Demonstration of Sustainable Subsurface Drip Irrigation in Arizona: The AZdrip Project, 2002-2005

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Abstract

The use of subsurface drip irrigation (SDI) has increased recently in Arizona, due to its many advantages compared to surface irrigation. These advantages include water savings, ease of harvesting specialty crops, and ease of cultural and pest control practices. However, SDI is still used on only a small percentage of Arizona crop acreage. In 2002, a demonstration/research project ("AZdrip") was established at the University of Arizona's Maricopa Agricultural Center. The objectives of the project are to 1) evaluate management practices for efficient and sustainable irrigation using SDI, and 2) provide information on and demonstration of SDI management practices for Arizona growers. Four large plots (67' x 405' each) are equipped with two different SDI tubing installations (3 lines per 80" bed, 1 line per 40" bed) and are irrigated using two different schedules (automated high frequency, low frequency). Another plot is irrigated with surface flood irrigation for comparison. Crop planting, management, and harvest are conducted using methods common to commercial agriculture and outcomes are compared among the various plots. As of fall 2005, five cropping seasons have been completed. Yield is usually higher with SDI compared to surface irrigation, and water use is usually lower with SDI. Even under conditions conducive to high irrigation efficiency with surface irrigation, water use efficiency (crop produced per unit of water) has been as much as 100% higher with SDI than with surface irrigation. Overall, outcomes with SDI have been excellent compared to surface irrigation. However, salt accumulation is a long-term threat to sustainability of SDI, and appropriate management practices must be employed to control salt accumulation.

Introduction

Subsurface drip irrigation offers many advantages for production of high-value crops, including increased water use efficiency, reduction of nitrate leaching compared to surface irrigation, (Phene, 1995), higher yields (Camp, 1998), better weed control, and reduced incidence of plant disease. In addition, irrigation of permanent crops with SDI allows maintenance of low root-zone salinity, even when using irrigation waters containing appreciable salinity (Oron et al., 1999; Oron et al., 2002).

Recent research in Arizona has determined best management practices for subsurface drip-irrigated vegetables. This research has focused on such management variables as N requirements and optimum soil water tensions for irrigation scheduling (Thompson et al., 1996a, 2000a, 2002a). Furthermore, this research has shown that maximum economic yields with SDI are compatible with environmental protection (Thompson et al., 1996b, 2000b, 2002b). In addition, tissue test guidelines for N management of drip-irrigated vegetable crops have been proposed (Hartz, 1994; Kubota et al., 1996, 1997).

Despite rapid urbanization in Arizona, agriculture is responsible for approximately 70% of water use. Our growing population places ever-increasing pressure on farmers to reduce water use. The objectives of the AZdrip project are to 1) evaluate management practices for efficient and sustainable irrigation using SDI, and 2) provide information on and demonstration of SDI management practices for Arizona growers. This project is a "showcase" for demonstration of SDI management practices to Arizona growers who may consider switching to SDI.

Materials and Methods

The AZdrip project site features five large plots (67' x 405') with SDI or surface flood irrigation (Fig. 1). Large plots allow the use of large-scale field equipment for effective demonstration of SDI management techniques. This project features long-term demonstration and evaluation of various aspects of crop production with SDI, in comparison with conventional surface flood irrigation. Four of the plots have SDI installed in one of two configurations (Table 1, Fig, 2), with two different irrigation scheduling treatments (Table 1). With “high-frequency" SDI irrigation, soil moisture is kept near “field capacity” at all times. Five Irrometer® transducer-equipped tensiometers located in each high-frequency plot are interfaced with a Campbell Scientific® Datalogger to trigger irrigation (0.07") when the average soil water tension reaches 10 cbar. Non-automated tensiometers in low-frequency plots are used to schedule irrigation events (0.5 - 1.0") when soil water tension reaches 30-50 cbar. Surface irrigation is scheduled using the AZSched program. These combinations of SDI configuration and management were chosen based upon input from experienced SDI growers in Arizona.

The drip tubing is Netafim® Typhoon, 13 mil wall thickness, emitter spacing 12", flow rate 0.18 - 0.25 gal/emitter/hr. A pump delivers 70 gpm @ 40 psi. Filters are two Netafim® 24" sand filters and one Netafim® disk filter. Acid, fluid fertilizers, labeled insecticides are injected with two LMI Milton Roy® Electromagnetic Dosing Pumps. Irrigation water for the SDI plots is continuously acidified to pH 6.0. The entire system is flushed and chlorinated twice per season. Filters backflush automatically when pressure differential is >5 psi. Irrigation water quality is shown in Table 2.

This project was established during summer 2002 and is intended to function for at least ten years, provided that adequate funds are available for its operation. The first crop, broccoli, was planted in October 2002 and harvested in February 2003. Seedless watermelon was planted in March 2003 and harvested in June-July 2003. A second broccoli crop was planted in November 2003 and harvested in March 2004. Another broccoli crop was planted in September 2004 and harvested in January 2005. A crop of watermelon was planted in April 2005 and harvested in July 2005. Finally, barley was planted in November 2005. Planting and harvest dates are summarized in Table 3. We will continue to grow 1-2 crops per year. Short and long-term evaluations allow comparisons of surface vs. SDI and among the various SDI treatments with respect to crop yield and quality, water use efficiency, fertilizer and pesticide use, and economic returns.

