Large-Scale Utilization of Saline Groundwater for Irrigation of Pistachios Interplanted with Cotton

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INTRODUCTION: A recently completed nine year field study on the salt tolerance of pistachios on the Westside of the San Joaquin Valley (Ferguson et. al., 2004 and Sanden, 2003), and previous pistachio studies in Iran (Fardooel, 2001) have shown the viability of using saline water up to 8 dS/m for irrigating these trees. A rootstock trial in sand tanks at the USDA Salinity Lab in Riverside (Ferguson et al., 2002) showed a significant increase in leaf burn when 10 ppm boron was added to irrigation water but no reduction in the biomass of year old trees. The salinity and B tolerance of cotton has been reported at similar levels in tank trials (Ayars and Westcott, 1985) and investigated in long-term field trials (Ayars et al., 1993).

In the early 1990's a number of studies investigated the use of thick-walled drip tubing for permanent subsurface drip irrigation (SDI). This system usually increased irrigation uniformity and efficiency, reduced deep percolation and helped to control perched water tables, and boosted yield to some degree. However, at a system cost of $1,000+/acre and water costs in the range of $30 to $50/ac-ft there was often an economic disadvantage using SDI compared to furrow irrigation (Fulton et al., 1991).

In 1990, State Water Project allocations to Westside irrigation districts went to zero; unleashing California's infant water market with the establishment of "Emergency Pool" water that could be bought for $100/ac-ft. Given the salt tolerance of cotton and other rotation crops on the Westside (such as processing tomatoes), some studies investigated utilizing fresh water blended with drainage from tile systems as a means of boosting available water supplies for furrow irrigation (Ayars et al., 1993, Sheenan et al., 1995). This approach generated some interest, since yields were maintained at similar levels to fresh water irrigations, but required a high degree of management with the possibility of long-term residual salinity problems that growers did not want to deal with. Even though in the middle of a six-year drought, most growers viewed the situation as a temporary aberration. In addition, cotton prices were low and interest rates high, making new capital investment into irrigation systems an unwise move.

This situation changed dramatically as California entered the 21st century. Restrictions on pumping from the Delta, rising urban demand and new legislation requiring builders to secure water before starting the construction of new subdivisions, along with opportunities for marketing and banking potable quality water have driven the "opportunity cost" of irrigation water to levels that can make the production of traditional field crops unprofitable. Water costs on the Westside over the last 15 years have increased four- to ten-fold depending on the irrigation district and total allocation for a given year. The current cost ranges from $60 to $160/ac-ft in an average water year depending on the irrigation district. Due to these costs, decreasing supply due to legislative mandates, pumping restrictions from the Delta and stagnant cotton prices until the last two years, a significant amount of cotton rotation acreage has been fallowed or converted to other crops.

The Cal Fed process, ushered into California's confusing water world at the start of the new millennium, is attempting to accommodate the state's growing water needs. Part of that process has identified "Agricultural Water Use Efficiency (AGWUE) Draft Quantifiable Objectives" for many regions of the state. Two of these objectives for Sub-region 19, western Kern County are reduction of irrigation deep percolation losses to saline sinks, and reducing "non-productive ET" as priority areas for efficiency improvements (Cal Fed, 2000). The total savings for both these numbers is estimated at < 5,500 ac-ft/year. This relatively low number is mostly due to the efficiencies of microirrigation systems applying the aqueduct water used to irrigate the permanent crops dominating Westside saline sink areas.

With the exception of some small inclusions in other districts, Westside Kern County irrigation districts are the ones overlaying saline sinks (TDS > 2000 ppm). Much of the marginal acreage has been fallowed and the accompanying water allocation shifted to the almonds and pistachios with micro irrigation systems that dominate the landscape. Several thousand acres of cotton, wheat, alfalfa, carrots and onions are still rotated in the better areas.

The Belridge Water District in western Kern County is one such district. The slightly rolling topography in this area has a bit too much relief for economic land leveling and thus requires either sprinkler or micro irrigation. Covering about 95,000 acres total, there are 41,000 acres of trees, 10,000 acres (maximum) rotated into cotton and alfalfa, and about 3,000 acres of vegetable crop rotation. Most of these crops have an ET requirement of 3 to 4 feet, where the district 100% allocation is only 1.99 ac-ft/ac. Thus, 40% of the District must remain fallow to supply additional water for the planted acreage. In water short years growers must often buy water from the Kern County Water Bank or other sources.

