney et al. (1980), and Singh (1975) showed, however, that moderate stress early in the season may sometimes be beneficial and a moderate preflowering stress may increase the rate of blooming and yield. Others have reported that moderate water stress can be positive by preventing excessive vegetative growth during flowering, decreasing flower shedding, and increasing the number of flowers and bolls produced (Dunlap, 1945; Harris and Hawkins, 1942; Stockton et al., 1961).

The timing, duration, and intensity of water stress are important. Researchers have reported that square shedding early in the season is not affected by water deficit (Bruce and Romkens, 1965; Mauney et al., 1980). However, water deficits after flowering has begun increases square shedding (Grimes et al., 1970; McNamara et al., 1940). Guinn and Mauney (1984b) reported that cotton severely stressed in early July retained 10% of the flowers that bloomed between 9 and 11 July and that water deficit significantly reduced subsequent flowering and fruiting rates. Similar findings have also been reported by Grimes et al. (1970) and Guinn et al. (1981).

Cutler and Rains (1977) reported that plant height, dry weight of tops and leaves, and leaf area of Acala SJ 2 was reduced with water stress. Singh (1975) concluded that the treatment of soil moisture stress during the post-flowering period showed unfavorable effects on most cotton plant characteristics and yield. Marani and Amirav (1971a) reported that lint yield was reduced significantly by moisture stress induced during both the beginning of the flowering period and during the second half of the flowering period. Lint yields of Acala 4-42 and Deltapine Smoothleaf grown in the Bet-She'an valley in Israel ranged from 0.27 Mg ha^{-1} in non-irrigated treatments to 2.00 Mg ha^{-1} in fully irrigated treatments in 1966 (Marani and Amirav, 1971b).

Nitrogen-Water Interaction

The growth and yield of cotton is dependent upon the availability of water and nitrogen throughout the growing season. Hamilton et al. (1956) working with Acala 44 cotton found a positive interaction between moisture and nitrogen on yield. High levels of moisture and N produced more lint cotton than would have been expected if the effects had been merely additive. Hearn (1975) reported that the interaction between water and nitrogen affected the number of bolls produced and crop yield. Scarsbrook et al. (1959) reported that water use efficiency was affected by water-nitrogen interaction. The interaction of high water and nitrogen applications resulted in 100% more lint than high water applications with no added nitrogen. Mezainis (1985) reported, in drip irrigated cotton, that nitrogen uptake during the season was significantly increased by both water and nitrogen additions, however, nitrogen by water interactions only slightly affected boll numbers and weight and fiber properties.

It is clear that cotton growth under drip irrigation is complex and requires research to better understand plant development. It is also clear that petiole analysis is an important tool by which the nutritional status of the plant may be monitored and adjusted throughout the season. The objectives of this research were:

1. To determine the effects of five drip irrigation treatments on petiole NO_3^--N concentration of three cotton cultivars.
2. To study the effects of five drip irrigation treatments on lint yield.
3. To evaluate the interaction of water and petiole NO_3^-

-N concentrations on yield and fruiting characteris-

tics.

MATERIALS AND METHODS

The study was conducted on a private farm near Eloy, AZ in 1985 on a variable Mohall sandy loam (fine-loamy, mixed, hyperthermic Typic Haplargids) soil containing areas of Denure loam (coarse-loamy, mixed, hyperthermic, Typic Camborthids) and in 1986 on a Denure sandy loam soil. Tillage in 1985 included deep plowing followed 9 months later by two diskings, land planing and furrowing to form the beds. Seedbed preparation in 1986 was similar with the exception of the deep plow. The 1985 field had previously been planted in cotton while the 1986 field had previously been the site of a feed lot and then been fallow since 1982.

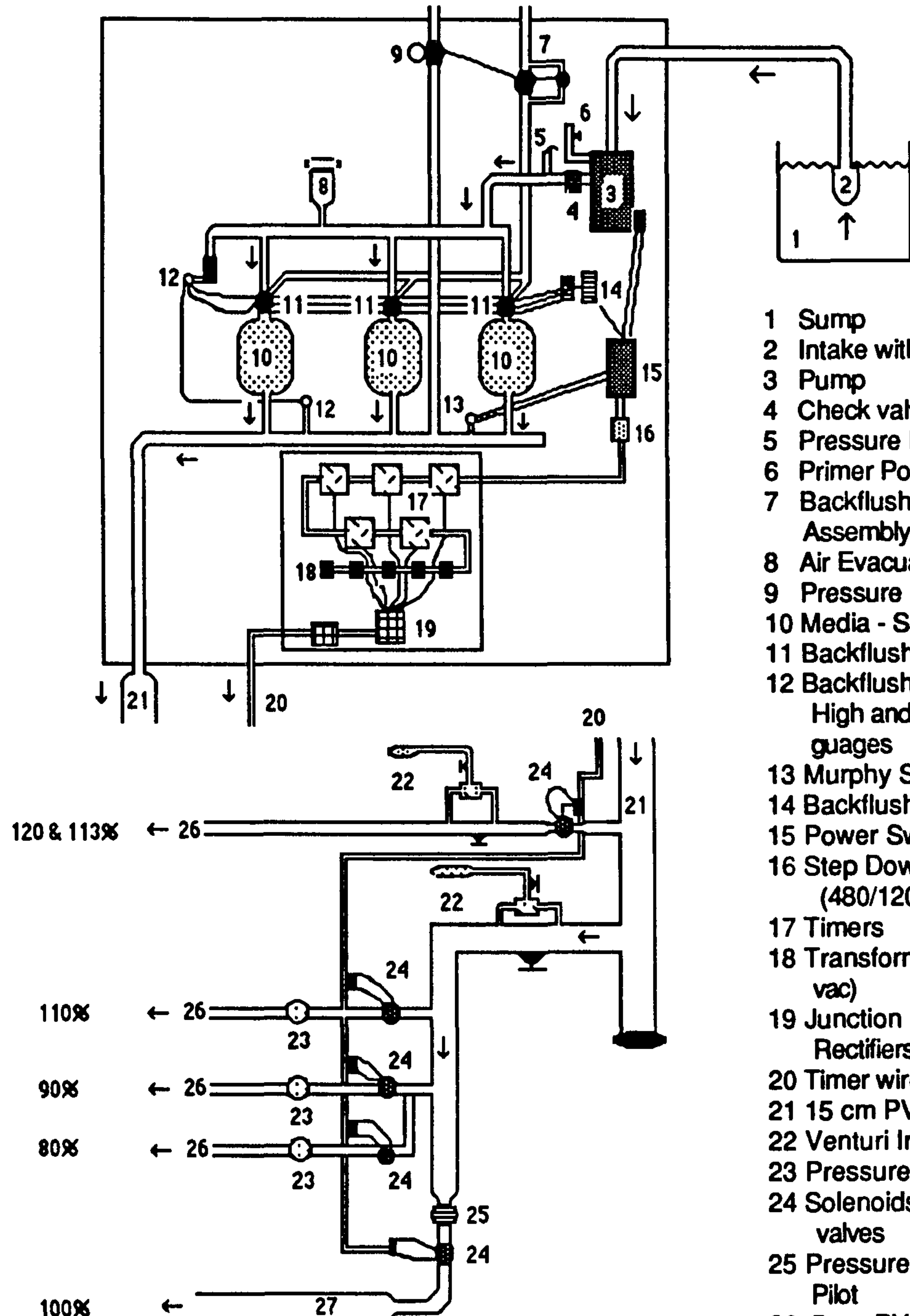
A split-plot experimental design with a factorial set of sub-plot treatments was used. Main plots were replicated six times. The main plots were made up of five water treatments 80, 90, 100, 110, and 120% of 76 cm in 1985 and 80, 90, 100, 110, and 113% of 71 cm in 1986. The 100% treatment was based on what the field manager felt was adequate moisture levels for normal growth of the cotton throughout the year. The sub-plots were three cotton cultivars (Deltapine (DP) 41, 90, and 77) grown under three planting rates (6, 11, and 22 kg seed ha^{-1}). In 1986, the planting rate of the 113% water treatment was increased to 34 kg seed ha^{-1}.

The main plots ran north to south and each contained nine sub-plots 12 m in length with six rows (97 cm spacing). Each sub-plot was separated by 2 m alleys and the outside rows served as borders. Rows two and five were used in flower and boll studies while rows three and four were used exclusively for machine harvesting. Three border plots on the north end of field separated the experiment from a road. Two border plots on the south side, along with 12 border rows on the east and west end, separated the experimental site from another cotton field.

A surface drip irrigation system, capable of supplying different volumes of water to the field, was developed (Fig. 1). Five electrical timers controlled the time irrigation water was applied to each main plot. Each timer was connected to a solenoid which controlled a diaphragm valve. Lateral lines, 191 m in length, connected to the main lines were positioned in the center of each seedbed. Emitters (1 L h^{-1}) were spaced at 1.0 m intervals along the lateral lines.

A 13 cm preplant irrigation was applied to the field in 1985. The 1986 field was planted dry and watered up. On 26 Apr. 1985 and 19 Apr. 1986, the plots were planted using a John Deere planter modified for planting experimental plots. Poor emergence in 1986 forced the replanting on 29 April. A second lateral line was added to each seedbed in 1986 to insure that adequate water was available for seed germination. Removal of the second set of drip lines occurred on 20 May. The 113% water treatment was hand thinned to 48 000 plants ha^{-1} on 12 May 1986.

In 1985, 28 cm of water were applied to all plots before treatments began. Water treatments were initiated on 7 June with total irrigation for the season equalling 60, 68, 76, 83, and 86 cm for the 80, 90, 100, 110, and 120% water treatments, respectively (Fig. 2). Water treatments in 1986 began on 4 June (Fig. 2) after 24 cm of water had been applied to all plots. Total irrigation was 59, 65, 71, 78, and 80 cm for the 80, 90, 100, 110, and 113% water regimes,



1 Sump
2 Intake with Footvalve
3 Pump
4 Check valve
5 Pressure Release valve
6 Primer Port
7 Backflush Throttling Assembly
8 Air Evacuation valve
9 Pressure Relief valve
10 Media - Sand Filters
11 Backflush valves
12 Backflush Switch with High and Low side guages
13 Murphy Switch gauge
14 Backflush Control Panel
15 Power Switch
16 Step Down Transformer (480/120 vac)
17 Timers
18 Transformers (120/24 vac)
19 Junction Box with Rectifiers
20 Timer wires
21 15 cm PVC Pipe
22 Venturi Injectors
23 Pressure Regulators
24 Solenoids and Diaphram valves
25 Pressure Regulating Pilot
26 5 cm PVC Pipe
27 10 cm PVC Pipe

Fig 1. Schematic of pumping and filtering station. Arrows indicate flow of water to plots when all diaphragm valves are open and backflush system is disengaged. Percentages represent different water treatments with 120 and 113% being treatments in 1985 and 1986, respectively.