Soil preparation is similar across the SDI plots and normally consists of the following before planting: 1) disking using an 80" ‘Sundance’ disk configured for the proper bed spacing, 2) rototilling, and 3) bed-shaping. After harvest the crop biomass is shredded and incorporated using the ‘Sundance’ disk. Operations performed in the surface irrigated plot are similar, but the plot is normally plowed between crops, and beds are listed again before planting. One mechanical cultivation is normally conducted early in each season, followed by hand-hoeing and spraying as needed. Weed and pest control chemicals are applied as needed, and a summary of chemical applications is given in Table 4.

In the SDI plots, N is applied as fertigated urea ammonium nitrate solution (32-0-0), and all P is applied as fertigated phosphoric acid (0-52-0). In the surface-irrigated plot, N and P are applied as preplant incorporated mono ammonium phosphate (11-52-0) and additional N is fertigated 32-0-0. Nitrogen is normally applied 5-6 times per season, and P 1-2 times per season. Nitrogen and P applications are summarized in Table 3.

Evaluation of Project Outcomes:

To date, we have evaluated outcomes with respect to agronomic and irrigation system performance, as follows.

Agronomic evaluation. Crop growth and development are evaluated at least weekly during each cropping season. All pertinent indices of crop yield and quality are measured. Yield potential is determined by hand-harvesting in four $2m^2$ sampling areas within each plot, and whole-plot yields are determined by harvests conducted by commercial harvest crews. Soil sampling for indices of soil fertility and quality are conducted at several locations within each plot at the end of each cropping season. Plant samples are collected several times during each season to monitor crop nutrient status, and at the end of each season to determine nutrient uptake and nutrient use efficiency. Amounts of water used are monitored for each plot, and are used to calculate water use efficiency.

System evaluation. The long-term performance of the SDI system will determine its longevity and is an important aspect of sustainability. Hydraulic performance of the irrigation system is evaluated at least monthly by comparing water flow rates with initial baseline values. Evaluations will also include inspection for any mechanical damage, emitter plugging, deterioration, animal damage, etc.

Results and Discussion

Irrigation System Evaluation

Irrigation system flow rates as of January 2006 are within 5% of the initial flow rates measured when the system was installed in July 2002 (data not shown). Therefore, we conclude that emitter clogging has been minimal.

Season 1: Broccoli 2002-2003.

'Marathon' broccoli was direct-seeded on Oct. 7, 2002. The yields shown in Fig. 3 are expressed as numbers of 24 lb. cartons/acre and include one commercial crown-cut harvest and one estimated bunch-cut harvest. Because of heavy rains after the crown cut harvest on Feb. 11, 2003, a second commercial harvest could not be conducted. Yields were approximately equal across the plots, and were all well above the statewide average yield of 520 cartons/ac during 2003 (Arizona Agricultural Statistics Service, 2005). Likewise, amounts of water applied were similar at the end of the season. No sprinklers were used for germination, and approximately 12" of water were applied through the SDI system to germinate and establish the crop. Thus, water use was higher with SDI during the early part of the season, and lower with SDI after the establishment period. Soil water tension stayed near 10cbar all season in the high frequency irrigation plots, and occasionally reached 30 cbar in the low frequency and surface irrigated plots. There was no difference in crop yield or quality among the different SDI plots or between the SDI plots and the surface-irrigated plot during this season. Broccoli petiole NO_3 concentrations were above critical values all season in all plots, indicating that the crop was adequately supplied with N.

Season 2: Watermelon 2003

'Slice-n-Serve 830' seedless watermelon and 'WX 263' seeded watermelon (pollinator) were direct-seeded on April 2, 2003. The yields shown in Fig. 4 represent three commercial harvests (Table 3). The SDI plots considerably out-yielded the furrow-irrigated plots. Plant populations in the surface -irrigated plot were lower than in the SDI plots all season, largely because of cool weather during April that inhibited germination and emergence. Repeated surface irrigation apparently resulted in cooler soil temperatures than SDI, thus plant populations were lower. Yields were also higher with high frequency SDI than with low-frequency SDI. As in the previous season, no sprinklers were used for crop germination, thus about 12" of water were needed for germination and establishment in the SDI plots. By the end of the season, water use was higher with surface irrigation (31") than with SDI (25"-30"). In the high-frequency SDI plots, soil water tension stayed near 10 cbar all season, and reached values up to 80 cbar in the low-frequency plots. The higher soil water tension with low frequency irrigation may have induced crop stress and may in part account for the lower yields observed with low frequency irrigation. These results suggest that maintaining low values of soil water tension through frequent irrigation will enhance watermelon yields. Petiole sap NO_3 concentrations were below critical values the entire season. Nevertheless, yields in most plots compared favorably with the statewide average yield of 46,000 lb/ac during 2003(Arizona Agricultural Statistics Service, 2005).

Season 3: Broccoli 2003-2004

'Marathon' broccoli was direct-seeded on Oct. 6, 2003. No sprinklers were used to germinate the crop. However, excessive salt accumulation resulted in soil EC values of 25-50 dS/m in the top 0.5", and effectively inhibited crop germination in the SDI plots. Salt concentrations were lower with furrow irrigation, with soil EC values of 15 dS/m in the top 0.5". This represented a complete crop failure, and 'Marathon' broccoli was replanted by direct-seeding on Nov. 10, 2003, and germinated using sprinkler irrigation. About 4" of water were applied to all plots with sprinklers, which were removed on 12/2/03 and SDI and surface irrigation was commenced.

