Review of two decades of progress in the development of successful drip irrigation for onions

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Abstract

*The irrigation needs of long day onion (*Allium cepa*) have been extensively studied at Ontario, Oregon, over the past 22 years. Drip irrigation has compared favorably with furrow and sprinkler irrigation systems. Onions were found to have very narrow soil moisture requirements. Drier soil than optima led to yield loss and wetter soil promoted bulb decomposition. Short term water stress at the three- to six-leaf stages of plant growth promoted multiple centers in long day onion varieties. Irrigation was successfully scheduled using soil water tension or evapotranspiration. Nitrogen fertilization and plant populations have been optimized. Drip system design must carefully consider the hydraulic conductivity of the soil in the placement of tape and onion rows since the soil moisture must wick over from the drip tape to the onion plant. The drip irrigation system design uniformity, operation, and maintenance are essential given onion's low tolerance to water stress.*

Key words: *Allium cepa,* irrigation criteria, soil water tension, drip system design

Introduction

Onions (*Allium cepa* L.) are more sensitive to water stress compared to many other crops. Onion leaves operate at low turgor pressure compared to other plants and stomata close at relatively low leaf water potentials (Millar et al., 1971). Gale et al. (1967) tested the response of bean, cotton, and onion plants to chloride salinity in the root medium and found that onions had the lowest capacity to adjust leaf turgor pressure in response to changes in salinity. In agreement with these physiological studies are studies that found that the soil water tension (SWT) at which onions should be maintained for maximum yields is close to or wetter than field capacity (10 to 30 cb). Coelho et al. (1996) describe onion yield responses to a SWT of 8.5 cb, and Abreu et al. (1980) report a yield response to a SWT of 10 cb. Klar et al. (1976) report onion yields to be highest with the lowest SWT tested (15 cb). Shock et al. (1998b) show onion yields to be highest with the lowest SWT tested (12.5 cb).

Onions have shallow root systems. Drinkwater and Janes (1955) found most onion roots to be located in the top 0.18 m of soil. Greenwood et al. (1982) found that 90% of onion roots are located in the upper 0.18 m of soil. Thorup-Kristensen (2006) found onions to have a final rooting depth of 0.3m. Onions, being sensitive to water stress and having shallow root systems, need frequent irrigations to maintain high soil moisture to produce high yields (Al-Jamal et al., 2000; Bucks et al., 1981; Chung, 1989; de Santa Olalla, 1994; Ells et al., 1993; Hanson and May, 2004; Hegde, 1986; Jones and Johnson, 1958; Kadayifci et al., 2005; Koriem et al., 1994; Nassar and Waly, 1977; Rajput and Patel, 2006; Rana and Sharma, 1994; Shock et al. 1998b, 2000b). Other studies have found that onion yields will respond to irrigation regimes applying more than full onion evapotranspiration (Al-Jammal et al., 2000; de Santa Olalla et al., 1994) or more than full pan evaporation (Kumar et al., 2007).

The negative environmental consequences of furrow irrigation can be exacerbated by the frequent irrigations and high soil moisture required by onions. With furrow irrigation, large amounts of water are unavoidably applied, leading to leaching and runoff. Halvorson et al. (2002) found N fertilizer movement to a 180 cm depth below onion with conservatively managed furrow irrigation. Feibert et al. (1995) found that N was leached from the soil profile when onions were furrow irrigated, but not when onions were drip or sprinkler irrigated. Drip irrigation can reduce the negative environmental consequences of irrigation by applying less total water and smaller amounts of water at a higher frequency than with furrow irrigation. Onion production with furrow irrigation is increasingly being replaced by drip irrigation.

The Malheur Experiment Station compared furrow, drip, and sprinkler irrigation for onion production in 1992-1994 in an attempt to find an irrigation method where it would be possible to grow a successful crop without leaching nitrogen fertilizer below the root zone. Based on the preliminary encouraging results, we initiated research in 1995 to improve the feasibility of commercial onion production under drip irrigation.

The Malheur Experiment Station is located in the Snake River valley on the border of southwest Idaho and southeastern Oregon, more commonly called Treasure Valley. The Treasure Valley annually produces 22,000 acres of Sweet Spanish onions classified as long day and medium-to-long storage (Shock et al., 2000a). Onions are marketed starting at harvest in August and out of storage through April, so maintaining bulb quality during storage is indispensable. Onion growers in the Treasure Valley target the larger onion size classes (jumbo, colossal, and super colossal) because of price premiums for the larger bulbs (Shock et al., 2005b).

Procedures

This paper summarizes research on drip irrigation of onion with emphasis on the studies conducted at the Malheur Experiment Station in Ontario, OR. A complete discussion of procedures for each study is omitted here and can be accessed using the citations. The following general procedures were used in all the Oregon studies unless otherwise stated.

The soil in all studies was an Owyhee silt loam (coarse-silty, mixed, mesic, Xerollic Camborthid). Onions were generally grown in a 5-year crop rotation with wheat, sugar beets, corn, and wheat preceding the onion crop. In the fall preceding the trials, the fields were plowed, roller harrowed twice, fumigated with dichloropropene and chloropicrin (77.9% 1,3-dichloropropene + 16.5% chloropicrin, sold as Telone C-17; Dow Agrosciences, Indianapolis, Ind.) at 225 $L•ha^{-1}$ and bedded. Onions were planted at 370,000 seeds/ha in two double rows per 1.1-m bed in mid-March. The onion double rows were spaced 0.56 m apart. The single rows within the double row were spaced 76 mm apart. One drip tape was installed at 0.08 – 0.10 m depth in each bed between the two double rows. The drip tape had emitters spaced 30 cm apart and an emitter flow rate of 0.55 $L•h^{-1}$.