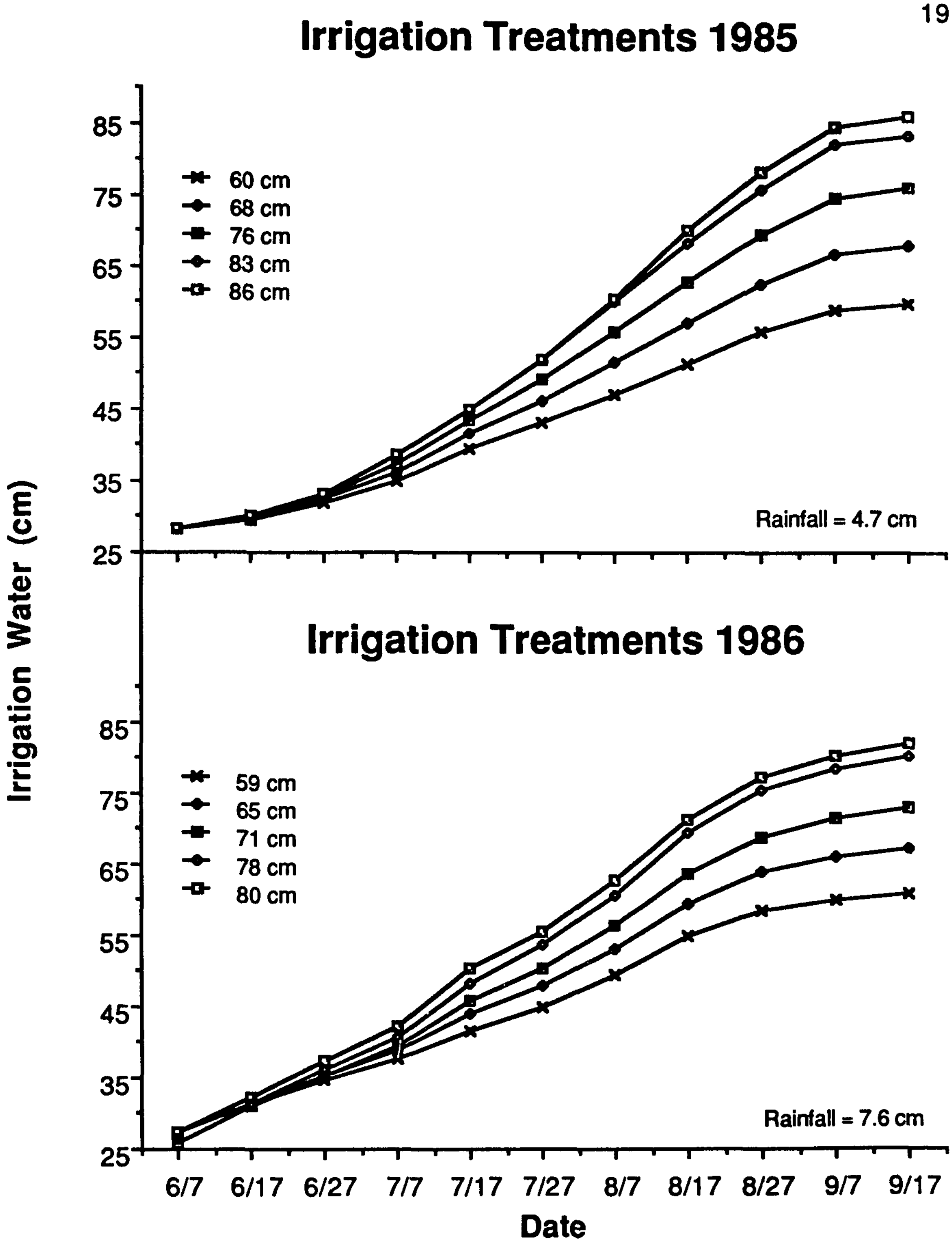


Fig 2. Total irrigation applied to all treatments over the growing season, Eloy, AZ, 1985 and 1986.

respectively. The plots were irrigated every other day between 7 to 19 June 1985 and 4 to 17 June 1986. After these initial periods, irrigation was run every day until treatments ended in September 1985 and 1986 except on days when rainfall occurred.

Preplant soil samples in 1985 contained 14 mg kg^{-1} NO_3-N and the well water contained 1.04 mg kg^{-1} of NO_3-N. The fertilizers Soln-32 (urea-ammonium nitrate) and N-pHuric (urea-sulfuric acid adduct) were injected into the lateral lines through Venturi injectors. Total N applied in fourteen applications throughout the year for the 80, 90, 100, and 110% irrigation treatments was 189 kg N ha^{-1}. The 120% irrigation treatment received 304 kg N ha^{-1} also applied in 14 applications throughout the year. In 1986, high residual soil NO_3-N (10.5-38.5 mg kg^{-1} in upper 15 cm and approximately 14 to 40 mg kg^{-1} in the next 30 cm) and irrigation water NO_3-N (1.46 mg kg^{-1}) resulted in relatively low total N fertilizer applied. The 80,90, 100, and 110% water treatments received a total of 38 kg N ha^{-1}, while the 113% water treatment received a total of 49 kg N ha^{-1} in seven separate applications. During both years, occasional applications of N-pHuric were used to prevent precipitation of lime in emitters and chlorine was used to prevent the build up of algae throughout the system.

In 1985, 0.7 kg active ingredient ha^{-1} of trifluralin (2,6, dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl) benzenamine) and 1.1 kg active ingredient ha^{-1} of prometryn (*N*,*N*'-bis(1-methylethyl)-6-(methylthio)-1,3,5-triazine-2,4-diamine) were applied preplant and incorporated to control annual grasses and broadleaf weeds. In 1986, a preplant unincorporated application of 1.1 kg active ingredient ha^{-1} of prometryn (*N*, *N*'-bis(1-methylethyl)-6-(methylthio)-

1,3,5-triazine-2,4-diamine) and 1.0 L ha^{-1} of pendimethalin (*N* -(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine) was applied on 25 April to control annual grasses and small-seeded broadleaf weeds.

In the 1985 season, the postemergent herbicide prometryn (*N* ,*N* '-bis(1-methylethyl)-6-(methylthio)-1,3,5-triazine-2,4-diamine) (0.4 kg ha^{-1}) was injected into the drip lines on 13 August for control of common purslane (*Portulaca oleracea* L.). On 3 July 1986, pendimethalin (*N* -(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine) (2.04 L ha^{-1}) was applied as a non-incorporated band over the drip lines to control common purslane. Hand hoeing was used both years.

The 1985 pest management program included applications on 16 May of adlicarb (2-methyl-2-(methylthio) Propionaldehyde-O-C-(methylcarbamoxyl)) and methomyl (S-methyl-N-(methylcarbamoyl) oxy-thioacetimidate). These were followed by sulfur (S) and cypermethrin (cyano-3-phenoxybenzyl (+) cis, trans, 3-(2,2-dichloro vinyl)-2,2-dimethyl cyclopropane carboxylate) on 28 August and a dual application of monocrotophos (dimethyl-(E)-1-methyl-2-methyl-carbomoyl vinyl phosphate) on the 14 and 17 July.

The 1986 pest management program began with an application on 31 July, 6 and 14 August of the pyrethroid insecticide tralomethrin ([1R [1(S*) 3 (RS*)]]-2,2-dimethyl-3-(1,2,2,2-tetrabromoethyl) cyclo-propanecarboxylic acid oc-cyano-3(3-phenoxyl phenyl) methyl ester) was flown on the field at 0.5 L ha^{-1}. Monocrotophos (dimethyl-(E)-1-methyl-2-methyl-carbomoyl vinyl phosphate) was applied on 22 August at 1.5 L ha^{-1} followed by three applications of methyl-ethyl parathion (methyl, ethyl, 0,0-diethyl 0-4-nitrophenyl phoshorothioate) (1.5 L ha^{-1}) flown on 28 August, 3 September, and 10

September.

Petiole samples were collected on 14 dates in 1985 uniformly spaced between 28 June and 24 September and 12 dates in 1986 between 26 June and 15 September. Twenty petioles picked randomly from the youngest, fully expanded leaves were collected from rows two and five for a total of 40 petioles per sub-plot. Samples were collected from all three cotton cultivars planted at 11 kg ha^{-1} over all five irrigation treatments and all six replications. Petioles were oven dried at 75^{o}C for 24 hrs and then ground using a U D Corporation Cyclone Sample Mill.

A 2-point calibration of a Corning 150 pH/ion meter (Corning Ltd., 1983) was performed using two working standards of 10 and 100 mg N kg^{-1} (Baker and Smith, 1969). To keep a constant background ionic strength, 26.4 g of reagent-grade $(NH_4)_2SO_4$ were placed in a 100 ml volumetric flask, dissolved and brought up to 100 ml with distilled water to form an ionic strength adjustor (ISA) (Corning 150 pH/ion meter manual). Two milliliters of ISA were added to every 100 ml of working standards. The outer chamber of the Orion double junction reference electrode (Corning, Ltd., Model 90-02) was filled with a filling solution made up of 2 ml of ISA in 100 ml of distilled water. The inner chamber was filled with Orion 90-00-02 colored filling solution and replaced weekly. Outer chamber fluid was changed daily.

Ground petiole samples weighing 0.1 g were placed in 125 ml Erlenmeyer flasks. Twenty-five ml of nitrate extracting solution (Baker and Smith, 1969) and 0.5 ml ISA were added to each flask. Solutions were agitated for 20 minutes at 100 rpm on a shaker table and then filtered through grade 613 VWR filter paper into 25 ml beakers. Samples were agitated by hand and analyzed using a

Corning 150 pH/ion meter with an Orion (Corning Ltd., Model 90-07) nitrate electrode.

In 1985, readings were taken directly from the pH/ion meter and NO_3^--N concen-trations were calculated using the following formula:

$$NO_3^- \text{-N} = \frac{R * ES}{S}$$

where R = readings from the meter - 10 mg kg^{-1} NO_3^--N in extracting solution

ES = ml of extracting solution used

S = grams of sample

In 1986, a calibration curve was developed using solutions of known con-centration. This curve was used to derive sample NO_3^--N concentrations in mg kg^{-1} from readings taken from the pH/ion meter.

In 1985, four of the water treatments (60,68,76 and 83 cm) planted with DP 90 at 11 kg seed ha^{-1} were selected for flower and boll studies. Subplots, 1.8 m in length, were randomly selected from rows two or five of each plot and staked. Color coded tags were attached to the peduncle of each 1 day old flower bi-weekly between 26 June and 29 Aug. 1985.

In 1986, tagging began on 7 July and continued bi-weekly until 8 September. Flower tagging was conducted on all plots planted at 11 kg seed ha^{-1}. Thirty subplots, 1.8 m in length, were randomly selected from row two of each plot. Tagging ended in late August 1985 and early September 1986 because flowers produced after these dates do not produce mature bolls (Erie et al., 1968).

On 6 and 7 Nov. 1985 and 23 and 24 Oct. 1986, mature bolls produced from tagged flowers were hand harvested. All untagged open bolls were collected to estimate yield. The number and weight of tagged bolls and the weight of the untagged bolls were recorded.

In 1985 Texas root rot (*Phymatotrichum omnivorum*) devastated 18 petiole nitrate and flower study plots in the southern end of the field. These plots were abandoned and subsequent data were treated as missing in statistical analysis. A mid-season infestation of rust (*Puccinia cacabata*) affected all plots uniformly. A pump breakdown between 16 and 20 July 1985 resulted in all plots being visibly stressed.

In 1985, the defoliant sodium chlorate was flown on the field 3-4 weeks before machine harvesting. Harvesting occurred on 18 Nov. 1985. In the 1986 season, the defoliants sodium chlorate and endothal (mono(N,N-dimethylalkylamine)) were applied at the rates of 23.4 and 1.2 L ha^{-1}, respectively. Machine harvesting followed on 19 Oct. 1986. In both years, a modified spindle picker was used to harvest rows three and four of each sub-plot. The seed cotton from each sub-plot was bagged and weighed separately.

In 1985, seed cotton yield was adjusted according to visual estimates of percent loss due to Texas root rot observed in machine harvested rows. Any plot with more than 25% loss was not included in statistical analysis. Any plot with less than 25% loss had its yield adjusted proportionally based on the percent root rot and the actual yield collected from the remainder of the plot. Samples collected during machine harvesting were weighed before and after ginning and a turnout percentage was calculated to determine lint yield.

Since flower tagging was conducted bi-weekly, a regression was used to estimate the number of flowers produced on days when tagging did not occur.

Two separate polynomial stepwise regression programs were performed as outlined by Kalazieh (1986).

Data were analyzed statistically using Analysis of Variance (ANOVA) and Multivariate Analysis of Variance (MANOVA). Treatment means were separated by Duncan's Multiple Range Test and Least Significant Difference (LSD). The 5% level of significance was used in all cases, unless otherwise designated.

RESULTS AND DISCUSSION

Yield

The average lint yield for the 1985 irrigation study was 1.33 Mg ha^{-1}. The analysis of variance, ANOVA, showed highly significant lint yield differences ($p=0.01$) among irrigation treatments. Lint yields ranged from 0.89 to 1.72 Mg ha^{-1} with the 60 cm irrigation treatments producing significantly lower yields than all other irrigation treatments (Table 1). Lint yields from the 86 cm irrigation treatment were 9 to 12% lower than lint yields reported for the same three cultivars (DP 41, 90, and 77) grown in 1985 with 87 cm irrigation at Maricopa, AZ (French et al., 1986). Lint yields were not influenced by cultivars or by the interaction between irrigation treatments and cultivars.

Several problems contributed to keep yields relatively low. Stand establishment was a major problem. Because the drip lines were positioned between the seed rows, water did not uniformly wet the seed beds and seeds did not emerge uniformly. Seedling emergence varied throughout the field from 2 to 6 weeks. Drip lines were moved from one seed row to another to alleviate this problem. This technique is quite labor and time intensive and may prove to be economically infeasible on large cotton farms such as those found in Arizona. Four hours were required by two research assistants to move drip lines from one seed row to another in the 8 ha experiment. After two days of constant irrigation, drip lines were moved to the other seed row for irrigating. Finally the drip lines were moved to the center of the seed beds. The Israelis have tried to solve this problem by furrow irrigating for stand establishment and

Table 1. Cotton lint yields of three cultivars grown under five irrigation treatments, Eloy, AZ, 1985.