The yields shown on Fig. 5 represent two commercial harvests–for crown cut broccoli on Mar. 19, and for bunch-cut broccoli on Mar. 20, 2004. A second harvest scheduled for Mar. 25 was cancelled due to very low market prices. The yields were much lower than during the first season, mostly because of the failure to conduct the final harvest, and as a result yields compared poorly with state average yields of 640 cartons/ac during 2004 (Arizona Agricultural Statistics Service, 2005). Because sprinklers were used for germination, water use was much lower than during season 1, and overall water use was less with SDI (ca. 12") than with surface irrigation (14"). As in the previous seasons, high frequency SDI resulted in soil water tension near 10 cbar all seaon, while low frequency irrigation resulted in soil water tension values up to 70 cbar. However, yield with high frequency SDI was not significantly higher than with low frequency SDI. Petiole sap NO_3 concentrations were above critical concentrations in all plots during the entire season.

Season 4: Broccoli 2004-2005

'Marathon' broccoli was direct-seeded on Oct. 1, 2004 and sprinkler irrigation was used to germinate the crop in all plots. Approximately 6" of water were applied with the sprinklers, which were removed on Oct. 15, 2004, at which time SDI and surface irrigation were initiated. The yields shown in Fig. 6 represent two commercial harvests, one each for crown cut and bunch cut broccoli. Yields were lower than expected because rain on Jan. 26 required a rescheduling of the commercial harvest, which resulted in some of the broccoli becoming too mature for harvest. Total water applied in the SDI plots was 13-16", while 20" were applied in the surface-irrigated plot because of poor water distribution within this plot. The yields were similar among SDI plots, which considerably out-yielded the surface-irrigated plot. Low yield with surface irrigation occurred because the crop was too mature to harvest this plot for bunch cut broccoli. This was likely the result of water stress induced by the need to withhold irrigation for harvest. The ability to continue irrigation in the SDI plots prevented crop stress.

Season 5: Watermelon 2005

Sakata variety 'SWD7201' diploid watermelons were transplanted on Apr. 27, 2005. Sprinklers were not used for crop establishment. About 8" of water were used for crop establishment in the SDI plots, while 6" were used in the surface-irrigated plot. Total water applied was 20-23" across all plots. High temperatures at transplanting and poor water distribution in the surface-irrigated plot resulted in considerable crop mortality. Despite replanting by hand, low plant populations resulted in the surface-irrigated plot, which affected yields. The yields shown in Fig. 7 reflect one commercial harvest on July 2, 2005. Due to adverse market conditions, no other harvests could be conducted. Nevertheless, yields in the high frequency SDI plots compared favorably with statewide average yields of 46,000 lb./ac during 2004. Yield in the SDI plots with high frequency irrigation were much higher than those with low frequency SDI. As in previous seasons, high-frequency irrigation resulted in soil water tension near 10 cbar throughout the season, while in the low-frequency plots soil water tensions were as high as 70 cbar. This may have resulted in differences in crop stress, and hence yield, among the SDI-irrigated plots. The very low yield in the surface-irrigated plot is a result of the low plant populations mentioned above.

Summary and Conclusions

Two caveats should be considered when interpreting these results:

1. The commercial harvest yields fluctuate from year-to-year because of market and weather conditions. During some seasons, low yields are the result of failure to harvest because of untimely rains or low market prices. Thus, yields should be compared among plots within seasons only.
2. The experimental conditions are conducive to high irrigation efficiency with furrow irrigation, with runs only 400' long. Therefore, water use with SDI was not consistently lower than with surface irrigation. With more typical run lengths (e.g. 800' or more), water use would increase considerably with surface irrigation.

The results so far indicate:

1. High frequency irrigation with SDI benefitted summer-grown watermelon crops, but did not benefit winter-grown broccoli crops compared to low-frequency irrigation with SDI.
2. Providing for high-frequency SDI irrigation for summer-grown crops (irrigation at least once/day) to maintain soil water tension near 10 cbar should result in higher yield of watermelons.
3. The plot design is conducive to high surface irrigation efficiency. However, the combination of generally lower water use and higher yields with SDI have resulted in substantially higher water use efficiency (crop produced per unit of water) with SDI than with surface irrigation (Fig. 8). With high-frequency SDI, cumulative water use efficiency was twice that with surface irrigation. Thus, twice as much crop was produced using the same amount of water with high-frequency SDI than with surface irrigation.
4. Continued use of SDI in Arizona will inevitably lead to salt accumulations detrimental to crop growth, unless salt accumulation can be minimized. Salt accumulation may pose the single largest constraint to the sustainable use of SDI in Arizona. Detrimental salt accumulations can be avoided by a) cultural techniques with some crops (e.g. pre-irrigation followed by removal of the bed cap with cotton), b) periodic leaching with sprinklers, or c) transplanting of high-value crops.

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Table 1 Plot treatments for the AZdrip project.

Plot	SDI Tubing Placement	Irrigation Treatment
1	3 SDI lines per 80" bed 10 beds per plot	Automated high frequency
2	1 SDI line per 40" bed 20 beds per plot	Automated high frequency
3	3 SDI lines per 80" bed 10 beds per plot	Low frequency
4	None	Surface flood irrigation
5	1 SDI line per 40" bed 20 beds per plot	Low frequency

Table 2. Water quality for AZdrip (Oct. 2005).

pH	7.8
EC	1.7 dS/m
HCO_3^-	178 ppm
Cl	261 ppm
SAR	6.9

Table 3 Planting and harvest dates for AZdrip cropping seasons.