The irrigations were automatically controlled by a datalogger (CR10, Campbell Scientific, Logan, Utah) connected to solenoid valves. Irrigation decisions were made multiple times per day by the datalogger and were based on soil water tension (SWT). Soil water tension was measured with granular matrix sensors (GMS, Watermark Soil Moisture Sensors Model 200SS, Irrometer Co. Inc., Riverside, Calif.) installed at 0.2 m depth in the center of the onion double row. Sensors had been previously calibrated to SWT (Shock et al. 1998a; Shock, 2003) and tensiometers were used in 1992 and 2005 to confirm the validity of watermark calibration. The GMS were connected to the datalogger using multiplexers (AM 410 multiplexer, Campbell Scientific). The datalogger read the sensors and recorded the SWT every hour.

Onion evapotranspiration (ET_c) was calculated by the Pacific Northwest Cooperative Agricultural Weather Network (AgriMet, U.S. Bureau of Reclamation, Boise, Idaho) from data collected at the Malheur Experiment Station by an AgriMet weather station using crop coefficients and a modified Penman equation (Wright 1982). Pan evaporation was measured using a class A pan at a NOAA weather station immediately adjacent to the AgriMet weather station.

In early September, the onions were undercut with a rod weeder to field cure for about a week. After curing, the onions were topped, bagged and placed into storage. The storage shed was managed to maintain air temperature as close as possible to 1°C.

Growers in the Treasure Valley market onions directly from the field and after up to 7 months of storage. For the data for drip-irrigated onion trials to be representative of the local marketing conditions, the onions were stored for approximately 2 to 3 months before grading each year. Onion yield, grade, and water use efficiency were all based on onion yield out of storage. The onions were graded in early December each year. Bulbs were separated according to quality: bulbs without blemishes (No. 1s), split bulbs (No. 2s), and diseased bulbs. The No. 1 bulbs were graded according to diameter: small (< 57 mm), medium (57 to 76 mm), jumbo (76 to 102 mm), colossal (102 to 108 mm), and super colossal (>108 mm). Marketable onions were considered perfect bulbs in the medium, jumbo, colossal, and super colossal size classes.

After grading, 50 bulbs ranging in diameter from 89 to 108 mm from each plot were rated for single centers. The onions were cut equatorially through the bulb middle and, if multiple centered, the long axis of the inside diameter of the first single ring was measured. These multiple-centered onions were ranked according to the diameter of the first single ring: small (< 38 mm), medium (38 to 57 mm), and large (> 57 mm). Onions were considered "functionally single centered" for processing if they were single centered or had a small multiple center.

Results and Discussion

Optimum SWT

Research was initiated in 1997 to determine the optimum SWT for scheduling irrigations for drip irrigated onion (Shock et al., 2000a). Onion was submitted to five SWT treatments (10, 20, 30, 50, and 70 cb) using subsurface drip irrigation in 1997 and 1998 (Fig. 1). The SWT in each plot was maintained relatively constant by automatically applying 1.5 mm of water up to 8 times a day as needed based on SWT readings.

The high frequency, short irrigations possible with the automated system were able to maintain the SWT at 0.2 m depth relatively constant for the 10 and 20 cb treatments (Fig. 1). As the treatments became drier than 20 cb the oscillations in SWT increased. The 10 cb treatment applied more water than onion ET_c for the season and the 20 cb treatment applied close to the same amount of water as onion ET_c for the season (Fig. 2). The drier treatments applied less water than onion ET_c for the season.

In 1997, onion total yield and size were highest with the wettest treatment (10 cb). However, marketable yield was maximized at a SWT of 21 cb due to an increase in decomposition in storage with wetter treatments (Fig. 3). Onion profits were maximized by a SWT of 17 cb. In 1998, decomposition in storage was not influenced by treatment, and onion total yield, size, marketable yield (Fig. 3), and profits were maximized by the wettest treatment of 10 cb. Considering the higher nitrate leaching potential with a SWT wetter than 20 cb and the difficulty of predicting the storage quality of the crop, the use of a SWT closer to 17 cb for drip irrigated onion is suggested.

These results are similar to those of Shock et al. (1998b), who found that, with furrow-irrigated long-day onions at the Malheur Experiment Station, the optimum SWT at 0.2 m depth as an irrigation threshold ranged from the highest tested level (12.5 cb) down to 27 cb, depending on the level of storage decomposition each year. However, with automated, high frequency, drip irrigation, the optimum SWT could be higher than with furrow irrigation. With furrow irrigation, large oscillations of SWT are difficult to avoid and could lead to longer periods of excessively wet soil, which could promote disease. Research with short-day onions has also shown similar results. Coelho et al. (1996) reported a yield response to a threshold of 8.5 cb, and Abreu et al. (1980) reported a yield response to a threshold of 10 cb. Klar et al. (1976) report onion yields to be highest with the lowest threshold tested (15 cb). However, comparison of the present study with others using less frequent irrigations (Abreu et al., 1980; Klar et al., 1976; Shock et al., 1998b) is complicated because of the different irrigation frequencies, environments and cultivars. In addition, all of the studies with short-day onions evaluated yields out of the field and none considered the possibility of bulb decomposition in storage or variable decomposition in storage as a function of irrigation treatment. Decomposition can be increased by a low SWT irrigation criterion (Shock et al., 1998b, 2000a).