Irrigation Treatments	Lint Yields: Cultivar DP 41	DP 90	DP77	Mean
cm	Mg ha^{-1}			
60	0.95 a†	0.94 a	0.89 a	0.92 a
68	1.25 ab	1.27 abc	1.24 ab	1.25 b
76	1.44 b	1.55 c	1.49 bc	1.49 c
83	1.42 b	1.14 ab	1.72 c	1.43 cb
86	1.58 b	1.47 bc	1.62 c	1.56 c

† Individual irrigation treatment means within a column followed by the same letter are not significantly different according to the Least Significant Difference test at the 5% level of confidence.

then installing the drip lines into the field (Avihi Danon, 1987, personal communication). In order to use this technique, farmers must have the ability to both furrow irrigate his field then switch over to a drip irrigated system. Also, the possibility of seedling damage when drip lines are placed into the field is another problem.

A mid-season infestation of cotton rust infected all plots and contributed to the relatively low yields. However, this was not as severe a problem as the pump breakdown between 16 and 20 July which stressed all plots during a peak flowering period. Any type of water stress during this period has been shown to reduce yields (Grimes et al., 1970, Guinn, 1982a; Guinn and Mauney, 1984a, 1984b; McMichael et al., 1973). Both of these problems affected all plots uniformly and relative differences among treatments are still valid.

The average lint yield in the 1986 irrigation study was 1.84 Mg ha^{-1}. The lint yields were significantly different ($p=0.05$) among irrigation treatments. Lint yields ranged from 1.66 Mg ha^{-1} to 1.97 Mg ha^{-1} with the 59 cm irrigation treatment producing significantly lower lint yields than that of the 65, 71, and 78 cm irrigation treatments (Table 2). Lint yields were not influenced by cultivars or by the interaction between irrigation treatments and cultivars.

The average lint yield for the 1985 and 1986 irrigation studies was 1.58 Mg ha^{-1}. The multivariate analysis of variance, MANOVA, found highly significant lint yield differences ($p=0.01$) among irrigation treatments. The 60 and 59 irrigation treatments produced significantly lower yields than all other treatments. Average lint yields were 1.33 (60 and 59 cm irrigation treatments), 1.56 (68 and 65 cm irrigation treatments), 1.68 (76 and 71 cm irrigation

Table 2. Cotton lint yields of three cultivars grown under five irrigation treatments, Eloy, AZ, 1986.

	Lint Yields			
	Cultivar			
Irrigation Treatments	DP 41	DP 90	DP77	Mean
	Mg ha^{-1}			
(cm)				
59	1.66 a†	1.77 a	1.79	1.74 a
65	1.86 b	1.87 ab	1.85	1.86 b
71	1.88 b	1.95 b	1.83	1.89 b
78	1.89 b	1.97 b	1.83	1.90 b
80	1.89 b	1.84 ab	1.77	1.83 ab

† Individual irrigation treatment means within a column followed by the same letter are not significantly different according to the Least Significant Difference test at the 5% level of confidence.

treatments), 1.66 (83 and 78 cm irrigation treatments), and 1.69 (86 and 80 cm irrigation treatments) Mg ha^{-1}. Highly significant lint yield differences (p=0.01) were also detected among years. In general, mean lint yields were 28% greater in 1986 than in 1985 (Tables 1 and 2). No interaction between years and irrigation treatments were detected.

Petiole Analysis

The MANOVA (Table 3) showed highly significant petiole NO_3^--N concentration differences (p=0.01) among irrigation treatments in 1985. The 60 cm irrigation treatment had significantly lower petiole NO_3^--N concentrations than did all other irrigation treatments (Fig. 3). This is contrary to the findings Mezainis (1985) reported in which seasonal petiole NO_3^--N concentrations were not influenced by irrigation treatments. There were significantly different (p=0.05) petiole NO_3^--N concentrations among cultivars with DP 90 mean seasonal petiole nitrate levels (5810 mg kg^{-1}) significantly lower than DP 77 (5880 mg kg^{-1}) which in turn was significantly lower than DP 41 (6260 mg kg^{-1}).

The MANOVA (Table 3) detected highly significant petiole NO_3^--N concentration differences (p=0.01) among sampling dates with nitrate levels tending to decrease with plant maturity. These results agree with research done by other workers (Abbott et al., 1955; Gardner and Tucker; 1967, Tucker and Tucker, 1968). Petiole NO_3^--N concentrations were significantly influenced (p=0.05) by the interaction between irrigation treatments and cultivars. In general, the lower irrigation treatments tended to have lower nitrate concentrations within all three cultivars (Tables 4, 5, and 6). Petiole NO_3^--N

Table 3. Analysis of variance for petiole nitrate concentrations of three cotton cultivars under five irrigation treatments, Eloy, AZ, 1985.

Source of Variation	df	SS	MS	F	Significance
Sub-subplots	1126	13905.929			
Subplots	89	822.634	9.243		
Main plots	29	659.719	22.749		
Blocks	5	104.706	20.941	13.370	*
Irrigation	4	523.688	130.922	83.590	**
Main Plot Error	20	31.326	1.566		
Cultivars	2	25.962	12.981	8.290	*
Irr. X Cultivars	8	58.660	7.333	4.680	*
Subplot Error	50	78.293	1.566		
Date	13	9882.726	760.210	485.350	**
Irr. X Date	52	661.363	12.719	8.120	*
Cultivars X Date	26	406.068	15.618	9.970	*
I X C X D	104	96.525	0.928	0.590	NS
Sub-subplot error	842	1318.841	1.566		

*, **, F ratios significant at the 0.05 and 0.01 levels of probability, respectively
NS, not significant..

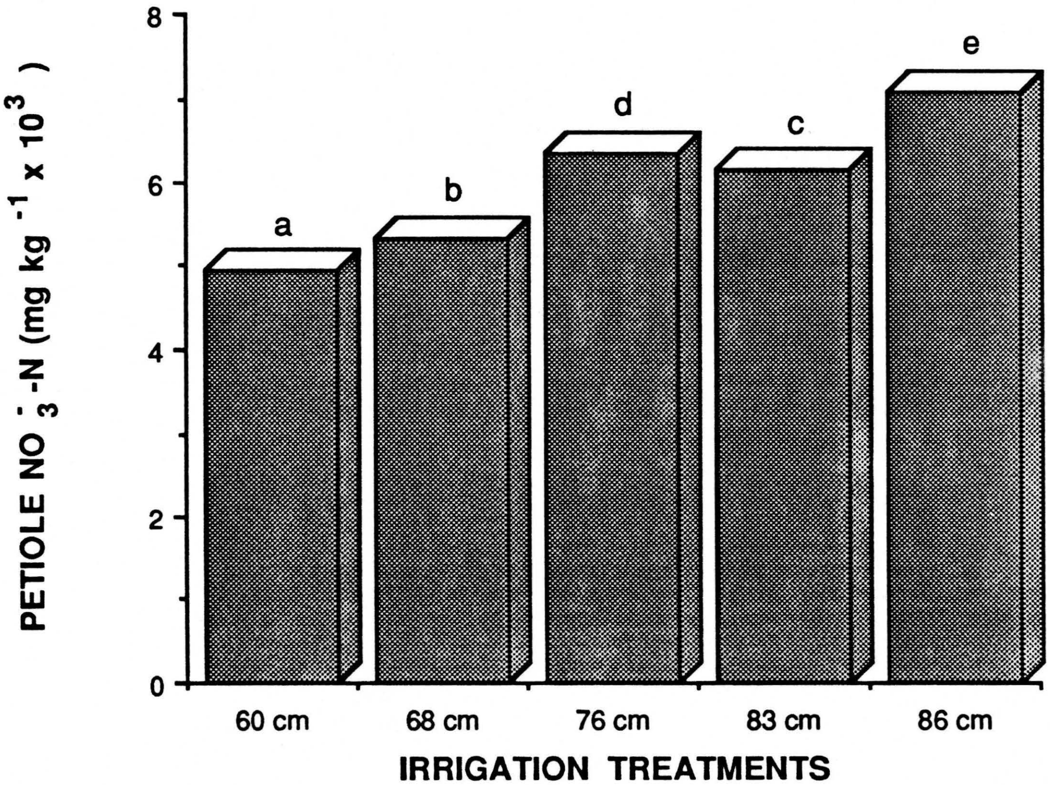


Fig. 3. Seasonal petiole NO_3^--N concentrations across cultivars for five irrigation treatments. Means with the same letter are not significantly different according to the Least Significant Difference test at the 5% level of confidence, Eloy, AZ, 1985.

Table 4. Petiole NO_3^--N concentrations of DP 41 grown under five irrigation treatments, Eloy, AZ, 1985.

Sampling Date	Petiole Nitrates (mg kg^{-1} * 10^4)				
	Irrigation Treatments (cm)				
	60	68	76	83	86
28 June	11.28	9.57	8.97	8.29	10.97
3 July	7.36 ab †	8.73 ab	8.01 ab	6.47 b	9.48 a
10 July	6.65 b	7.00 b	6.59 b	6.39 b	9.58 a
19 July	6.84 b	7.41 b	10.31 a	8.20 b	10.12 a
25 July	7.57 b	8.45 b	11.45 a	10.00 a	11.06 a
1 Aug.	6.25 b	7.61 b	9.80 a	9.38 a	9.48 a
8 Aug.	5.52 b	6.55 ab	7.40 a	7.84 a	7.56 a
15 Aug.	4.69 b	5.34 b	7.00 a	7.45 a	6.75 a
22 Aug.	3.08	3.28	3.21	3.72	3.32
27 Aug.	2.93	2.75	3.37	2.94	3.24
3 Sept.	2.00 c	2.28 bc	3.47 ab	3.27 ab	3.99 a
10 Sept.	2.04 c	2.81 bc	3.90 abc	4.32 ab	4.95 a
17 Sept.	2.98 b	4.48 ab	5.31 a	4.76 a	5.44 a
24 Sept.	3.34 b	4.98 ab	5.19 ab	5.41 ab	6.13 a

† Means within a row followed by the same letter are not significantly different according to Duncan's Multiple Range test at the 5% level of confidence.

Table 5. Petiole NO_3^--N concentrations of DP 90 grown under five irrigation treatments, Eloy, AZ, 1985.

Sampling Date	Petiole Nitrates (mg kg^{-1} * 10^4)				
	Irrigation Treatments (cm)				
	60	68	76	83	86
28 June	9.39 b †	9.77 b	9.04 b	10.34 ab	12.59 a
3 July	8.67 abc	9.47 ab	8.34 bc	6.86 c	10.86 a
10 July	6.78 b	7.08 b	6.73 b	5.22 c	8.93 a
19 July	7.08 b	8.87 a	10.09 a	9.47 a	9.72 a
25 July	8.14 b	9.51 ab	10.59 a	9.91 ab	9.84 ab
1 Aug.	6.89 c	8.31 bc	10.31 a	8.93 ab	9.66 ab
8 Aug.	5.41 b	7.18 ab	7.49 a	8.00 a	8.17 a
15 Aug.	4.12 b	4.81 b	7.04 a	7.19 a	8.28 a
22 Aug.	2.49 b	2.01 b	2.95 ab	3.67 a	2.95 ab
27 Aug.	2.19 a	1.73 b	2.24 a	2.32 a	2.24 ab
3 Sept.	1.15 b	0.97 b	1.50 ab	1.94 a	1.99 a
10 Sept.	1.32 cd	0.96 d	1.62 bc	1.89 b	2.41 a
17 Sept.	2.73 ab	2.27 b	1.82 b	2.95 ab	3.72 a
24 Sept.	2.99	2.93	3.85	3.58	4.50

† Means within a row followed by the same letter are not significantly different according to Duncan's Multiple Range test at the 5% level of confidence.

Table 6. Petiole NO_3^--N concentrations of DP 77 grown under five irrigation treatments, Eloy, AZ, 1985.

Sampling Date	Petiole Nitrates (mg kg^{-1} * 10^4)				
	Irrigation Treatments (cm)				
	60	68	76	83	86
28 June	9.93 b †	9.90 b	8.22 cb	7.00 c	12.99 a
3 July	8.92 b	9.94 ab	9.21 b	8.41 b	11.00 a
10 July	6.35 bc	6.65 b	5.93 bc	5.45 c	9.37 a
19 July	8.46 b	8.97 b	10.31 a	10.65 a	11.16 a
25 July	7.87 c	9.56 b	11.69 a	11.85 a	12.05 a
1 Aug.	6.75 c	8.94 b	11.34 a	11.45 a	11.66 a
8 Aug.	4.82 c	6.59 b	8.50 a	8.60 a	8.58 a
15 Aug.	4.24 b	4.82 b	7.15 a	6.58 a	7.27 a
22 Aug.	2.23 cd	2.11 d	3.39 ab	2.87 bc	3.58 a
27 Aug.	2.28 ab	1.95 b	2.62 ab	2.15 b	3.03 a
3 Sept.	1.26 b	1.26 b	1.96 ab	1.91 ab	2.31 a
10 Sept.	1.44 c	0.96 d	1.71 b	1.48 c	2.12 a
17 Sept.	2.52 a	1.89 bc	2.14 ab	1.55 c	2.44 a
24 Sept.	1.55	2.08	2.10	2.78	3.03

† Means within a row followed by the same letter are not significantly different according to Duncan's Multiple Range test at the 5% level of confidence.

concentrations were significantly influenced ($p=0.05$) by the interaction between irrigation treatments and date of sampling which indicated that the response of petiole nitrate levels to irrigation treatments depended on the sampling date. As sampling progressed throughout the season, the lower irrigation treatments tended to have lower petiole nitrate levels than did the higher irrigation treatments. Petiole NO_3^--N concentrations were also significantly influenced ($p=0.05$) by the interaction of cultivars and date of sampling. In general, DP 41 nitrate concentrations were lower during the early stages of growth than either DP 90 or DP 77, while this trend reversed during the later part of the season (Tables 4, 5, and 6).