Season	Planting Dates	Crop	Commercial Harvest Dates	N Applied	P Applied
				-------lb ac^{-1}-------	
1	Oct. 7, 2002	Broccoli	Feb. 11, 2003	320	70
2	Apr. 2, 2003	Watermelon	Jun. 24, 2003 Jul. 3, 2003 Jul. 16, 2003	160-190†	60
3	Nov. 10, 2003	Broccoli	Mar. 19, 2004 Mar. 20, 2004	160-180†	
4	Oct. 1, 2004	Broccoli	Jan. 28, 2005 Feb. 2, 2005	120-190†	60
5	Apr. 27, 2005	Watermelon	July 2, 2005	120-140‡	30

† The higher N rate was applied to the SDI plots, the lower to the surface-irrigated plot.
‡ The higher N rate was applied to the surface-irrigated plot, the lower to the SDI plots.

Table 4. Summary of chemical applications in the AZdrip project.

Season	Operation	HFI, 80" beds	HFI, 40" beds	LFI, 80" beds	LFI, 40" beds	Surface
1	Preplant bensulilde for weed control (6 qt./ac)	X	X	X	X	X
	Zeta-cypermethrin for insect control (4 oz/ac)	X	X	X	X	X
	Acetamiprid for insect control (1.5 oz/ac)					X
	Imidicloprid for insect control (12 oz/ac)	X	X	X	X	
2	Imidicloprid for insect control (21 oz/ac)					X
3	Preplant bensulide for weed control (6 qt/ac)	X	X	X	X	X
4	Preplant bensulide for weed control (6 qt/ac)	X	X	X	X	X
5	None					

Figure 1 Plot plan for the AZdrip field at the Maricopa Agricultural Center.

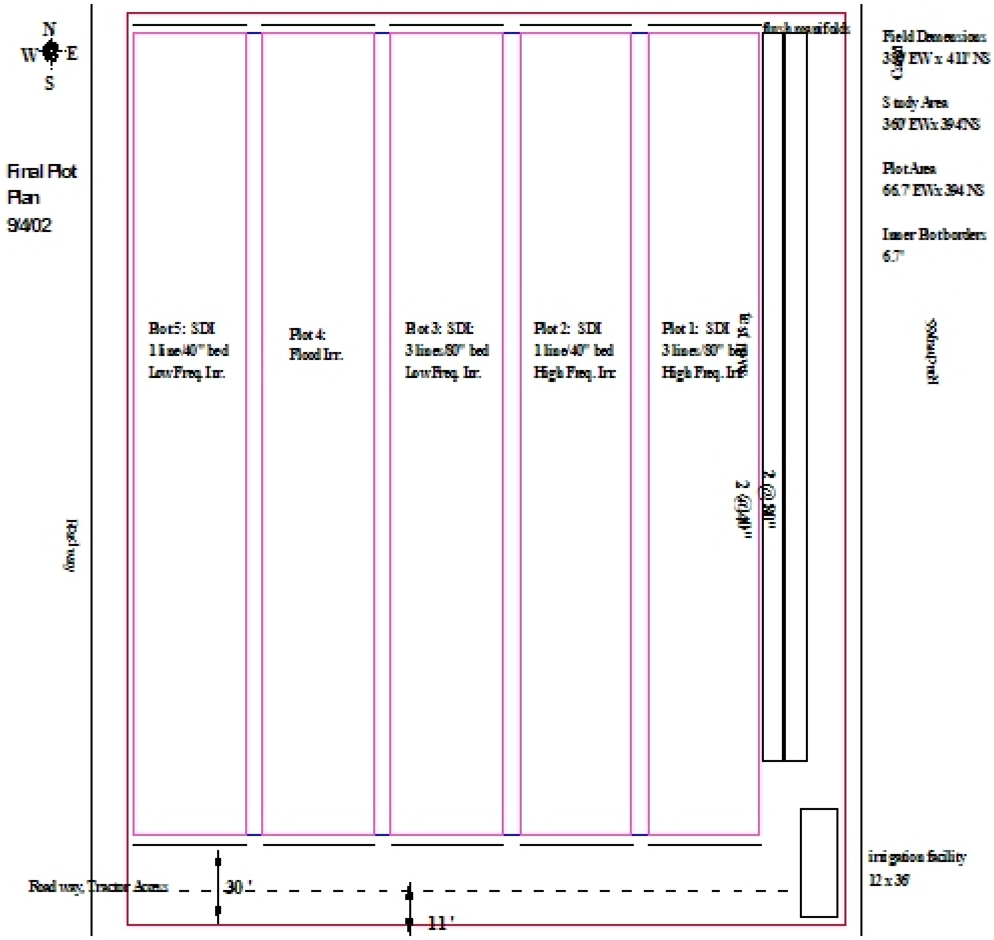

Figure 2. Bed configurations and drip tubing locations for the AZdrip project. Diagrams A) to C) illustrate bed configurations used when growing broccoli, and D) through F) illustrate bed configurations used when growing watermelons.