Reduction of season-end irrigation threshold for reduction of storage decomposition

In conjunction with the 1997 and 1998 soil water tension trials, the effect of reducing the SWT in the last third of the growing season on onion storage decomposition was also tested (Shock et al., 2000b). The soil water tension at which automated irrigations were started was increased from 20 cb to 30, 50, or 70 cb after July 15. Any increase of the SWT from 20 cb did not reduce storage decomposition, but reduced colossal onion yield in 1997 and marketable and total yield in 1998. These results are consistent with van Eeden and Myburgh (1971) and Dragland (1974) who found water stress in the latter part of the season reduced onion yields, but did not reduce storage decomposition.

N fertilization and plant population

In 1999, 2001, and 2002, research to determine N fertilization requirements and plant population for drip irrigated onion was conducted (Shock et al., 2004). Drip irrigation can reduce leaching, because a smaller amount of water can be applied at each irrigation, avoiding a large oscillation in soil moisture and saturation of the soil profile that occurs with furrow irrigation. Lower N fertilizer requirements would be expected with drip irrigation. With a new onion size category being used for marketing (super colossal) and the increased revenue accrued from larger bulbs, a reexamination of the relationship between plant population and bulb size and yield became necessary.

Each year, onions were grown on fields that had been cropped with wheat for 4 years. Each wheat crop received moderate N fertilization (168 kg/ha). Onions were drip irrigated automatically using a soil water tension of 20 cb to initiate irrigations every three hours if necessary. The irrigation intensity was 1.6 mm of water/ irrigation. Onions were subjected to a combination of seven N rates (0, 56, 112, 168, 224, 280, and 336 kg/ha) and four plant populations (185, 250, 300, and 370 thousand plants/ha). The nitrogen for each treatment was split into 5 equal amounts and applied through the drip tape every 10 days from mid-May to early July. Soil was sampled before and after the onion crop. Irrigation water N content was determined and onion N uptake (bulbs and tops) was measured for each treatment.

Onion marketable yield increased and bulb diameter decreased with increasing plant population (Fig. 4). Within the range of plant populations tested, gross returns were not always responsive to plant population. Returns were increased by the increase in marketable yield obtained by higher plant population, but higher plant populations also reduced the production of the largest size bulbs which had the highest value per weight. In 1999, when super colossal bulbs were not measured, gross returns increased with increasing plant population and reached a maximum at 371,000 plants/ha. In 2000, the plant population maximizing gross returns was 266,000 plants/ha. In 2001, gross returns were not responsive to the range of plant populations tested. The plant populations maximizing gross returns in this study were substantially lower than the range of 309,000 to 514,000 plants/ha found to maximize gross returns previously (Shock et al., 1990), when colossal and super colossal bulbs were neither measured nor as important in onion marketing.

Onion yield and grade were not responsive to N fertilizer rate or the interaction of N fertilizer rate with plant population. Preplant soil available N, N mineralization, and N in irrigation water all contributed N to the crop (Fig. 5). Previous research at the Malheur Experiment Station investigating N rates for furrow irrigated onions found no response of onion yield to N fertilizer in 3 out of 4 site years (Shock et al., 1991, Miller et al., 1992). Low N needs for drip-irrigated onion are consistent with full size commercial demonstrations (Shock and Klauzer, 2003). The N mineralization rates in this study are within the range determined for Treasure Valley soils (Carter et al., 1975; Stieber et al., 1995; Shock et al., 1998c).

Despite the carefully managed irrigations, leaching of nitrate and or volatile N losses from the crop root zone occurred in 1999 and 2001 for the higher N rates. Other research, with highly efficient drip irrigation systems, has also found that some leaching below the crop root zone will occur when irrigating for maximum yield. In New Mexico on a sandy loam, with one drip tape per bed and irrigations on alternate days, deep percolation occurred when the irrigation system was operated for maximum onion yield and to keep the full bed surface wet (Al-Jamal et al., 2001). For cauliflower (*Brassica oleracea* L.) (Thompson et al., 2000), collard (*Brassica oleracea* L.), mustard (*Brassica juncea* L.), and spinach (*Spinacea oleracea*, L.) (Thompson and Doerge, 1995b), lettuce (*Lactuca sativa* L.)(Thompson and Doerge, 1995a), and watermelon (*Citrullus lanatus* Thumb.)(Pier and Doerge, 1995) drip irrigated daily on a sandy loam in Arizona, irrigating for maximum yield was just below or at the SWT that resulted in N leaching. Sweet corn (*Zea mays* L.) grown on sandy loam in Israel with one tape per row and irrigated daily using Et_c replacement, resulted in drainage below the crop root zone even with 0.25 $L \bullet h^{-1}$ emitters (Assouline et al., 2002).

Irrigation intensity and emitter flow rate

The automated irrigation system used for research at the Malheur Experiment Station used an irrigation intensity of 1.5 mm per irrigation with an irrigation frequency of up to 8 times per day, which would be impractical on a commercial scale. The emitters had a flow rate of 0.5 $L \bullet h^{-1}$, but lower flow emitters have been advocated as a means of improving irrigation uniformity. In 2002 and 2003, research was conducted to determine onion response to drip irrigation intensity and emitter flow rate (Shock et al., 2005a). Onions were submitted to eight treatments as a combination of four irrigation intensities (1.6, 3.2, 6.4, and 12.7 mm of water per irrigation) and two drip tape emitter flow rates (0.5 and 0.25 $L \bullet h^{-1}$). Onions in each plot were submitted to one irrigation intensity and one emitter flow rate. Each plot was irrigated independently and automatically when the SWT reached 20 cb. Irrigation intensities of 12.7 mm per irrigation slightly increased onion yield and grade above the irrigation intensity of 1.6 mm per irrigation. An irrigation intensity of 12.7 mm did not result in an increase in water applied (Fig. 6) nor in any significant difference in average soil water tension (Fig. 7). The 12.7 mm irrigation intensity corresponded to an irrigation frequency of every 1 to 2 d. Lowering the emitter flow rate from the currently used of 0.5 $L \bullet h^{-1}$ to 0.25 $L \bullet h^{-1}$, resulted in slightly lower onion yield and grade.