Petiole NO_3^--N concentrations were not influenced by the interaction between irrigation, cultivar and date. Petiole NO_3^--N concentrations remained below recommended levels (Tucker and Tucker, 1968) throughout the season. First square petiole nitrate concentrations ranged from 8290 mg kg^{-1} to 12 990 mg kg^{-1} which were 45 to 13% lower than recommended levels which range from 15 000 to 18 000 mg kg^{-1} at first square and in general remained below recommended levels (Fig. 4) throughout the season.

No correlations were detected between final yield and petiole NO_3^--N concentrations. In general, no correlations could be found with any particular growth stage (first square or peak flowering) and petiole nitrate concentrations. However, plants with lower nitrate concentrations did produce lower lint yields. This agrees with work done by others (Amer and Abuamin, 1969; Baker et al., 1972; Gardner and Tucker, 1967; Grimes et al., 1973; Mackenzie et al., 1963; Maples et al., 1977; Sunderman et al., 1979).

Petiole NO_3^--N concentrations in 1985 indicated that plant nutrition was

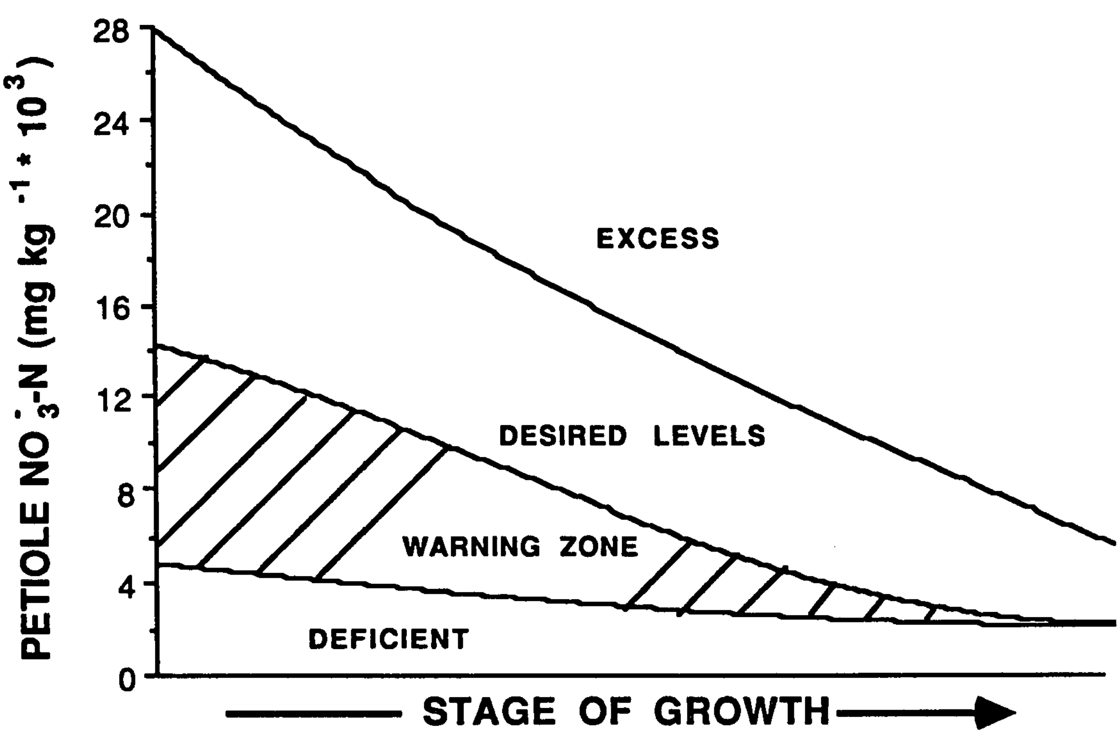


Fig. 4. Recommended petiole NO_3^--N concentrations in cotton as related to growth stage (Tucker and Tucker, 1968).

inadequate to achieve maximum yields at the various irrigation treatments. The results indicate that nutritional factors may have been one of the major limiting factors to yield in 1985.

In 1986, the MANOVA (Table 7) detected highly significant petiole NO_3^--N concentration differences (p=0.01) among irrigation treatments. Seasonal nitrate means of the 59, 65, and 71 cm irrigation treatments were significantly lower than the 78 cm irrigation treatment which was significantly lower than the 80 cm irrigation treatment (Fig. 5). There were no significant petiole NO_3^--N concentration differences detected among cultivars.

Highly significant petiole NO_3^--N concentration differences (p=0.01) among date of sampling were detected (Tables 8, 9, and 10) with nitrate concentrations decreasing with plant maturity. Petiole NO_3^--N concentrations were significantly (p=0.05) influenced by the interaction between irrigation treatments and cultivars and also between irrigation treatments and date of sampling. Petiole NO_3^--N concentrations were also significantly (p=0.05) influenced by the interaction between cultivars and date of sampling. Deltapine 41 had lower nitrate concentrations early in the season than either DP 90 or DP 77 (Tables 8, 9, and 10). This trend began reversing itself towards the end of the season which was similar to the results reported in 1985. Petiole NO_3^--N concentrations were not influenced by the interaction between irrigation treatments, cultivars, and date of sampling.

Petiole nitrate concentrations remained close to recommended levels at first square and remained close to recommended levels throughout most of the season (Fig. 4). However, nitrate concentrations fell into the deficient zone during the latter part of the season. Levels ranged from 12 080 to 18 280 mg

Table 7. Analysis of variance for petiole nitrate concentrations of three cotton cultivars under five irrigation treatments, Eloy, AZ, 1986.

Source of Variation	df	SS	MS	F	Significance
Sub-subplots	1256	37615.549			
Subplots	89	4516.760	50.750		
Main plots	29	4163.873	143.582		
Blocks	5	3497.817	699.563	183.160	**
Irrigation	4	589.668	147.417	38.600	**
Main Plot Error	20	76.388	3.819		
Cultivars	2	23.770	11.885	3.110	NS
Irr. X Cultivars	8	138.043	17.255	4.520	*
Subplot Error	50	191.074	3.821		
Date	11	26385.153	2398.650	628.030	**
Irr. X Date	44	1077.250	24.483	6.410	*
Cultivars X Date	22	476.419	21.655	5.670	*
I X C X D	88	228.861	2.601	0.680	NS
Sub-subplot error	1002	3827.132	3.819		

*, **, F ratios significant at the 0.05 and 0.01 levels of probability, respectively
NS, not significant.

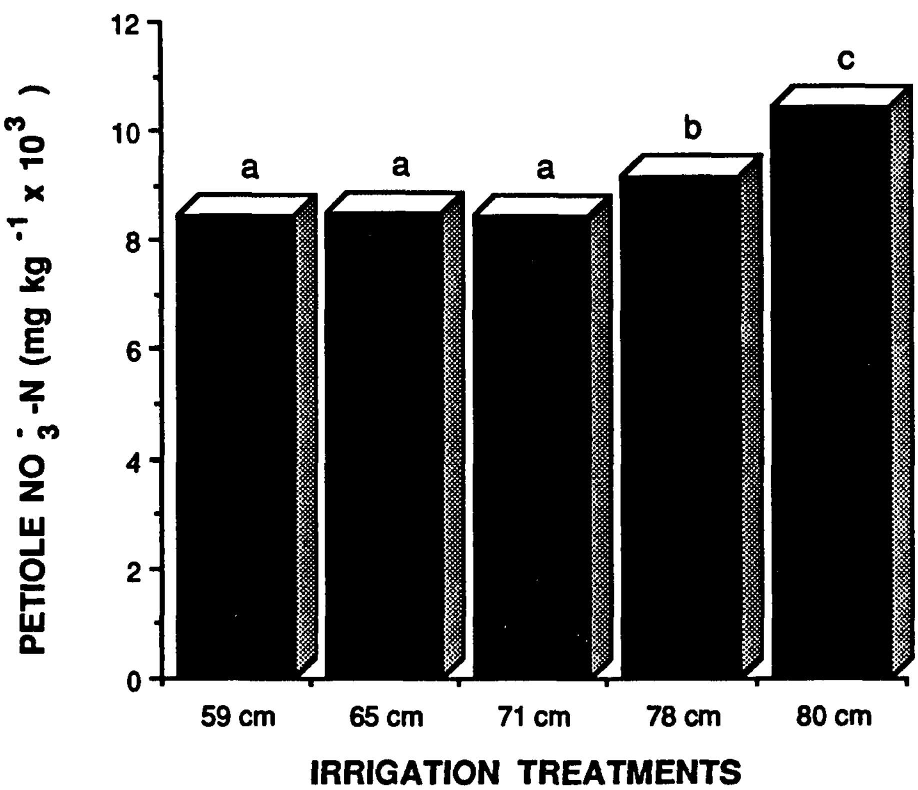


Fig. 5. Seasonal petiole NO_3^--N concentrations across cultivars for five irrigation treatments. Means with the same letter are not significantly different according to the Least Significant Difference test at the 5% level of confidence, Eloy, AZ, 1986.

Table 8. Petiole NO_3^--N concentrations of DP 41 grown under five irrigation treatments Eloy, AZ, 1986.

	Petiole Nitrates (mg kg^{-1} * 10^4)				
	Irrigation Treatments (cm)				
Sampling Date	59	65	71	78	80
26 June	13.71 ab †	13.94 ab	12.08 b	14.01 ab	16.41 a
1 July	11.35 b	12.32 b	8.81 b	11.09 b	17.76 a
8 July	14.70 b	14.49 b	11.97 b	14.08 b	17.52 a
15 July	11.79	13.35	10.71	12.24	14.33
22 July	9.31	10.15	9.49	9.63	11.26
29 July	9.64 b	11.95 ab	14.18 a	11.51 ab	14.00 a
5 Aug.	5.72	7.45	7.48	6.08	7.47
12 Aug.	2.87 b	4.13 ab	5.12 a	4.39 ab	5.00 a
19 Aug.	2.35 b	3.25 ab	4.55 a	3.56 ab	3.84 ab
25 Aug.	1.97 b	2.67 ab	3.39 a	2.75 a	3.09 a
8 Sept.	6.50 ab	5.68 abc	4.94 bc	4.57 c	6.64 a
15 Sept.	5.40	5.81	5.81	5.84	7.16

† Means within a row followed by the same letter are not significantly different according to the Least Significant Difference test at the 5% level of confidence.

Table 9. Petiole NO_3^--N concentrations of DP 90 grown under five irrigation treatments Eloy, AZ, 1986.

Sampling Date	Petiole Nitrates (mg kg^{-1} * 10^4) Irrigation Treatments (cm) 59	65	71	78	80
26 June	14.13 ab †	13.98 ab	12.30 b	15.97 ab	18.28 a
1 July	13.40 b	10.92 b	10.51 b	13.83 b	18.86 a
8 July	16.53 ab	13.78 b	13.26 b	15.13 ab	18.13 a
15 July	13.70	12.45	12.57	14.26	14.63
22 July	10.58 ab	8.55 b	11.15 ab	10.01 b	13.18 a
29 July	12.12 bc	11.62 c	15.30 ab	14.41 abc	16.12 a
5 Aug.	7.01	8.40	8.84	8.03	9.35
12 Aug.	4.01 b	5.07 ab	6.76 a	5.70 ab	5.70 ab
19 Aug.	2.47 b	4.07 ab	4.84 a	3.83 ab	4.70 a
25 Aug.	1.78 b	2.08 a	3.19 a	2.91 a	3.26 a
8 Sept.	3.61 bc	3.38 c	3.85 abc	4.17 ab	4.50 a
15 Sept.	4.32	3.83	3.61	4.78	4.75

† Means within a row followed by the same letter are not significantly different according to the Least Significant Difference test at the 5% level of confidence.

Table 10. Petiole NO_3^--N concentrations of DP 77 grown under five irrigation treatments Eloy, AZ, 1986.