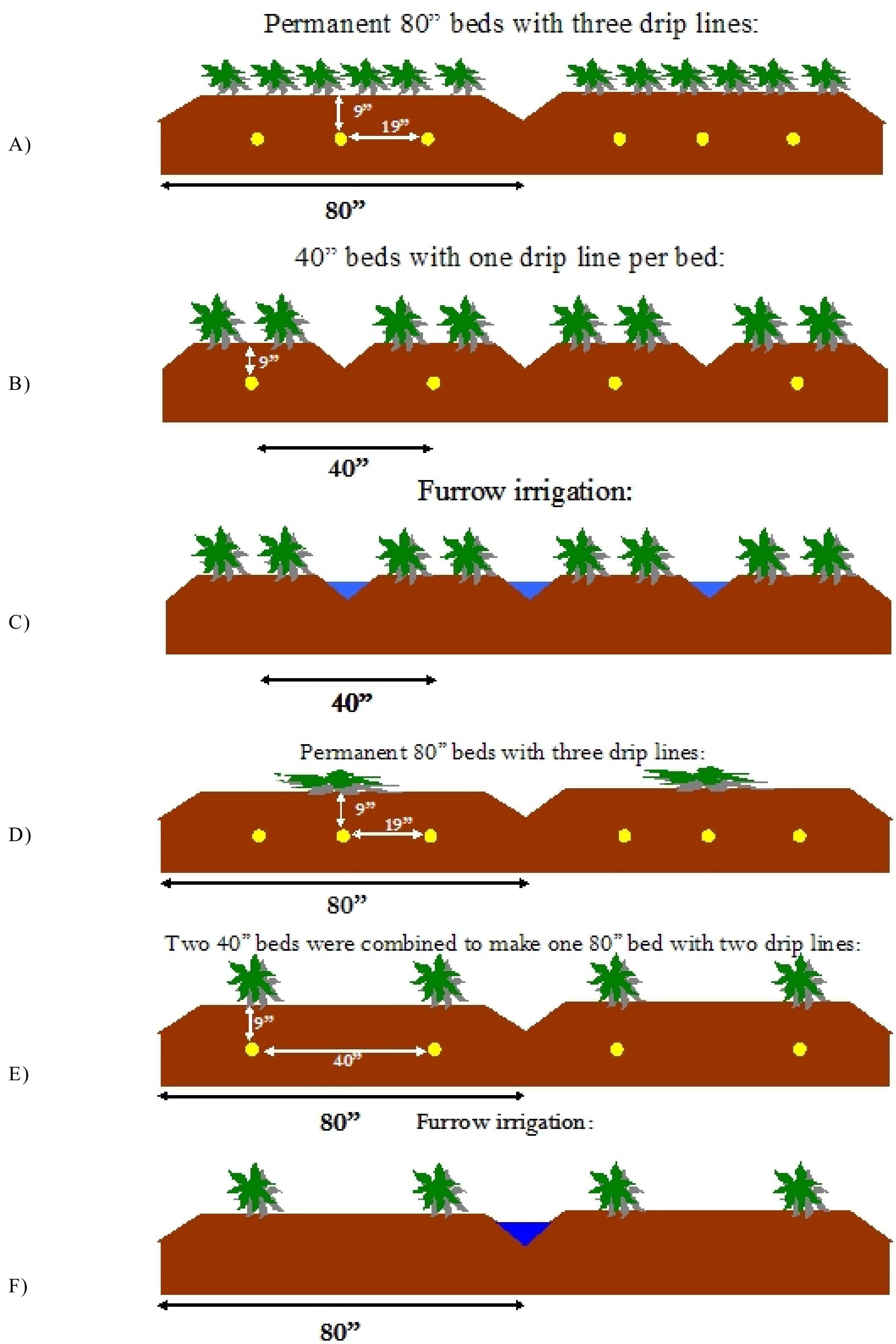

Figure 3. Yield, water use, soil water tension, and petiole sap NO_3 for the first AZdrip season: broccoli 2002-03.