Other studies investigating irrigation intensity and emitter flow rate are not comparable, because of varying factors. The irrigation frequencies tested were much lower than ours or the onion production and marketing conditions were different from our studies (Bucks et al., 1981; Ellis et al., 1986; Kannan and Mohamed, 2001). Some studies were done with processing onions (Hanson et al., 2003), or onions marketed at much smaller size classes. In other studies, the irrigations were not automated and scheduling was not based on SWT feedback (Assouline et al., 2002).

Response of onion single centeredness to short duration water stress

Single centeredness has become an important onion attribute for marketing due to the use of onions in food products such as onion rings. Onion single centeredness is dependent on cultivar (Shock et al., 2005b), and is also influenced by growing conditions. Trials in 2003, 2004, and 2005 tested the effects of early season short duration water stress on onion single centeredness (Shock et al., 2007). The effects of the short duration water stress were also evaluated on onion yield, grade, and translucent scale. Translucent scale is a physiological disorder that might be influenced by water stress (Werner and Harris, 1965). Onions were drip irrigated automatically at a SWT of 20 cb and an irrigation intensity of 6.4 mm of water per irrigation. Onions in each treatment were stressed once at either the 2-leaf, 4-leaf, early 6-leaf, late 6-leaf, or 8 leaf stage and compared to a minimally stressed check (Fig. 8). Onions were stressed by interrupting irrigations until the SWT at 0.2 m depth reached 60 cb, at which time the irrigations were resumed. Onion single centeredness was reduced by short duration water stress in 2003 and 2005 (Fig. 9). Onions were sensitive to the formation of multiple centers with water stress at the 2-leaf to late 6-leaf stages. The 2004 growing season was characterized by cool, moist conditions and water stress did not affect single centeredness. Among all treatments and years, marketable yield was only reduced in 2005 with stress at the 4-leaf and 8-leaf stages. The incidence of translucent scale was very low each year and not related to early season water stress.

Our results are in agreement with Pelter et al. (2004) who found that water stress at the 3-leaf stage reduced single centeredness. However, contrary to our results, in the Pelter et al. (2004) study the reductions in single centeredness with stress at the 5-leaf stage were not significantly different from the check. Pelter et al. (2004) found that total yield was reduced by all stress treatments and colossal yield was reduced by stress at the 5, 7, and 9-leaf stages, contrary to our results. Our results showed yield reductions only in 2005 for total marketable yield from stress at the 8-leaf stage and for yield of combined jumbo, colossal, and super colossal bulbs from stress at the 4-leaf and 8-leaf stages. The yield reductions in the Pelter et al. (2004) study may be related to the more intense and longer water stress than in our study. The more intense water stress was due to the consistently higher SWT that the stressed plots were allowed to reach (70 cb) than in our study, and also due to their delays in restarting irrigation at the end of the stress treatments. Several of the stress treatments in the Pelter et al. (2004) study had SWT reaching or exceeding 100 cb for 10 days or more. The stress levels used in the Pelter et al. (2004) study are less likely to occur in commercial onion fields.

Conclusions of research in eastern Oregon

On silt loam soil, the optimum soil water tension for maximizing yield of long day onions after storage is 25 cb with furrow irrigation and 17 cb with drip irrigation.

Increasing the soil water tension in the latter part of the season did not reduce storage decomposition, but reduced bulb yield and size. Short duration water stress coinciding with warmer weather early in the growing season (Shock et al. 2007) was associated with yield reductions.

Within the range of plant populations tested (185,000 to 370,000 plants/ha), marketable yield increased and bulb size decreased with increasing plant population. Using gross returns as a criterion for determining the ideal plant population, gross returns were maximized by plant populations in the range from 266,000 plants/ha to 371,000 plants/ha, depending on the maximum bulb size desired and the prevailing market price structure.

Onions grown on silt loam in eastern Oregon previously cropped for 4 consecutive years of moderately fertilized wheat showed no response to N fertilizer under carefully managed drip irrigation. Preplant soil available N, N mineralization, and N in irrigation water all contributed N to the crop. Onion N uptake was maximized with no added N fertilizer and there was no difference in uptake between N treatments. Onion N uptake averaged 239 $kg \cdot ha^{-1}$ over all N rates and over three years.

When onions grown on silt loam were drip irrigated automatically to maintain a soil water tension of 20 cb, irrigation intensities of less than 13 mm of water per irrigation did not increase yield or size and did not reduce the total amount of water applied. An irrigation intensity of 13 mm per irrigation resulted in an irrigation frequency of every 1 to 2 days.

Onions were sensitive to formation of multiple centers with short-duration water stress (allowing SWT to reach 60 cb from 20 cb once during the season) at the four-leaf to six-leaf stages. The incidence of translucent scale was very low and was not affected by early season short-duration water stress.