	Petiole Nitrates (mg kg^{-1} * 10^4)				
	Irrigation Treatments (cm)				
Sampling Date	59	65	71	78	80
26 June	14.45 †	12.95	12.95	14.71	15.38
1 July	13.84 b	10.68 bc	9.89 c	13.25 b	17.42 a
8 July	17.00 ab	14.85 bc	12.69 c	16.01 ab	18.52 a
15 July	14.71	13.51	11.74	12.83	14.39
22 July	9.96 bc	9.17 c	10.32 abc	12.43 a	11.52 ab
29 July	13.58	14.14	13.92	14.53	13.86
5 Aug.	7.53	8.73	8.73	9.74	8.17
12 Aug.	3.31 b	5.37 ab	5.98 a	6.79 a	5.42 ab
19 Aug.	2.73 b	4.19 ab	4.75 a	5.50 a	4.43 ab
25 Aug.	2.51 d	2.77 c	3.38 b	4.10 a	3.08 bc
8 Sept.	3.28 b	3.09 b	2.84 b	4.76 a	3.38 b
15 Sept.	3.01 b	3.61 ab	2.76 b	3.97 ab	4.32 a

† Means within a row followed by the same letter are not significantly different according to the Least Significant Difference test at the 5% level of confidence.

kg^{-1} at first square. The high early season nitrate concentrations in the plant may be attributed to the high preplant soil NO_3^--N concentrations which ranged from 24.5 to 78.5 mg kg^{-1}. These levels were 25 to 460% greater than preplant soil NO_3^--N levels reported in 1985.

No correlations between cultivar NO_3^--N concentrations averaged over the season and final yield were detected. The 59 cm irrigation treatment, which had the lowest nitrate concentration, produced the lowest lint yields. However, no other relationships between nitrate concentrations and yield could be seen. This contradicts the findings of 1985. Since nutrition levels were adequate throughout most of the 1986 season, nutrition was probably not as great a limiting factor for maximum yields as it was in 1985.

The MANOVA for both years found highly significant petiole NO_3^--N concentration differences (p=0.01) among irrigation treatments and years, while no apparent petiole NO_3^--N concentration differences could be detected among cultivars. The 60 and 59 cm irrigation treatments had significantly lower petiole NO_3^--N concentrations than did all other irrigation treatments (Fig. 6). Mean seasonal nitrate concentrations were 23% higher in 1986 than in 1985 with 1986 having significantly higher petiole nitrate concentrations (8256 mg kg^{-1}) than 1985 (6284 mg kg^{-1}). An observed trend between petiole nitrate concentrations and yield could be seen within the 2 years. A 23% increase in petiole nitrate concentrations between 1985 and 1986 corresponded to a 28% increase in yield. Highly significant petiole NO_3^--N concentration differences (p=0.01) among sampling dates were detected with nitrate levels decreasing with plant maturity.

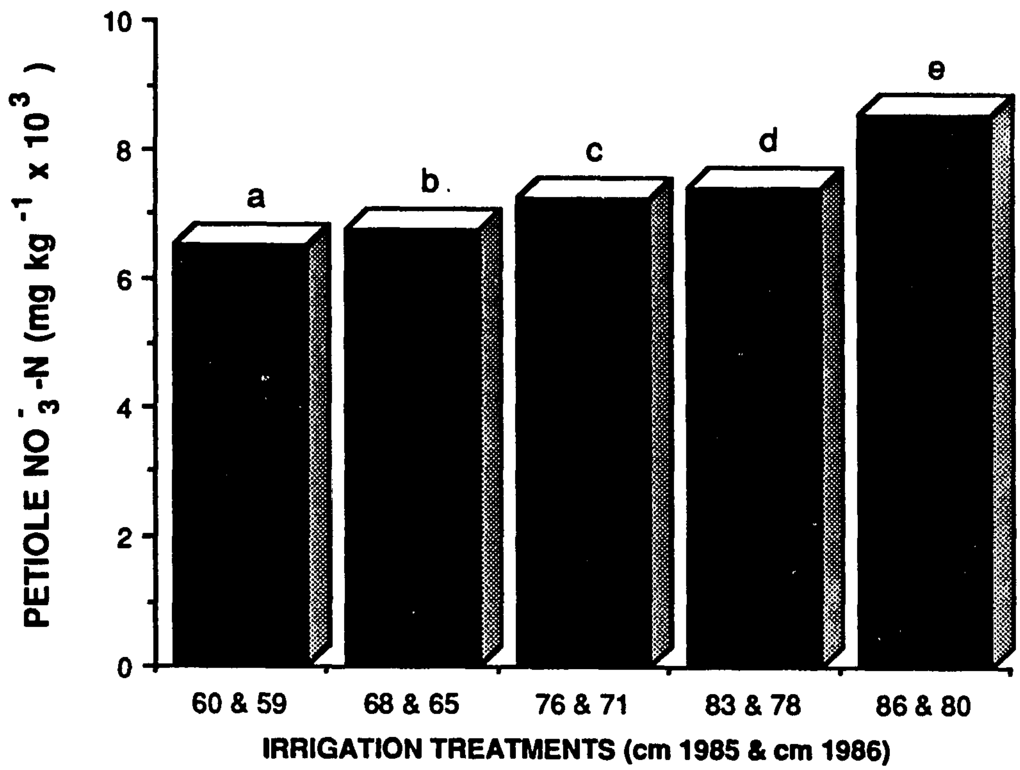


Fig. 6. Petiole NO_3^--N concentrations across cultivars for five irrigation treatments in 1985 and 1986. Means with the same letter are not significantly different according to the Least Significant Difference test at the 5% level of confidence, Eloy, AZ.

Flower and Boll Development

In 1985, DP 90 grown under four irrigation treatments (60, 68, 76, and 83 cm) was tagged twice a week with the assumption that estimates of flower numbers could be made on days when flowers were not tagged using polynomial regression. This proved to be an inaccurate means by which to calculate flower production. From the data collected in the flower tagging plots, an estimate of the percent boll set and the average weight per boll was derived. Seed cotton yields were hand harvested from each plot and these figures were then divided by the estimated weight per boll to get the approximate number of bolls produced in each plot. The number of bolls produced divided by the percent boll set gave an estimate of the number of flowers produced in each flower study plot. When comparisons of total flower numbers estimated by the data were compared against total flower numbers estimated by the polynomial regression formulas, large discrepancies were detected. In some cases, the polynomial regression estimates of total flower production was 53% greater than total flower production estimated from the collected data. In other cases, the regression estimates were 57% lower than estimates from the collected data.

There was no consistent under or over estimation of flower and boll numbers by this technique. Therefore, flower data could not be analyzed on a cumulative basis and interpretations were carried out on year-end seasonal estimates of mean total flower and boll production from the data collected from the flower tagging plots.

Some general trends could be visually detected by looking at bi-weekly flower and boll data (Fig. 7 and 8). All treatments in 1985 began intensive

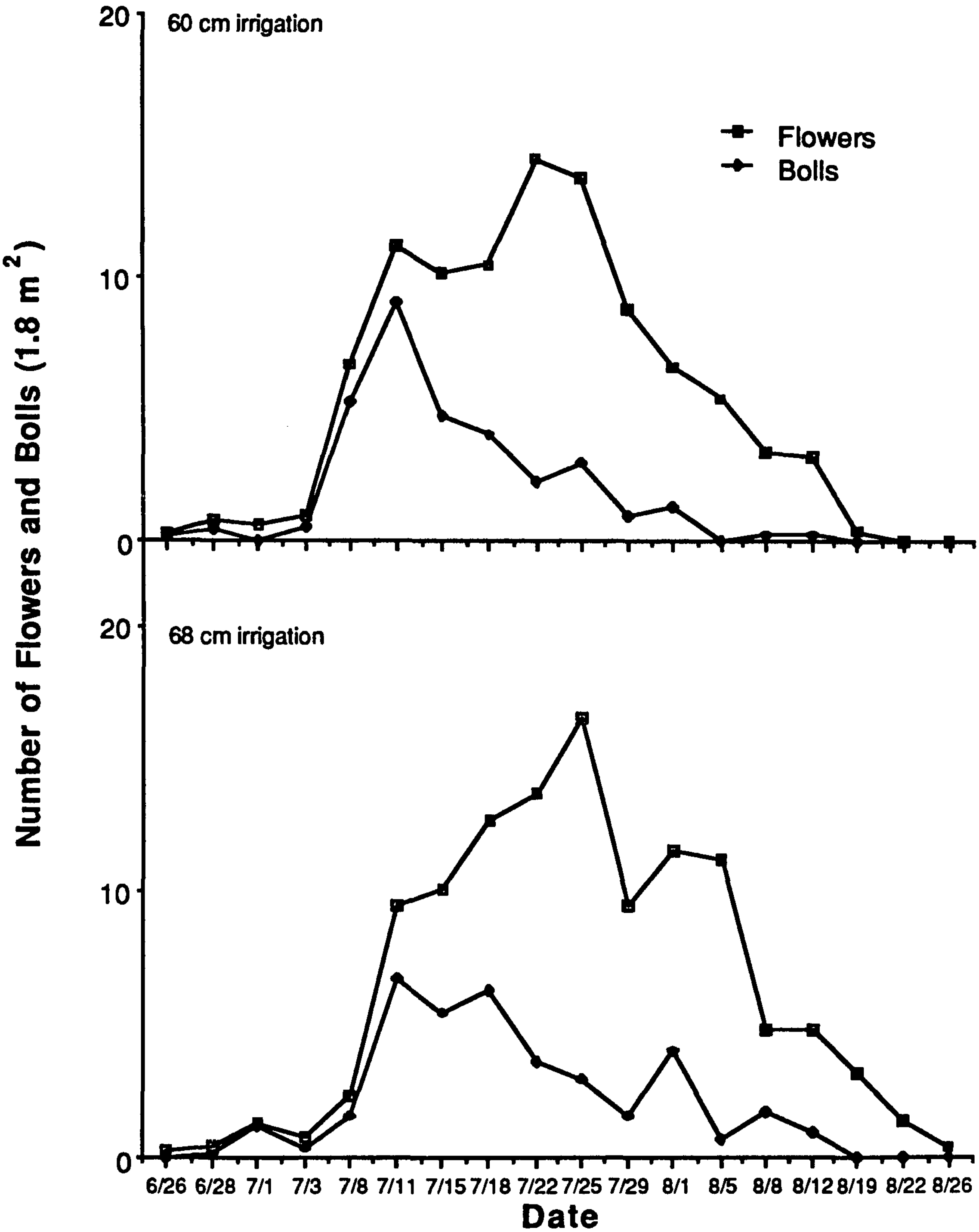


Fig. 7. Tagged flowers and bolls produced from those flowers on eighteen sampling dates for DP 90 grown with 60 and 68 cm of irrigation, Eloy, AZ, 1985.