The groundwater in the southeast part of the District (underlaying about 15,000 acres in the project area) varied from 1,000 to 3,000 ppm TDS and 1 to 10 ppm boron, with a depth of about 50 to 80 feet below the surface. From 400,000 to 800,000 ac-ft of water at this quality may have been available in this area – enough water to irrigate more than 3,000 acres of cotton for 50 years! Unfortunately, highly saline production water separated from oil pumping in this area has been leached into the western zone of this aquifer for more than 30 years, continuing to degrade water quality. One new production well was shut down after only one season when salinity climbed to 18 dS/m.

At the same time water supplies have decreased and costs have soared, SDI systems using improved, thin-walled drip tape have become cheaper than ever before, with capital costs as low as $750/acre for grower installed systems. With a much lower energy requirement than sprinklers, greater uniformity and reduced loss to evaporation (a total savings of 6 to 8 inches) this type of system becomes the most cost effective in this setting. All these factors have combined to make the time right for developing irrigation system management approaches that can use hybrid fresh and saline water supplies to irrigate salt tolerant crops.

With a 100% water allocation the grower/cooperator farming this area will normally plant 3,000+ acres of cotton with alfalfa, almonds and pistachios on other fields. He has not had a 100% allocation for the last three years, and even when he does water costs are around $100/ac-ft. The marginally saline groundwater in this area can be pumped for < $30/ac-ft using diesel boosters. After a successful test using drip tape on a 140 acre field planted to cotton in 2003, with a better yield than the ranch average for sprinkler irrigated fields, the grower has begun a phased development of nearly 1,800 acres of this type of system. Even though total salinity levels are well within the tolerance ranges of cotton and pistachio, minimizing potential boron accumulation and boron/salinity interactions are the big unknowns (Grattan, et al., 2003). This is the long-term "make or break" issue for the project.

The physical setting, the current economic constraints and water supply picture in this project area present a unique opportunity to accomplish the overarching objective of decades of salinity research in California: namely, proving the sustainability of profitable long-term irrigation using significant quantities of marginally saline water in a large-scale production setting. That is the primary objective of this project.

METHODOLOGY: Encouraged by the results of the above trials, a large-scale grower in the Belridge Water District of NW Kern County started pumping brackish groundwater for an experimental drip tape field in cotton in 2003; with the intent of interplanting pistachios in the following years. Pumping costs for this water are about $50/ac-ft compared to $100+/ac-ft for California Aqueduct water. The regional salinity of this groundwater varies from 3 to 8 dS/m with 8 to 12 ppm boron.

Starting in 2004, twelve 19.5 acre test plots were set up in a randomized complete block design in two adjacent 155 acre fields to test the use of saline water for commercial-scale cotton production and development of a new pistachio orchard using shallow sub-surface drip tape (SDI). With each plot being nearly 20 acres in size, the 240 acres dedicated to this trial is possibly the largest replicated salinity irrigation test ever attempted in the SJV. Irrigation treatments consist of fresh (Aque), blended (Blend) and full strength saline well (Well) water (average EC of 0.5, 2.5 and 5 dS/m and boron @ 0.3, 6 and 11 ppm, respectively). The highest salinity treatment is more than 4 times as saline as almost all irrigation waters currently used in the SJV. The SDI system allows the grower to meet the much higher cotton water demand while avoiding saturation of the young trees – thus maintaining critical cash flow during the early years of orchard development.

The field was planted to solid pima cotton in 2004. Pioneer Gold (PG1) rootstocks were planted in March 2005 to an 18 x 22 foot spacing inter-planted with four 38 inch rows of pima cotton. A set of 10 trees in the middle of each 19.5 acre plot, along with the adjacent cotton is used for intensive monitoring and sampling. A total of 23 UCB rootstocks were also planted adjacent to these monitoring areas. Pistachios were budded with a Kerman scion in July. All plots are irrigated with a total of 8 to 12 inches of fresh (Aqueduct) water (wetted area basis) during the winter and/or cotton germination, followed by 18 to 26 inches of treatment water, depending on seasonal demand. Pistachios receive about 18 inches based on a 9.5 foot wide area between the cotton (7.8 inches for the 22 foot row spacing). Four rows of Pima were again interplanted in 2006. A final fourth season of interplanted cotton for 2007 was canceled due to a 40% reduction of district water and the grower canceling his entire Westside cotton program. Pistachios only are to be grown for 2008.