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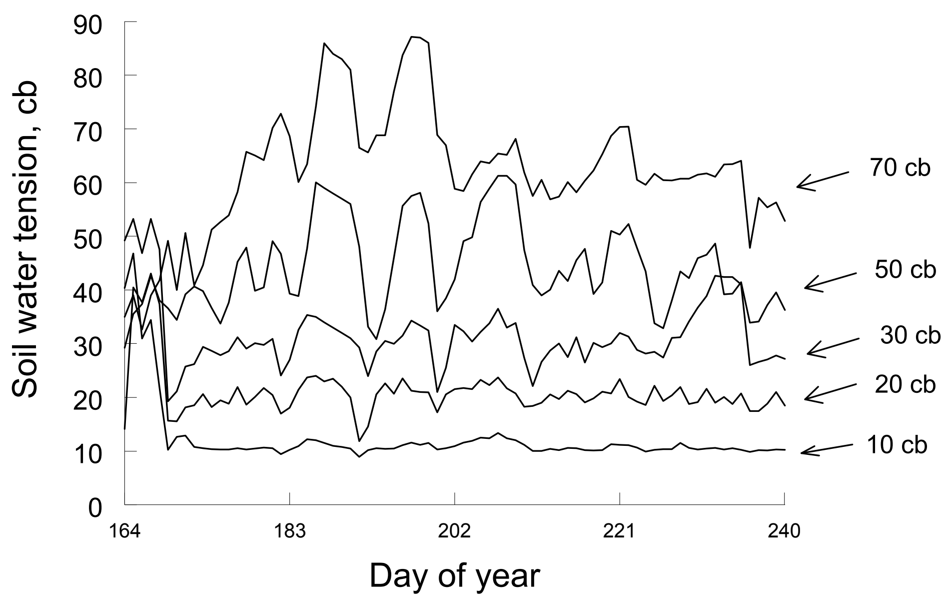

Fig. 1. Soil water tension over time for onions drip-irrigated automatically at five soil water tensions in 1997 (Shock et al., 2000a).

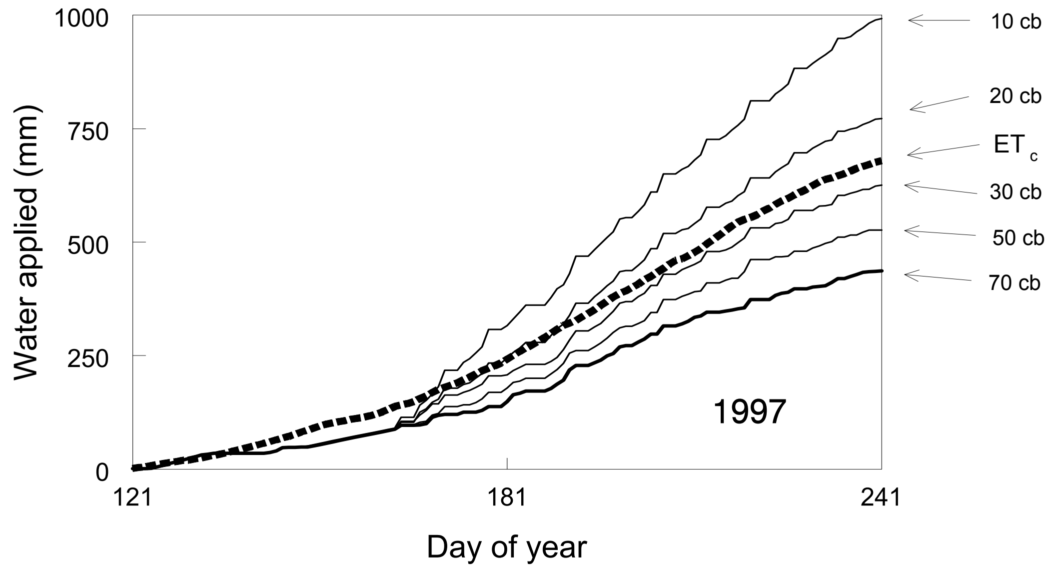

Fig. 2. Water applied over time and ET_c for onions drip-irrigated automatically at five soil water tensions in 1997 (Shock et al., 2000a).

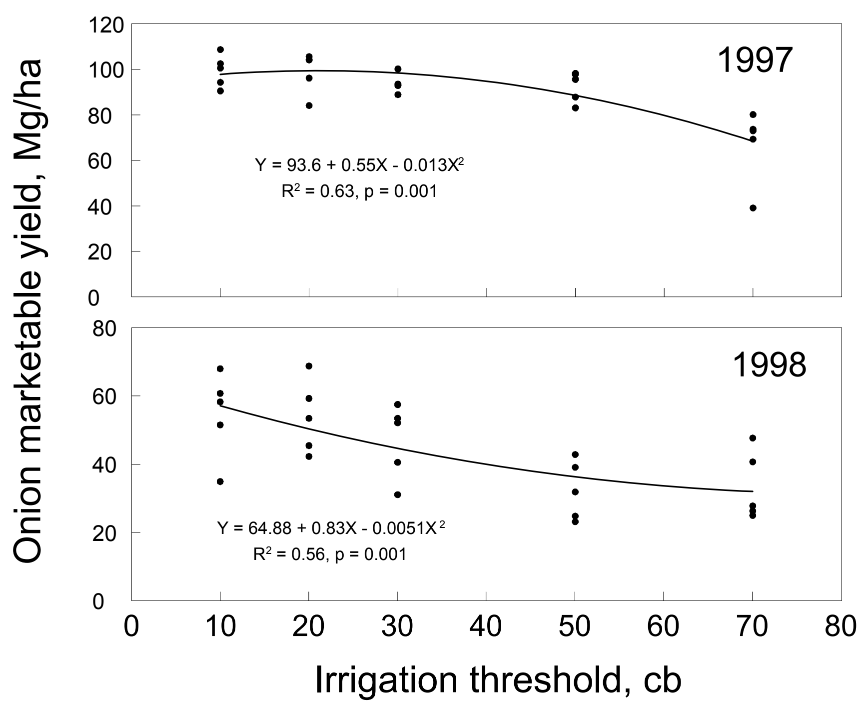

Fig. 3. Marketable yield for onions drip-irrigated automatically at five soil water tensions (Shock et al., 2000a).