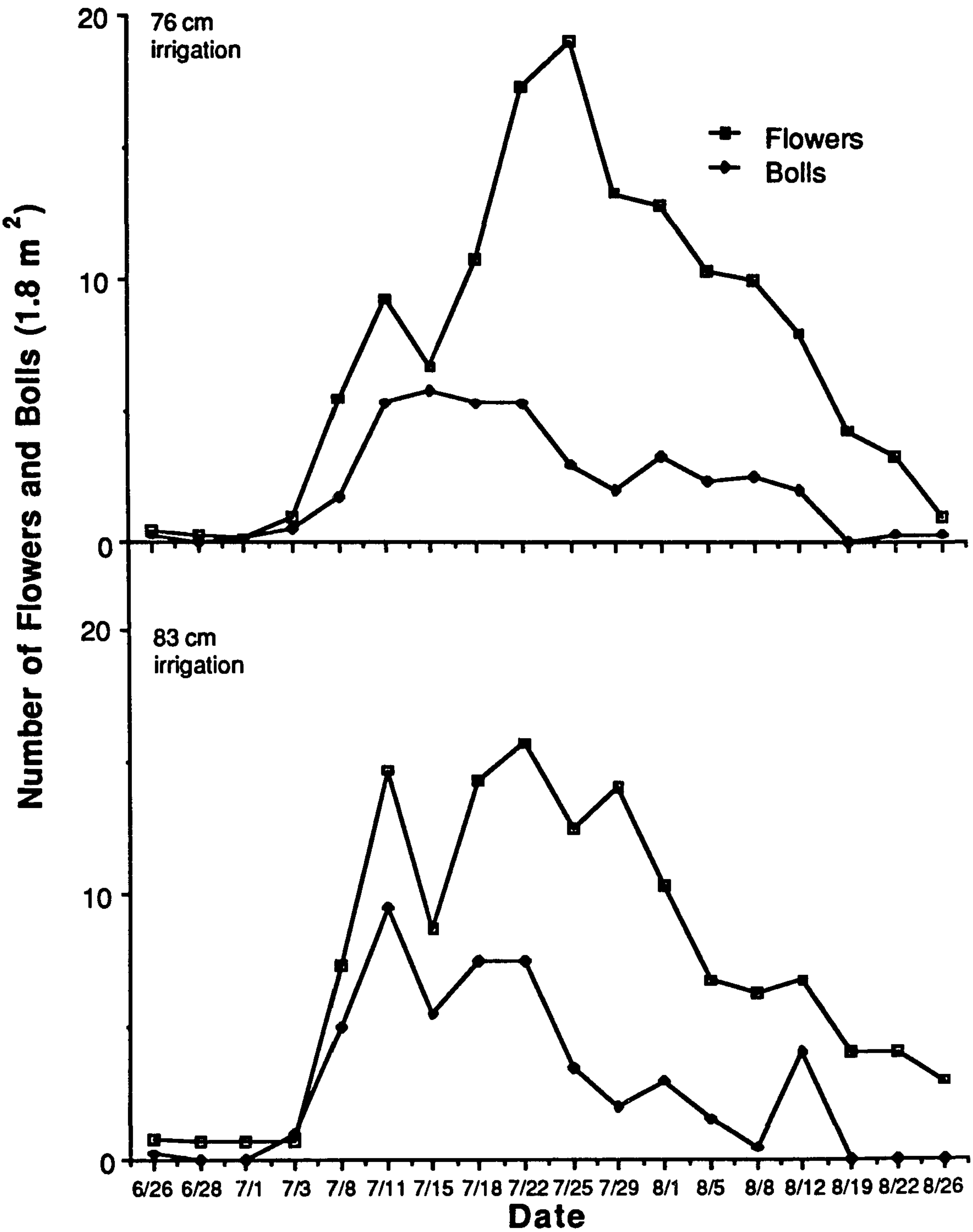


Fig. 7. Tagged flowers and bolls produced from those flowers on eighteen sampling dates for DP 90 grown with 76 and 83 cm of irrigation, Eloy, AZ, 1985.

flowering around 8 July. The intensive flowering period (days when 10 flowers or more were tagged) of DP 90 grown under 60 cm of irrigation lasted approximately 2 weeks while intensive flowering periods for the other irrigation treatments ranged from 3 to 4 weeks. The 76 cm irrigation treatment showed the longest period of intensive flowering at 4 weeks followed by the 68 cm irrigation treatment at 3.5 weeks and the 83 cm irrigation level at 3 weeks. Briggs et al. (1983) reported similar intensive flowering periods of 3 to 4 weeks on DP 90 grown with above-grown drip (106 cm total irrigation) in Casa Grande, AZ. They also reported that flowering began earlier and was more intense under drip irrigation than furrow irrigated cotton (152 cm total irrigation). The drop in flower production observed around mid-July (Fig. 7 and 8) can be attributed to a pump failure of 4 days. The pump failure did not seem to affect the lower irrigation treatments as severely as the two higher irrigation treatments. Since the lower irrigation treatments had been under some water stress, they may have been better able to cope with the more intensive water stress.

Boll production peaked between 11 and 15 July in all irrigation treatments, a full week before peak flowering occurred. Boll set remained fairly high until mid-July when the number of bolls set decreased throughout the rest of the season (Fig. 7 and 8). Nutritional deficiencies seem to have played an important role in limiting boll set. Nitrogen is a component of IAA, which inhibits abscission, and of cytokinins, which have mobilizing nutrients to developing bolls and thereby helps prevent senescence (Guinn, 1982b). Nitrogen is also essential for photosynthesis as it is a component of chlorophyll, enzymes, and membranes (Nevins and Loomis, 1970). Therefore, a nitrogen deficiency could decrease available photosynthates which has been shown to increase boll abscission (Guinn, 1985).

The longer intensive flowering periods tended to produce greater lint yields. The 60 cm irrigation treatment, which showed intensive flowering of 2 weeks, produced sign-ificantly lower lint yields than the other three treatments (Table 11). Highly significant hand-picked lint yield differences ($p=0.01$) among irrigation treatments were detected. The lower irrigation treatments produced significantly lower yields than did the higher irrigation treatments (Table 11). Except for the 83 cm irrigation treatment, no real differences between the machine picked and hand picked lint yields were observed . There was a 24% decrease in yield between the machine picked and hand harvested lint yields which could be attributed to experimental error.

The ANOVA for both hand picked and machine harvested lint yields of the flower plots detected significant lint yield differences ($p=0.05$) among irrigation treatments. In the hand-picked harvest, the 60 cm irrigation treatment yield was significantly lower than the yield of the 68 cm treatment which was significantly lower than the yields of the 76 and 83 cm irrigation treatments (Table 11). In the machine harvested plots, the 60 and 83 cm irrigation treatments were significantly lower in yield production than the 76 cm irrigation treatment (Table 11).

The ANOVA showed highly significant flower and boll production differences ($p=0.01$) among irrigation treatments. The 76 cm irrigation treatment produced significantly more flowers ha^{-1} when compared to the other irrigation treatments and significantly more bolls ha^{-1} than the 60 and 68 cm treatments (Table 11). Mezainis (1985) and Guinn and Mauney (1984a) reported that

Table 11. Fruiting characteristics of DP 90 grown under four irrigation treatments collected from flower tagging plots only, Eloy, AZ, 1985.

Fruiting Characteristics	Irrigation Treatments (cm) 60	68	76	83
Flowers ha^{-1} (* 10^4)	210.7 a †	258.8 ab	350.8 c	292.1 b
Bolls ha^{-1} (* 10^4)	70.8 a	85.2 b	101.7 c	106.5 c
Boll Set (%)	33.8	33.5	29.3	37.6
Boll Weight (g seed cotton)	3.62 a	4.19 b	4.40 b	4.13 b
Hand Picked Lint Yield (Mg ha^{-1})	0.90 a	1.25 b	1.57 c	1.54 c
Machine Picked Lint Yield (Mg ha^{-1})	0.92 a	1.27 ab	1.55 b	1.14 a

† Treatment means within rows followed by the same letter are not significantly different according to Least Significant Difference test at the 5% confidence level.

increased irrigation rates significantly increased seasonal flower production. Mezainis (1985) also reported that there was a trend of increased boll production with increased water applications, although no significant differences could be detected for total boll production.

No significant percent boll set differences were detected by the ANOVA among irrigation treatments. Boll set ranged from 29% at the 76 cm irrigation level to 38% at the 83 cm irrigation treatment (Table 11). Mezainis (1985) also reported that percent boll set was not significantly affected by irrigation treatments. The ANOVA found significant average boll weight differences ($p=0.05$) among irrigation treatments. Average boll weight ranged from 4.40 g at the 76 cm irrigation level to 3.62 g at the 60 cm irrigation treatment with the 60 cm irrigation treatment producing significantly lighter bolls than all other irrigation treatments. This agrees with the results of Mezainis (1985) who found that boll weight increased with increased irrigation.

Correlations were run on six fruiting characteristics, flowers ha^{-1}, bolls ha^{-1}, boll set, average seed cotton boll weight, hand picked lint yield, and machine picked lint yields against average petiole NO_3^--N levels and final lint yield. In general there was no correlation between flower and boll numbers, percent boll set, and average boll weight with either petiole NO_3^--N concentrations or yield.

In 1986, the fruiting characteristics of DP 41 and DP 77 were studied along with those of DP 90. DP 41 began intensive flowering between 11 and 15 July (Fig. 9 and 10). The intensive flowering periods ranged from 3 weeks at the 71 cm irrigation treatment to 4 weeks at the 65, 78, and 80 cm irrigation treatments. The 59 cm irrigation treatment showed an intensive flowering period of 3-4

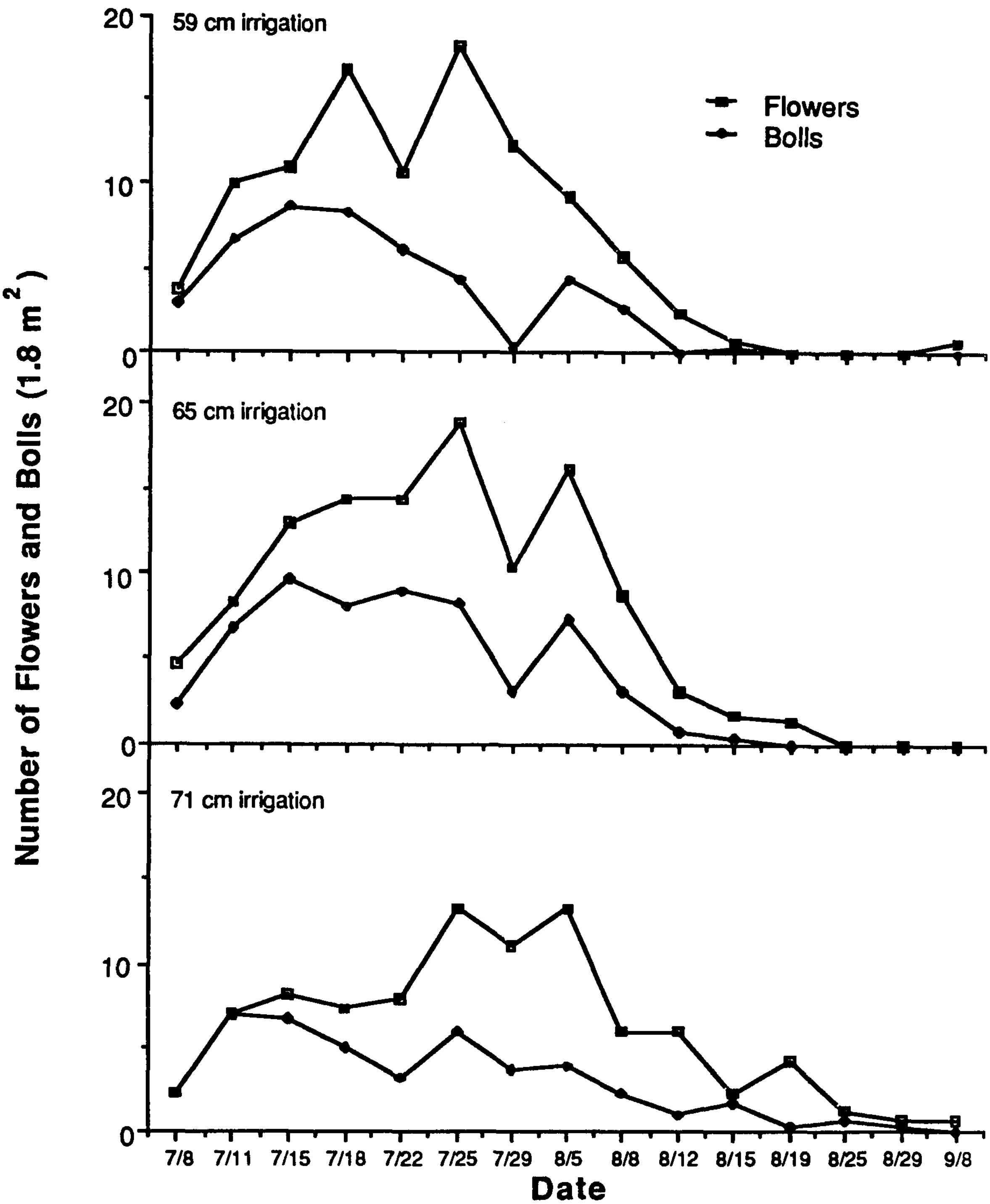


Fig. 9. Tagged flowers and bolls produced from those flowers on fifteen sampling dates for DP 41 grown with 59, 65, and 71 cm of irrigation, Eloy, AZ, 1986.