RESULTS: Cotton yields were virtually the same for all treatments (3.4 bale/total acres, 3.9 bale/ac based on a 38" row, with the Well Treatment producing just over 4 bale/planted ac, Table 1). Pistachios (PG1 rootstock with a small-scale subplot of UCB in each plot) were planted March 2005 on 22 foot centers with a reduced, 4-38 inch row cotton planting in between tree rows. Tree growth was good and unaffected by salinity. Cotton yields for 2005 were poor (2.1 bale/ac) due to a cold spring and excessive heat in July/August, but increase in pistachio trunk circumference was excellent. Cotton yields and tree growth were unaffected by salinity. Plant tissue analysis showed a significant 0.5 to 3 fold increase in chloride and boron levels in both cotton and pistachio (Table 1), but

Site: 2, 155 acre blocks will be used to set up a cotton/pistachio interplant for a large-scale production trial testing the viability of using saline shallow groundwater for irrigation.

Treatments (RCB Design):

Control: Aqueduct water only
EC ~ 0.5 dS/m

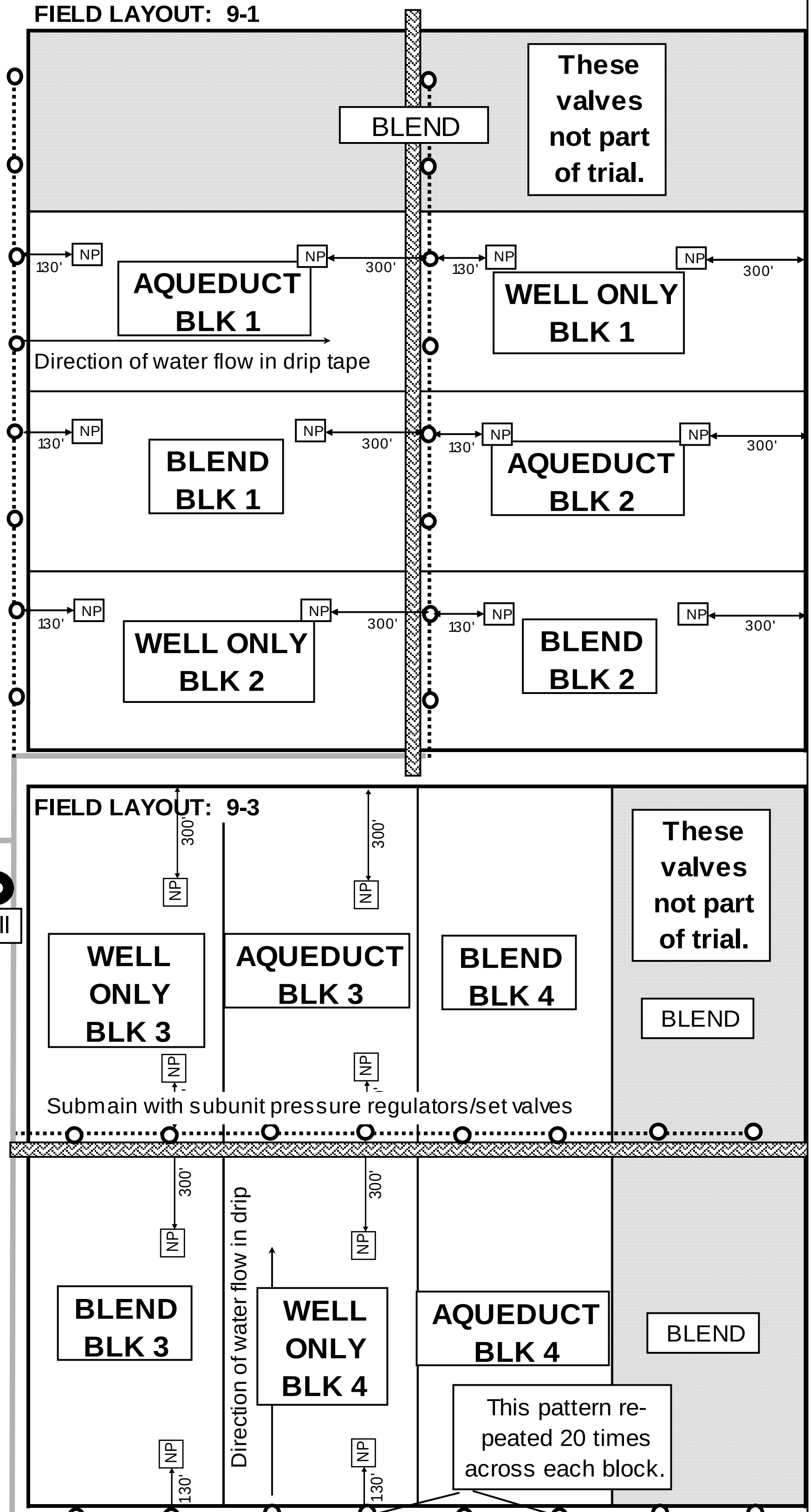
Blend: 50/50 mix of above
EC ~ 2.5 dS/m

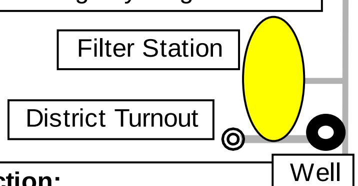
Well: Shallow groundwater only
EC ~ 5.0 dS/m

2004 Season: Cotton only. Solid plant
2005-2008: Pistachios planted in April on 22 ft row spacing with 4-38" rows of cotton in the middle through 2007.

Irrigation System:
System flowrate requires 4 subunits open per set, 2 per submain running opposite of each other. A small road divides the 160 acres into 2, 77.5 acre blocks but these are treated as one field. Drip tape adjacent to pistachios has separate manifold to allow for separate scheduling of young trees

STARRH & STARRH -- FIELDS 9-1&3