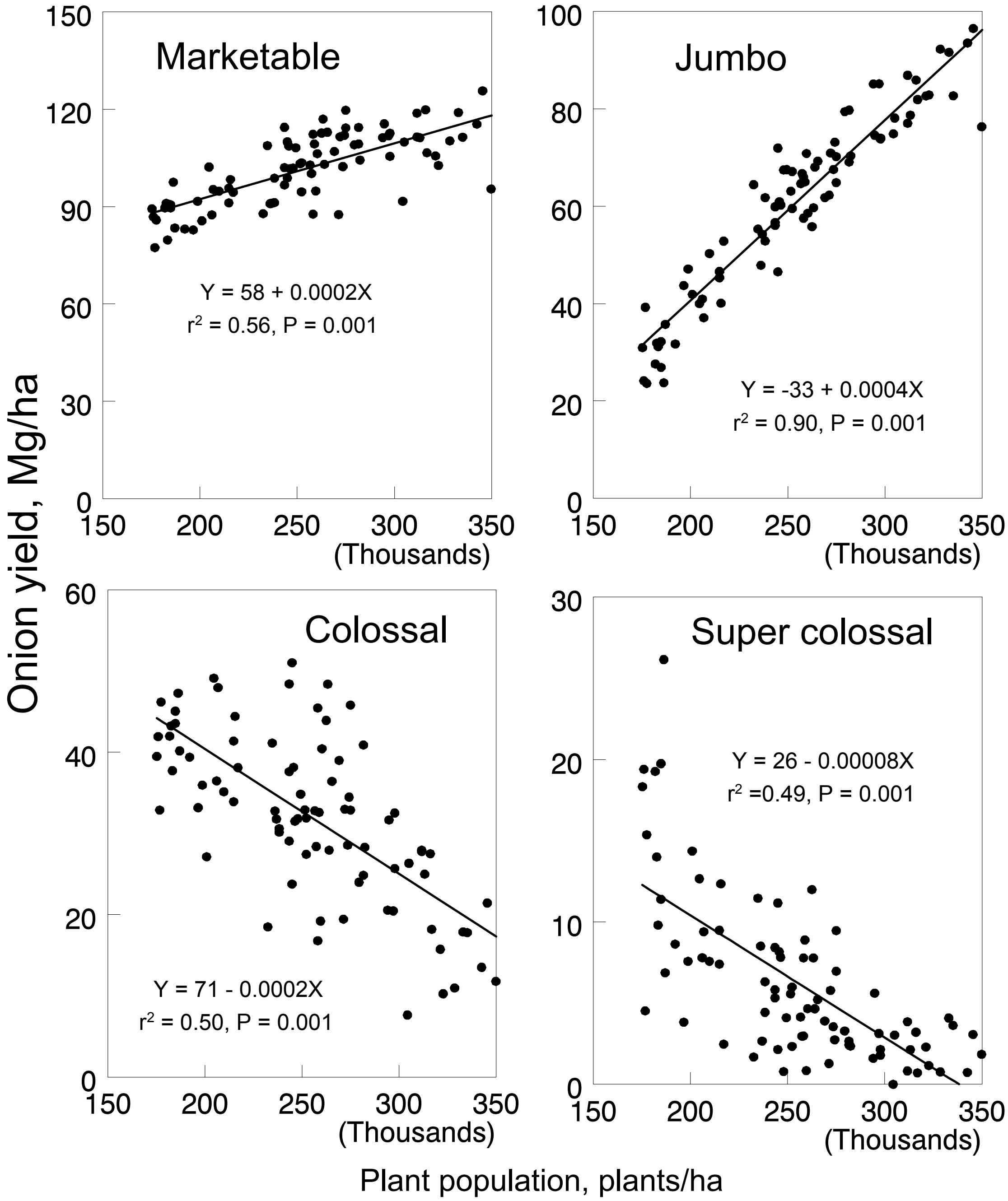

Fig. 4. Onion yield response to plant population in 2001 over seven N rates (Shock et al., 2004).

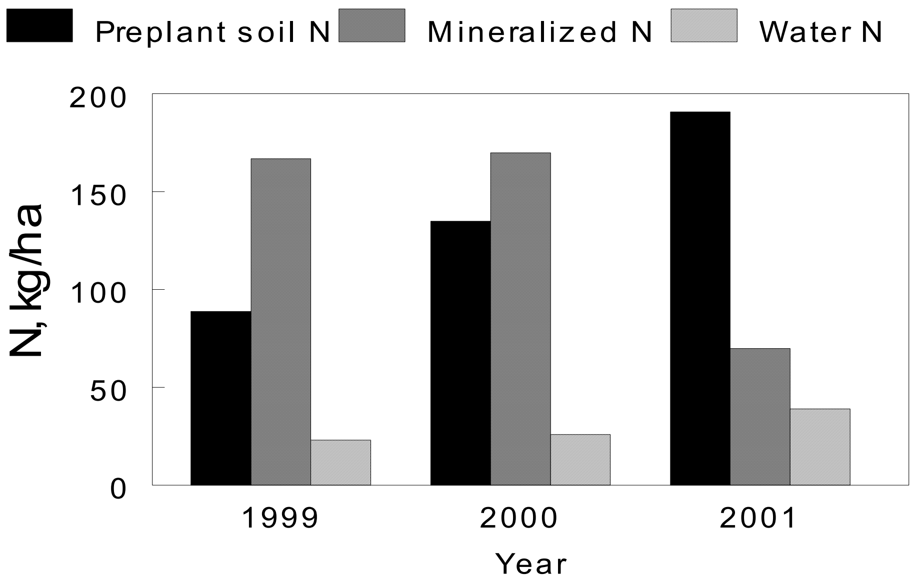

Fig. 5. Natural sources of N available to drip-irrigated onion (Shock et al., 2004).