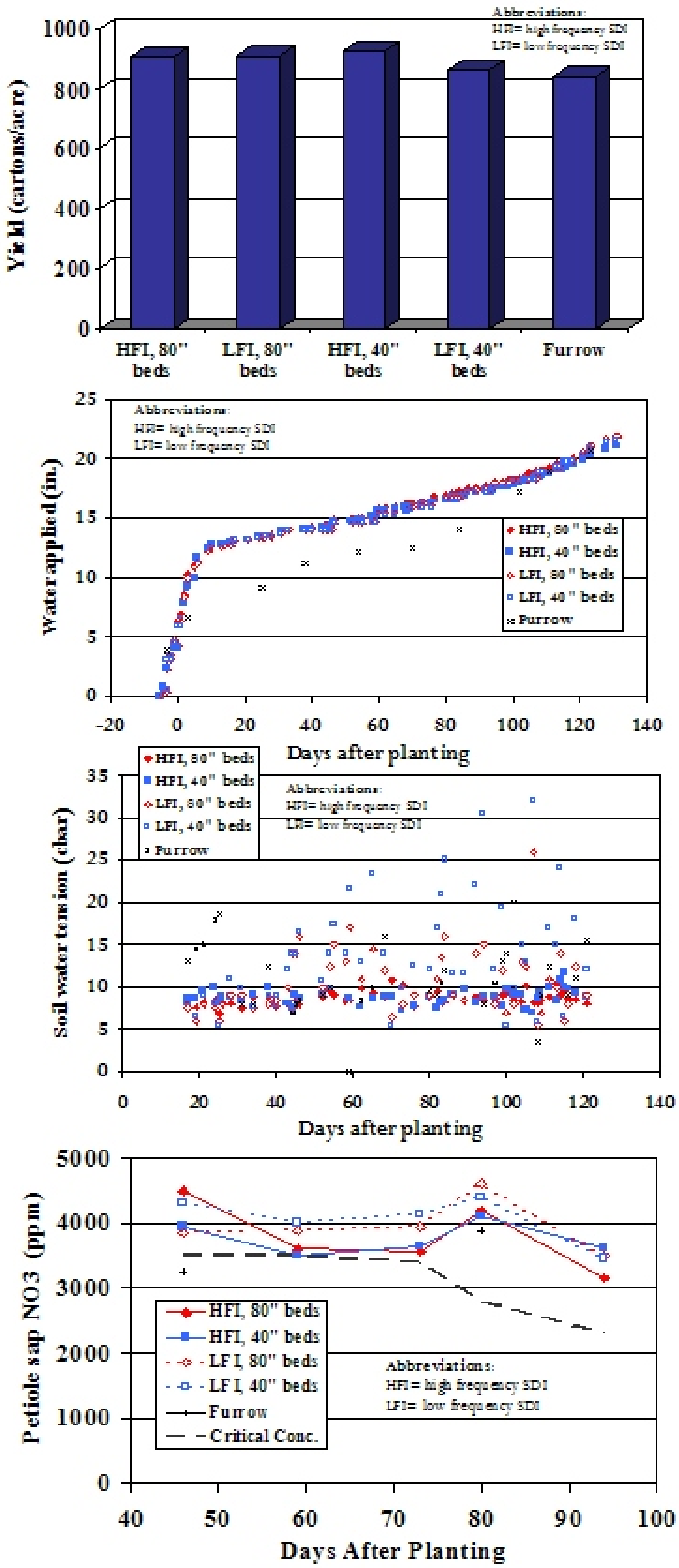

Figure 4. Yield, water use, soil water tension, and petiole sap NO_3 for the second AZdrip season: watermelon 2003.

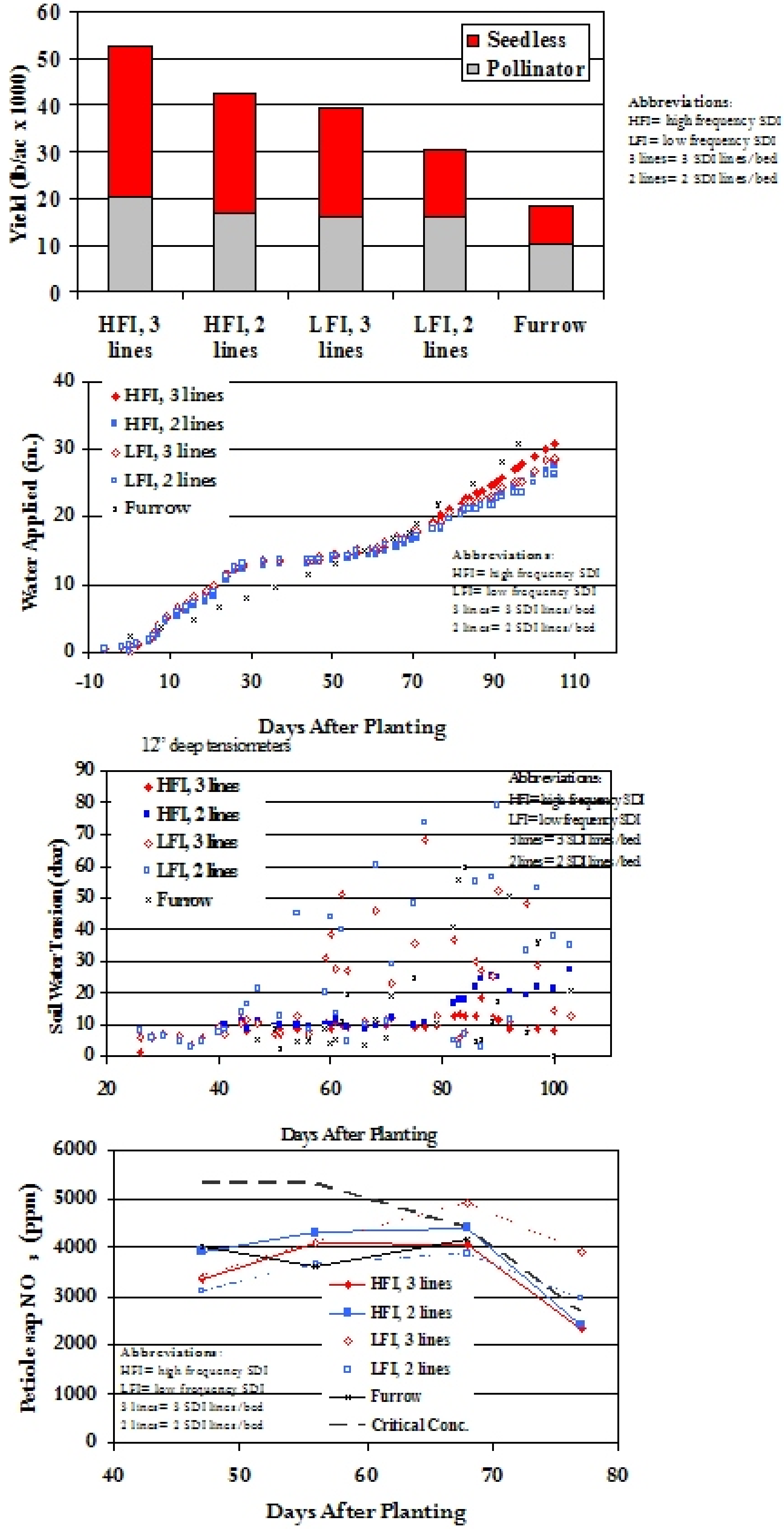

Figure 5. Yield, water use, soil water tension, and petiole sap NO_3 for the third AZdrip season: broccoli 2003-04.