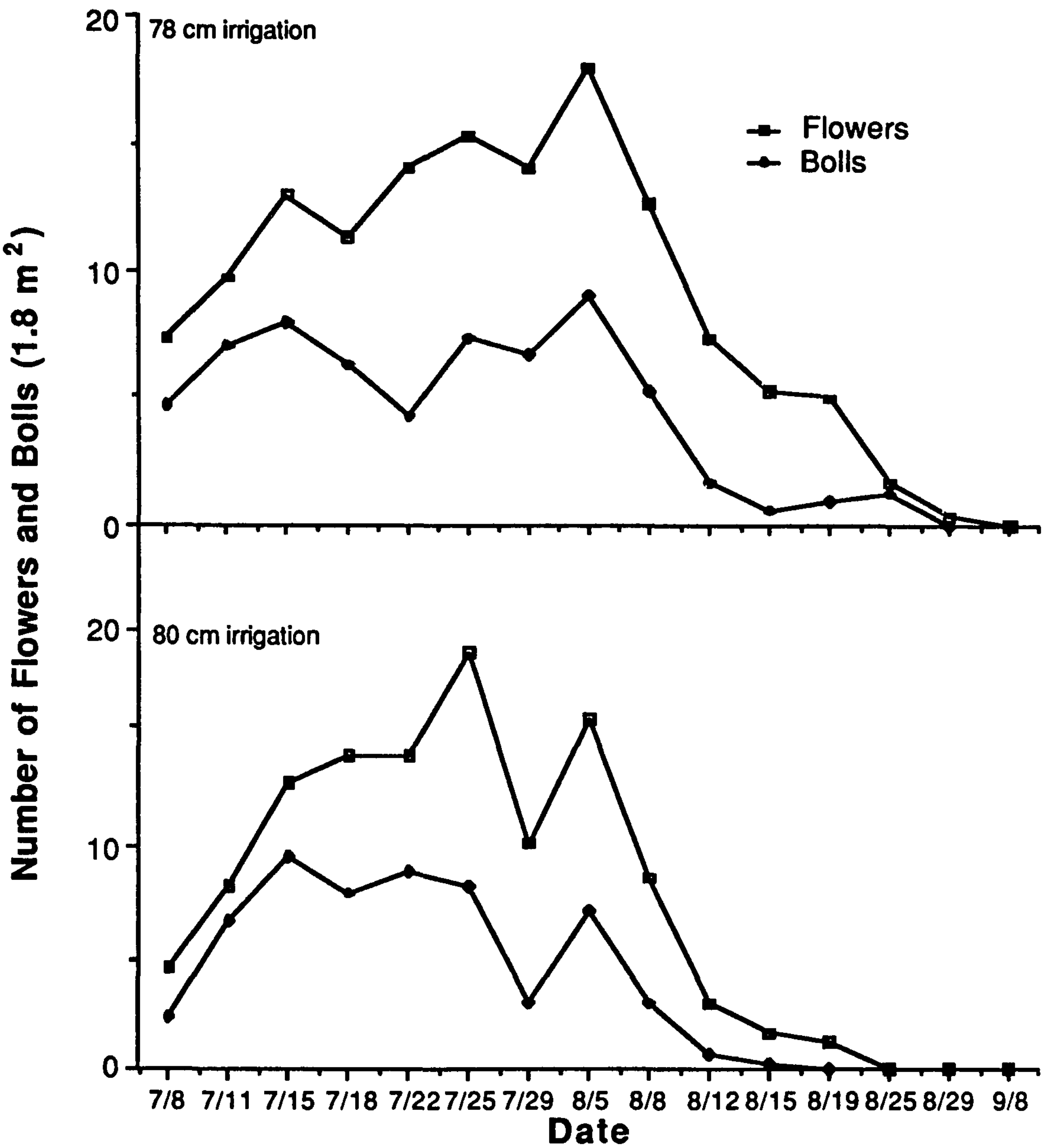


Fig. 10. Tagged flowers and bolls produced from those flowers on fifteen sampling dates for DP 41 grown with 78 and 80 cm of irrigation, Eloy, AZ, 1986.

weeks.

Deltapine 90 began intensive flowering between 18 and 22 July, 7 to 10 days later than DP 41 (Fig. 11 and 12). The intensive flowering periods lasted between 2-3 weeks at the 59 cm irrigation treatment, 3-4 weeks at the 78 and 65 cm irrigation levels, to 4 weeks at the 71 and 80 cm irrigation regimes.

Intensive flowering of DP 77 began between 22 and 25 of July 4 to 7 days after DP 90 (Fig. 13 and 14). Duration of intensive flowering periods ranged from 3 weeks (71 cm irrigation treatment), 3-4 weeks (59 and 65 cm irrigation treatments), to 4-5 weeks (78 and 80 cm irrigation treatments), respectively.

Boll set remained above 50% until late July in almost all flower plots studied. In most cases boll set dropped below 40% until the end of August. Nutritional factors may have played a role in higher boll retention in the early part of the season. Nitrate concentrations remained close to desired levels until early August when they fell into the deficient zone (Fig. 4). Decreased boll retention may have been caused by the drop in available N in August.

The ANOVA for hand harvested lint yields detected highly significant lint yield differences ($p=0.01$) among irrigation treatments. The 78 cm irrigation treatment produced significantly greater yields than the three lower irrigation treatments (Table 12). Yields were lower in the hand picked plots than in the machine picked plots for the three lower irrigation treatments.

The ANOVA for flower numbers found significant differences ($p=0.05$) among irrigation treatments, while no significance differences among cultivars were detected (Table 12). The higher irrigation treatments produced significantly more flowers than did the lower irrigation treatments. Deltapine 90 produced more flowers (249.3×10^4) ha^{-1} than either DP 41 (248.1×10^4) or

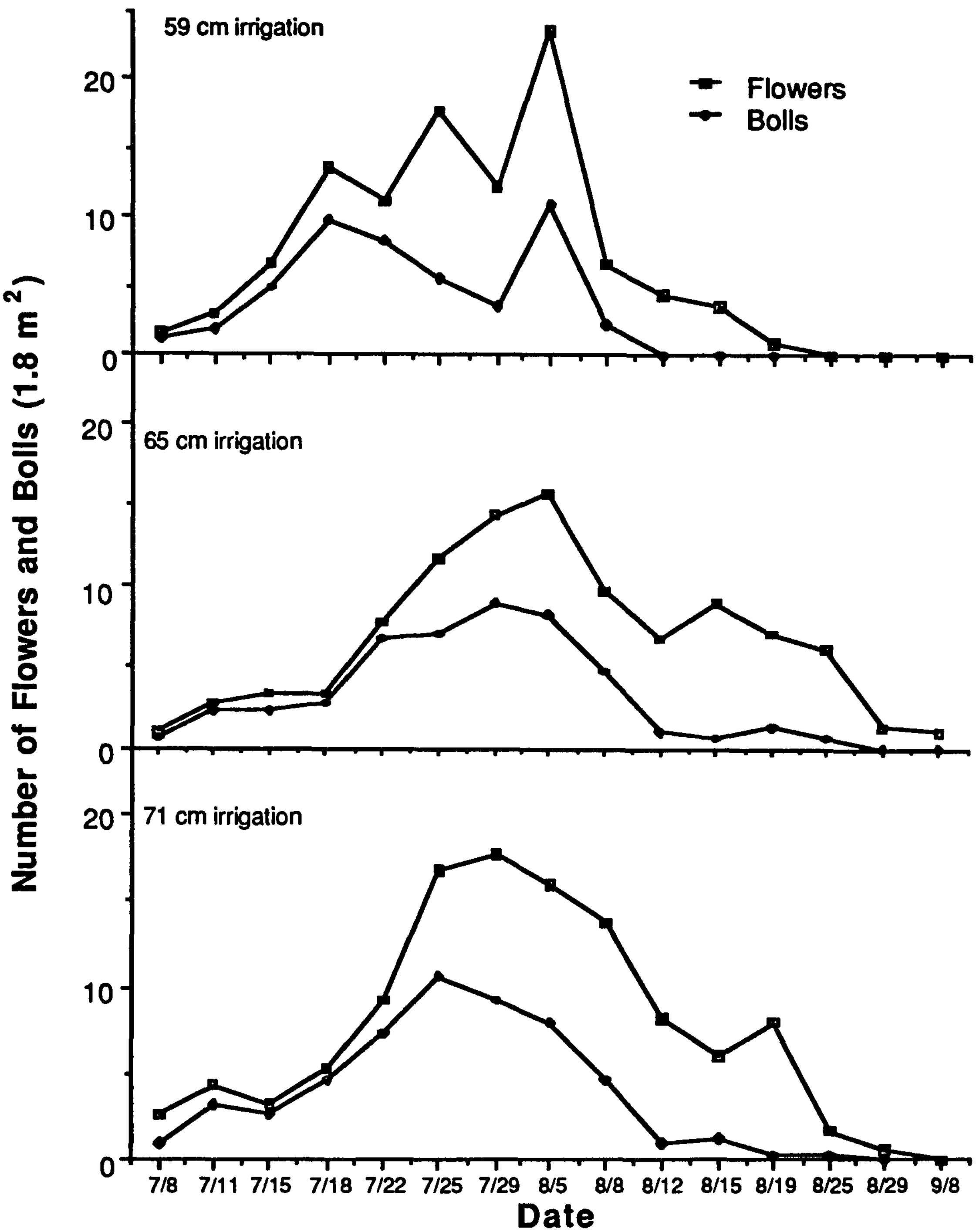


Fig. 11. Tagged flowers and bolls produced from those flowers on fifteen sampling dates for DP 90 grown with 59, 65, and 71 cm of irrigation, Eloy, AZ, 1986.

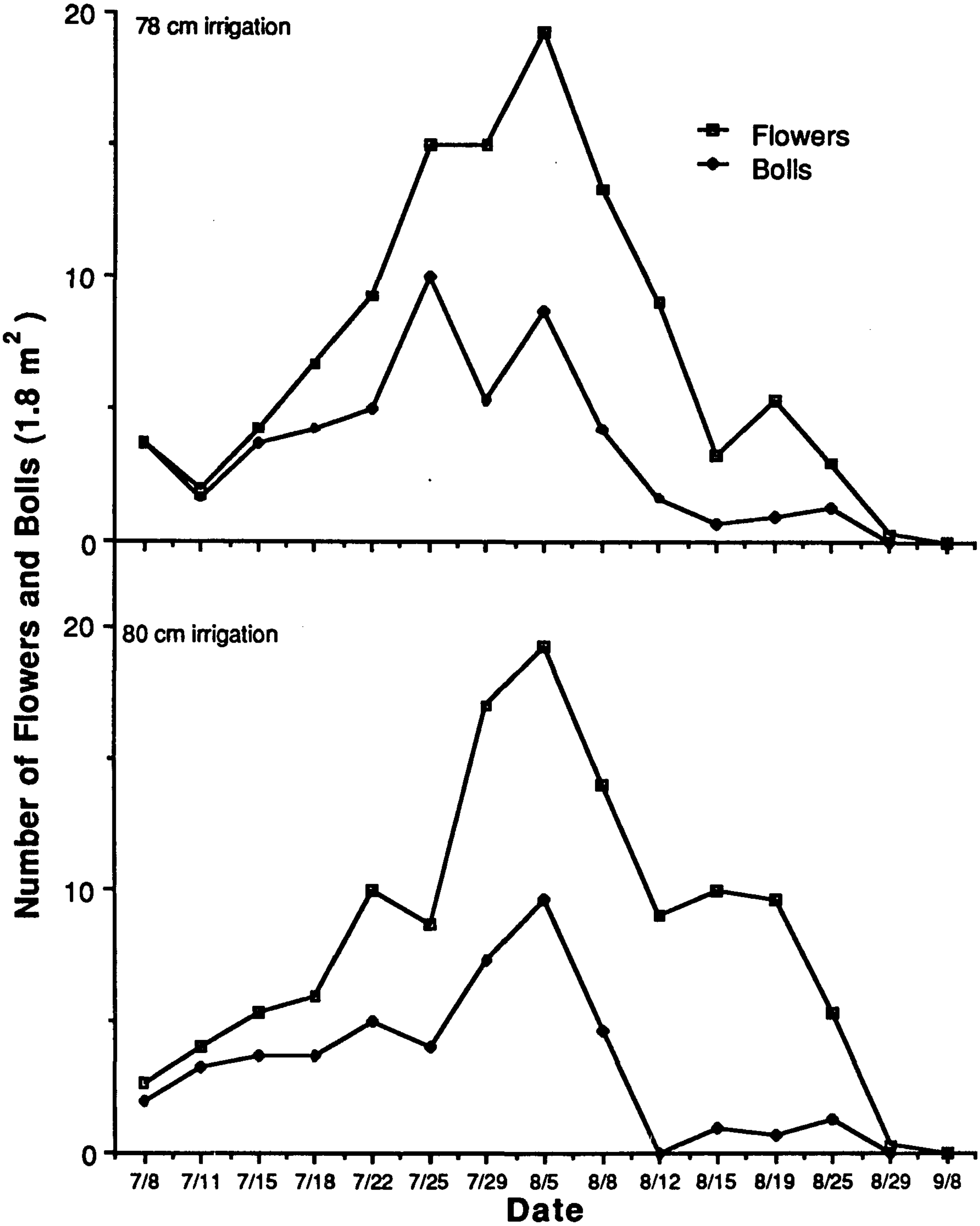


Fig. 12. Tagged flowers and bolls produced from those flowers on fifteen sampling dates for DP 90 grown with 78 and 80 cm of irrigation, Eloy, AZ, 1986.