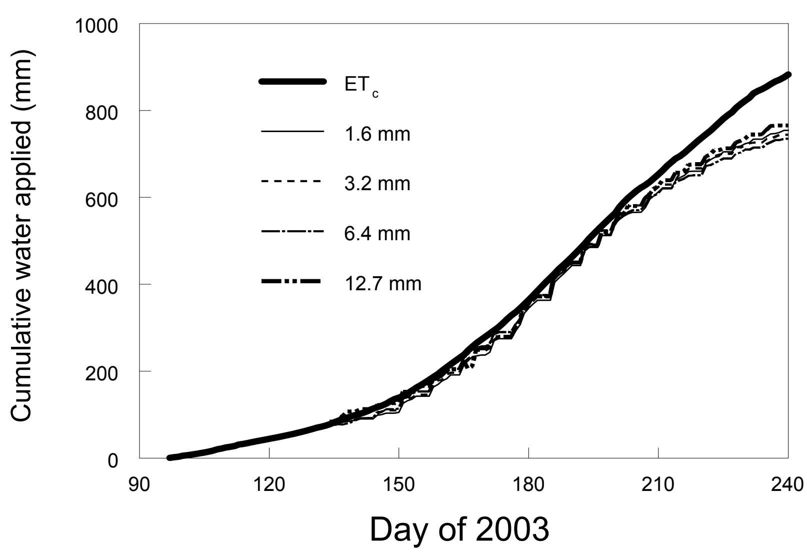

Fig. 6. Onion evapotranspiration (ET_c) and total water applied (includes precipitation) over time for four irrigation intensities (amount of water applied per irrigation) with 0.5 L•h^{-1} emitter in 2003 (Shock et al., 2005a).

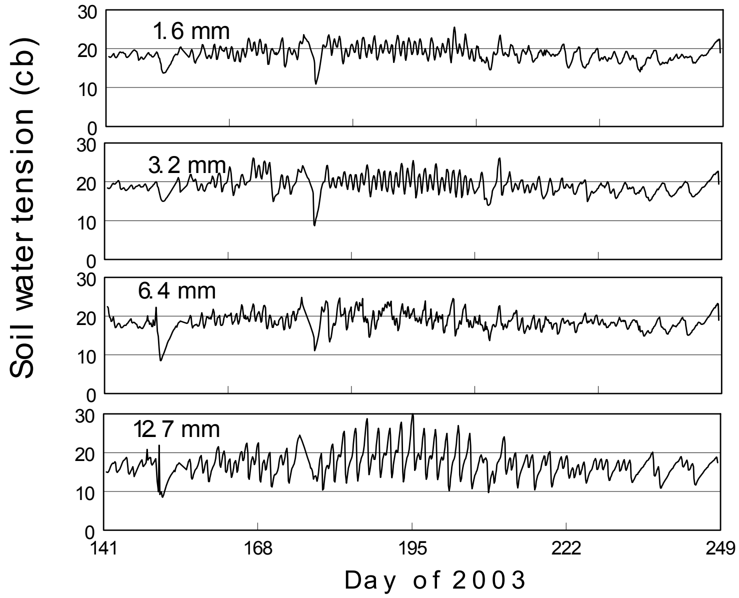

Fig. 7. Soil water tension at 0.2 m depth over time for onions drip irrigated at four intensities with an emitter flow rate of 0.5 L•h^{-1} (Shock et al., 2005a).