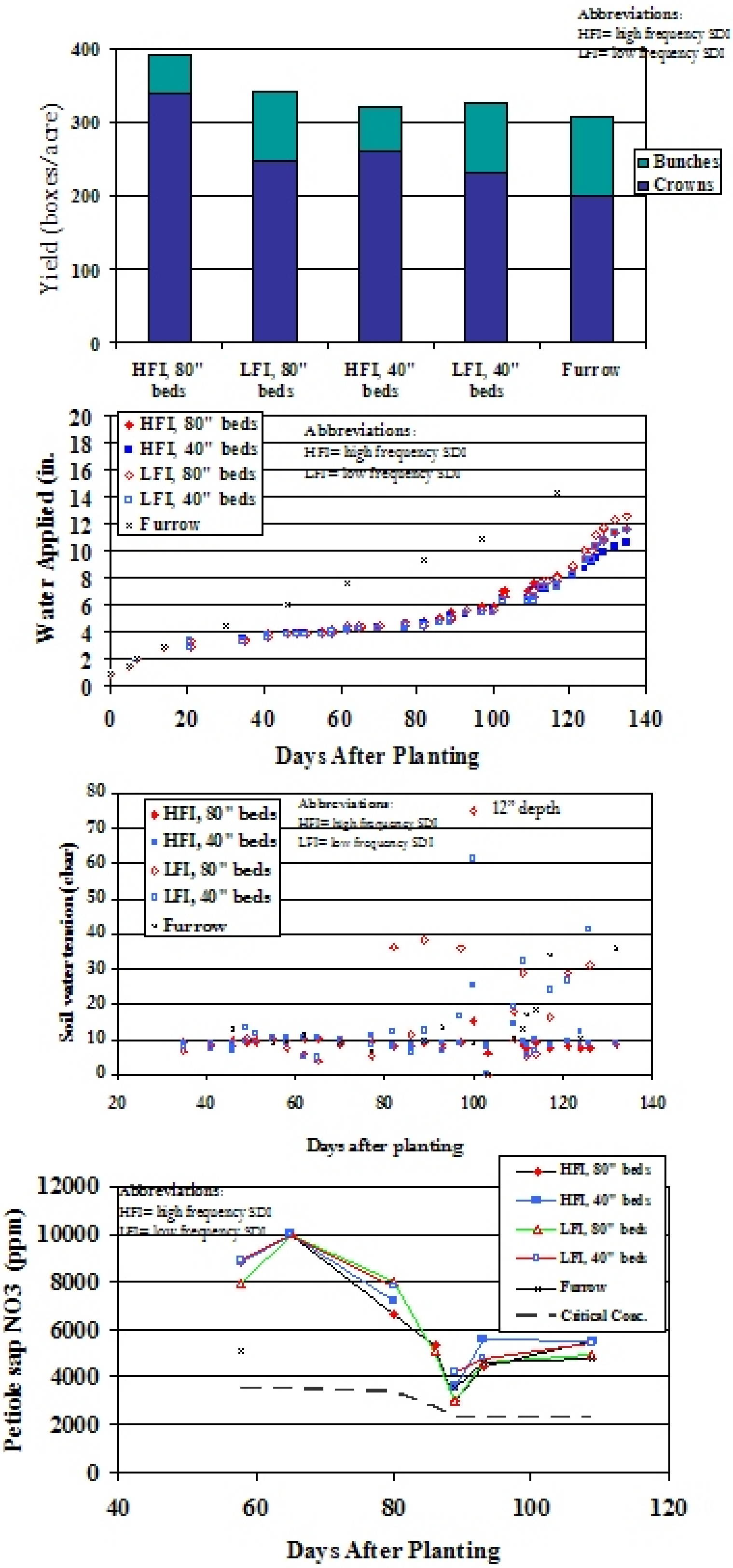

Figure 6. Yield, water use, soil water tension, and petiole sap NO_3 for the fourth AZdrip season: broccoli 2004-05.