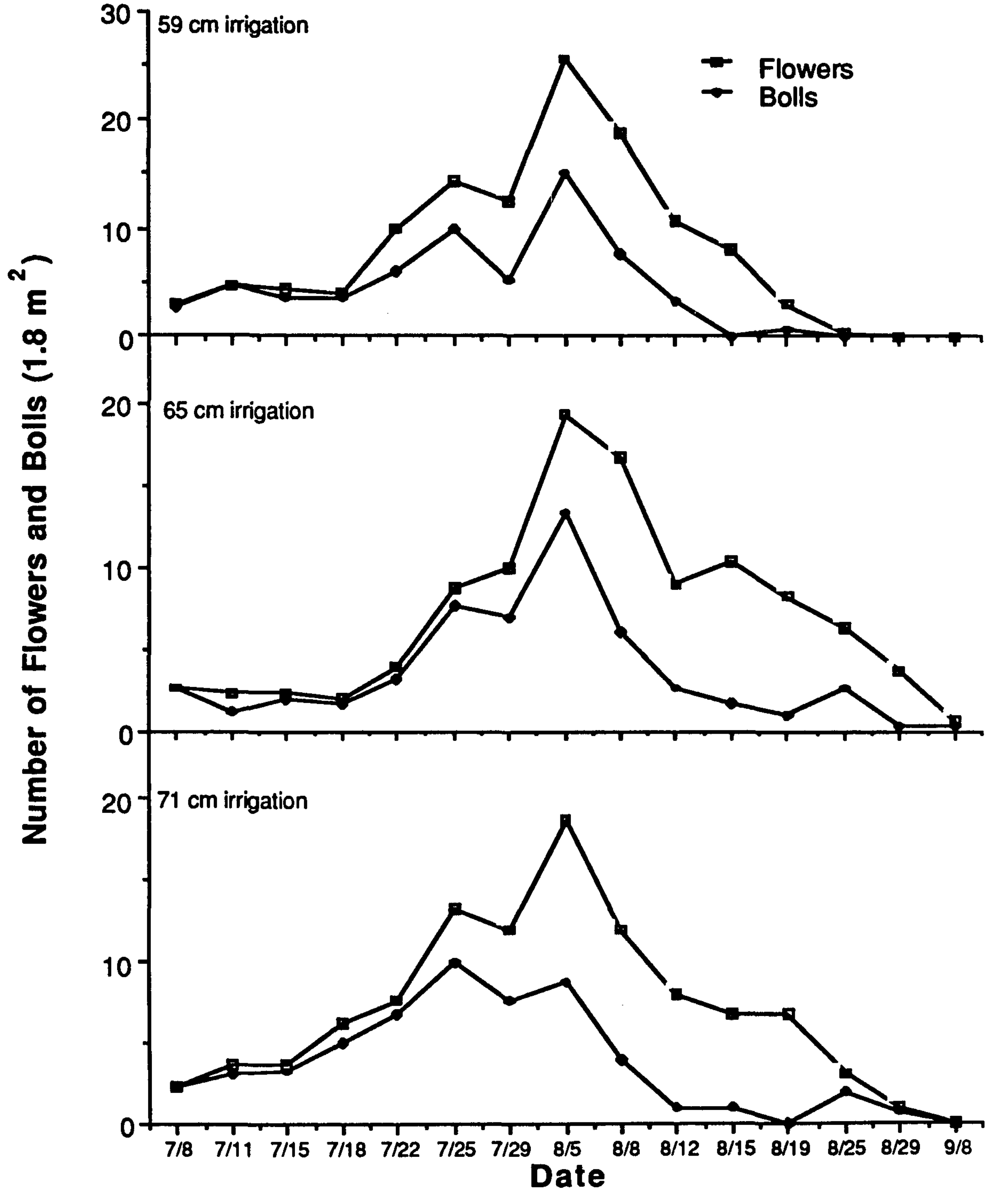


Fig. 13. Tagged flowers and bolls produced from those flowers on fifteen sampling dates for DP 77 grown with 59, 65, and 71 cm of irrigation, Eloy, AZ, 1986.

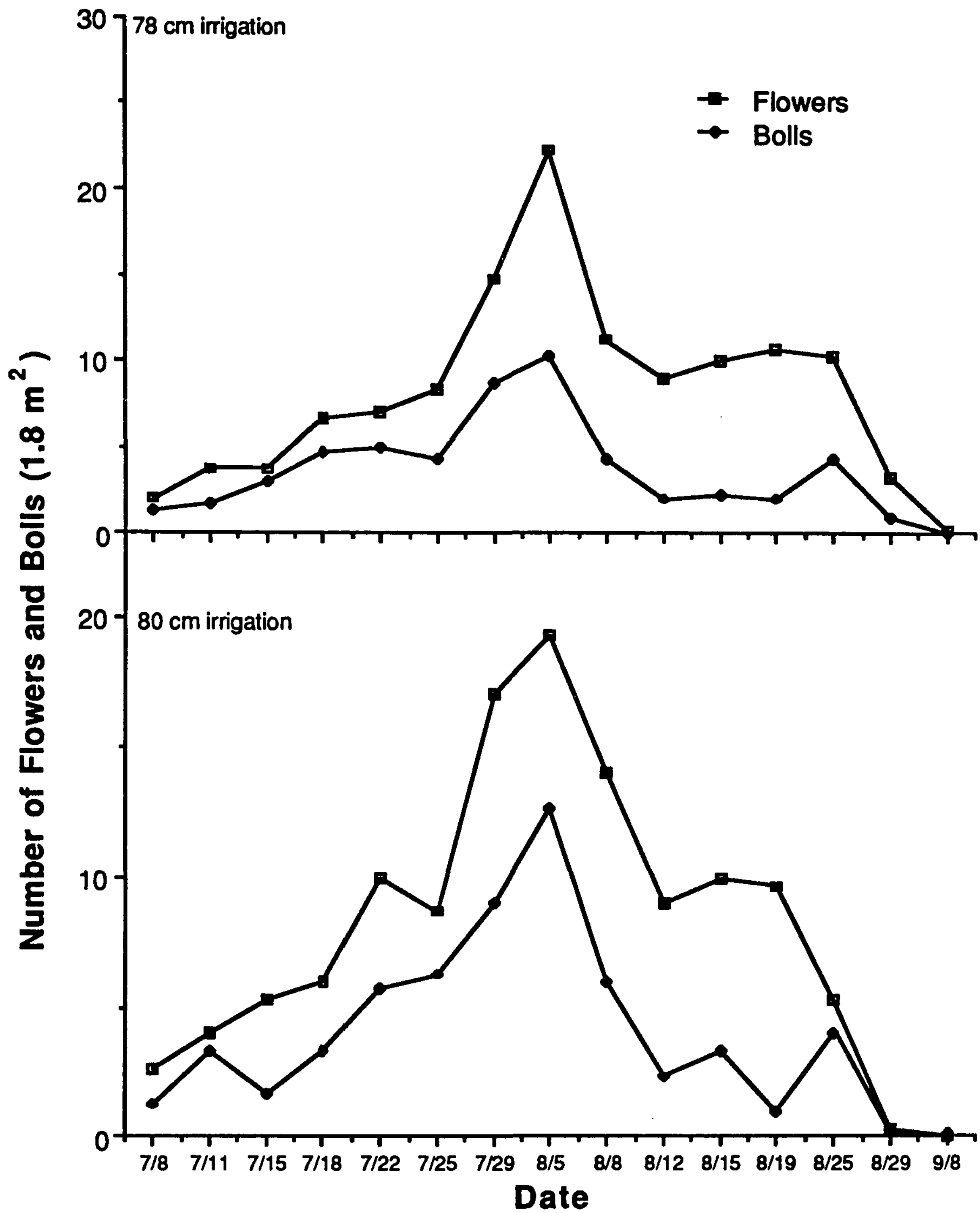


Fig. 14. Tagged flowers and bolls produced from those flowers on fifteen sampling dates for DP 90 grown with 78 and 80 cm of irrigation, Eloy, AZ, 1986.

Table 12. Data on fruiting characteristics across cultivars for five irrigation treatments collected from flower tagging plots only, Eloy, AZ, 1986.

Fruiting Characteristics	Irrigation Treatments (cm) 59	65	71	78	80
Flowers ha^{-1} (* 10^4)	224.4 a†	229.7 a	216.4 a	276.4 b	279.2 b
Bolls ha^{-1} (* 10^4)	105.9	114.6	127.9	126.8	119.5
Boll Set (%)	47.4	50.2	49.7	46.1	43.9
Boll Weight (g seed cotton)	4.30	4.30	4.28	4.48	4.44
Hand Picked Lint Yield (Mg ha^{-1})	1.60 a	1.73 ab	1.71 ab	1.98 c	1.86 bc
Machine Picked Lint Yield (Mg ha^{-1})	1.77 a	1.89 ab	1.93 b	1.92 b	1.83 ab

† Treatment means within rows followed by the same letter are not significantly different according to Least Significant Difference test at the 5% confidence level.

DP 77 (238.2×10^4). The ANOVA for boll production found no significant production differences among either irrigation treatments or cultivars. However, higher irrigation treatments did tend to produce greater numbers of flowers and bolls. No significant percent boll set differences among irrigation treatments were observed. The two higher irrigation treatments tended to set a smaller percentage of bolls than the other treatments (Table 12). Boll set ranged from 38% for DP 90 at the 80 cm irrigation treatment to 53% for DP 77 grown under 71 cm of irrigation. Highly significant average boll weight differences ($p=0.01$) were observed among cultivars with DP 41 producing significantly lighter bolls than either DP 90 or DP 77. No significant average boll weight differences among irrigation treatments were detected (Table 12). However, the lower irrigation treatments did produce smaller bolls.

Correlation analyses were run on all six fruiting characteristics against average petiole NO_3^--N levels and final lint yield. In general, there was no correlation between flower and boll numbers, percent boll set, and average boll weight with either petiole NO_3^--N concentrations or yield.

Comparisons made between DP 90 in both years showed that even though flower production was greater in 1985, there tended to be greater production in all other fruiting characteristics in 1986 (Table 13). Not only did 1986 produce a greater overall number of bolls, it also set more bolls, had a greater average weight per boll, and had higher yields. Nutritional factors seem to have been the greatest limiting factor in the production and yield differences between the two years, however, a pump failure and diseases may have contributed to lower production in 1985.

Table 13. Comparisons of DP 90 fruiting characteristic averaged over the four lower irrigation treatments, Eloy, AZ, 1985 and 1986.

	Yearly Mean		
Fruiting Characteristics	1985	1986	% difference
Flower ha^{-1} (* 10^4)	278.1	235.2	-15.4
Boll ha^{-1} (* 10^4)	91.1	111.2	22.0
Boll Set (%)	33.8	47.5	40.5
Boll Weight (g seed cotton)	4.10	4.45	8.6
Hand Picked Yield (Mg ha^{-1})	1.32	1.73	31.1
Machine Picked Yield (Mg ha^{-1})	1.22	1.94	60.0

SUMMARY AND CONCLUSIONS

Yield, petiole nitrate concentrations, and fruiting characteristics of three cotton cultivars were analyzed with respect to five irrigation treatments. Parameters measured included lint yield of cotton, petiole nitrate concentrations, flower and boll numbers ha^{-1}, percent boll set, and boll weight. The results of this investigation may be summarized as follows:

1) Irrigation treatments had a significant affect on yield with lower irrigation treatments tending to produce lower yields. No significant lint yield differences could be detected among cultivars. The mean lint yield of 1985 was 28% lower than lint yield in 1986. Percent boll set was not significantly affected by irrigation treatments. Irrigation treatments had a significant affect on average boll weight in 1985 but not in 1986. In 1986, there was a tendency for the higher irrigation treatments to produce heavier bolls. In 1986, there were highly significant boll weight differences among cultivars with DP 41 producing significantly lighter bolls than either DP 77 or DP 90.

2) Petiole nitrate concentrations were affected by irrigation treatments with the lower irrigation treatments showing lower concentrations of petiole nitrates throughout the year. Mean seasonal nitrate concentrations were 23% greater in 1986 than in 1985 due to high soil nitrate concentrations present in 1986. In 1985, significant petiole nitrate concentrations were detected

among cultivars with DP 90 nitrate concentrations being significantly lower than DP 77 which in turn were significantly lower than DP 41. In 1986, no significant petiole nitrate concentration differences among cultivars were detected.

3) Flowering was generally influenced by irrigation treatments with higher irrigation treatments producing more flowers (Tables 11 and 12). In 1985, duration of intensive flowering periods was influenced by irrigation treatments with lower irrigation treatments having shorter intensive flowering periods. With adequate nitrate levels in 1986, irrigation did not seem to influence duration of intense flowering periods.

In conclusion, these results generally agree with other research done on furrow and drip irrigated cotton. Results on the effects of drip irrigation treatments on petiole nitrate concentrations did conflict with results found by Mezainis (1985). This research indicates the need to further evaluate growth and management of cotton under drip irrigation. It is also evident that petiole analysis can play an important role in evaluating and correcting the nutritional status of cotton under drip irrigation.

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