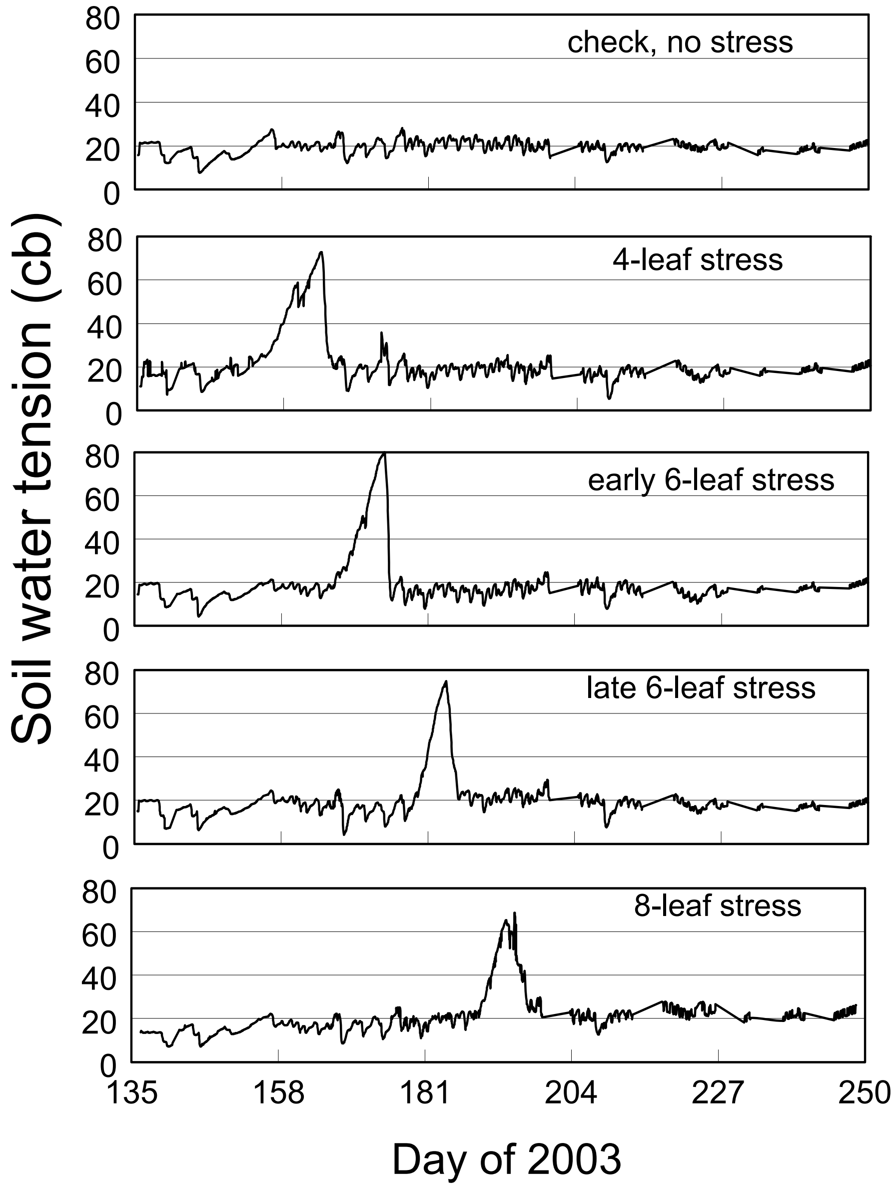

Fig. 8. Soil water tension for onions drip irrigated automatically at 20 cb and submitted to short-duration water stress (Shock et al., 2007).

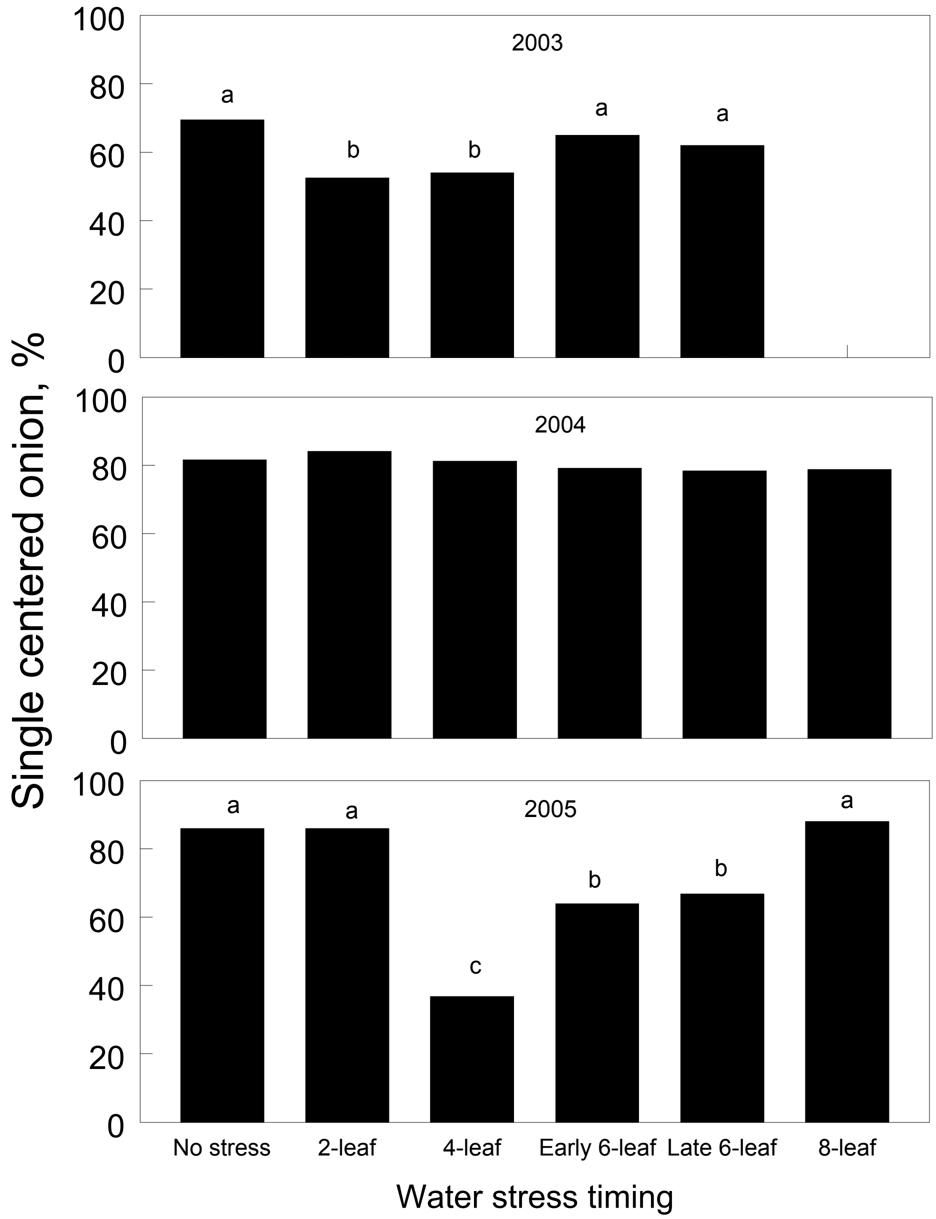

Fig. 9. Onion single centeredness response to short duration water stress at five growth stages. Columns followed by different letters are significantly different according to Fisher's protected least significant difference test at 0.05 probability level (Shock et al., 2007).