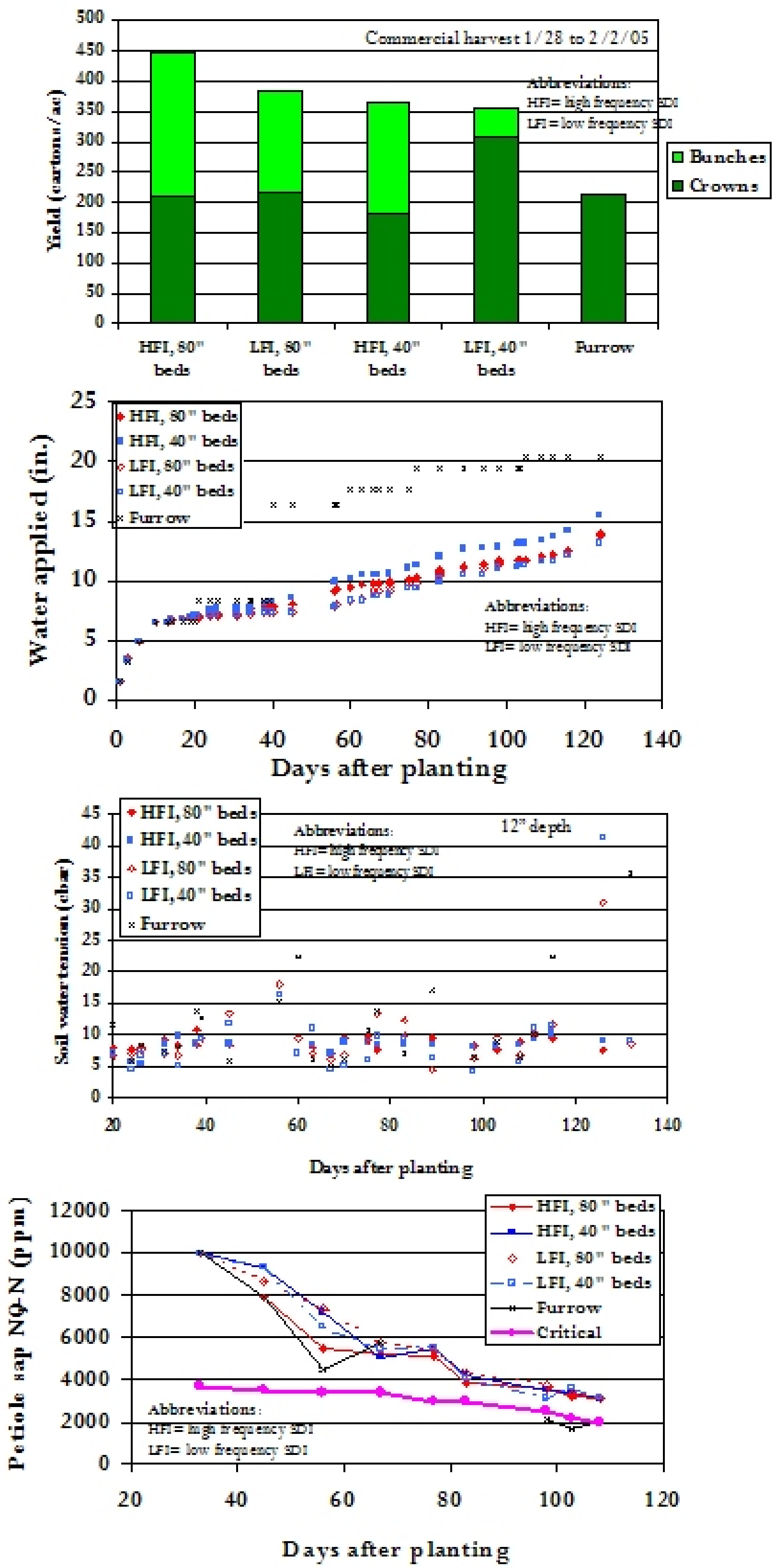

Figure 7. Yield, water use, soil water tension, and petiole sap NO_3 for the fifth AZdrip season: watermelon 2005.

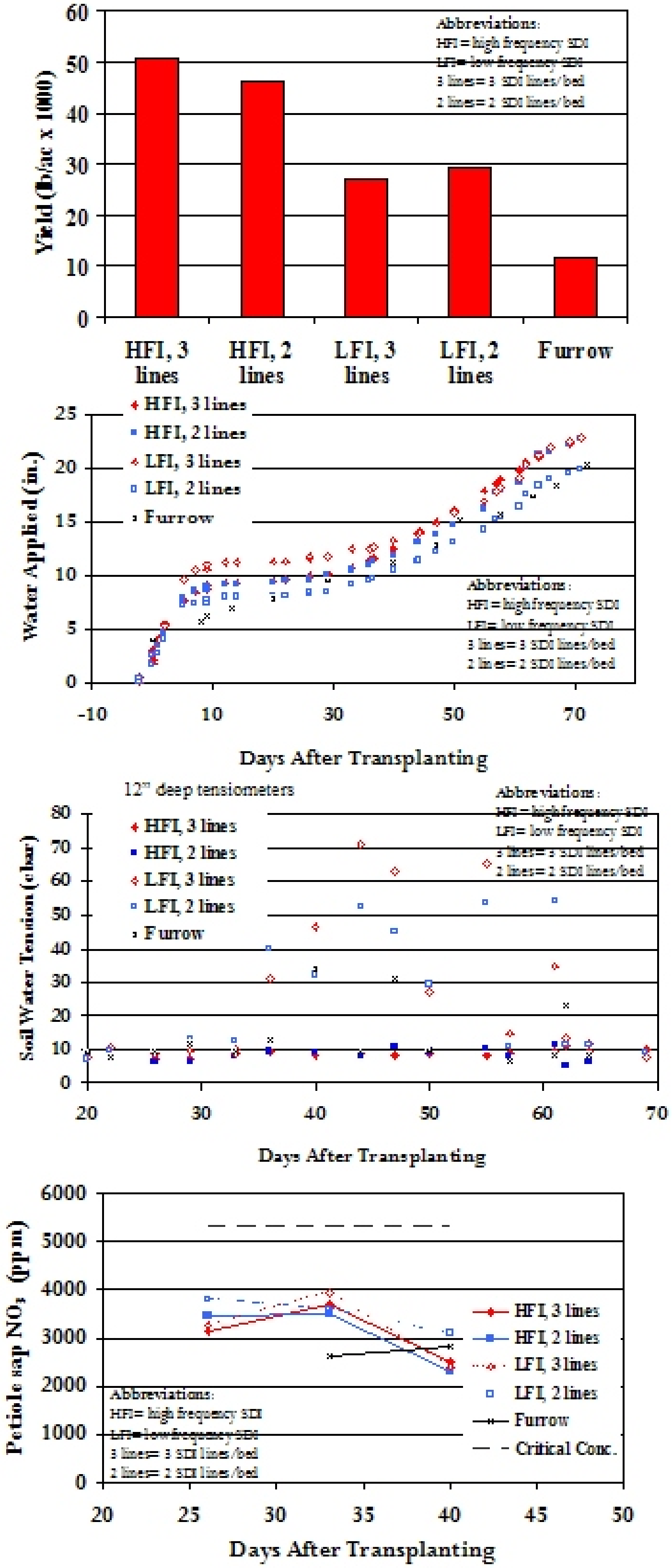

Figure 8. Cumulative water use efficiency for the first five AZdrip seasons.