Project Monitoring Duration: 2004-2008





Data Collection:

Soil water content: replicated neutron probe sites for weekly measured depletion/ET, data logger/Watermark blocks recording estimated matric potential using electrical resistance.

Soil salinity patterns: sampling, at planting and post harvest. GIS survey with EM38 and aerial imagery.

Plant data: leaf water potential monthly just prior to the start of irrigation. Trunk diameter annually. Leaf tissue Ca, Mg, Na, Cl, B and petiole NO3, P and K. Lint yield and quality.

Drip tape spacing showing "blank" areas for separation of cotton & 2005 pistachios, which will be planted to a 22 foot spacing.

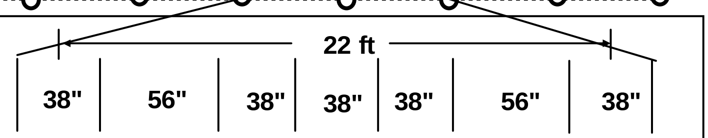


Table 1. Summary of plant tissue data, cotton height/lint yield, PG1 rootstock circumference and total applied salts.								Root-zone EC_e to 5 ft	[1]Cotton Ht, Pistachio Circum	Cotton Lint Yield	[2]Total Salts Applied in Irrigation
	NO3-N (ppm)	NH4-N (ppm)	PO4-P (ppm)	K (%)	Na (ppm)	Cl (%)	B (ppm)	(dS/m)	(inch)	(lb/ac)	(lb/ac)
2004	**Petioles 8/27/04**				**Cotton 2004**			**10/6/04**	**9/14/04**	**10/6/04**	**Cotton'04**
Aque	170	75	368	1.84	570	**2.58**	**34**	**2.71**	42.2	**1933**	2,343
50/50	273	95	463	1.73	712	****3.23**	**37**	***4.08**	*35.8	**1928**	11,390
Well	548	108	413	1.72	574	***3.00**	**37**	***4.68**	38.8	**2016**	21,444
2005	**Petioles 9/15/05**				**Cotton 2005**			**10/18/05**	**9/15/05**	**10/19/05**	**Cotton'05**
Aque	403	53	760	2.06	605	**2.71**	**42**	**1.42**	41.6	**954**	2,305
50/50	158	40	573	1.79	539	***3.13**	**46**	**3.71**	43.1	**1129**	10,144
Well	288	85	593	1.91	546	****3.38**	****50**	***4.74**	42.1	**999**	16,975
	Rootstock Leaves 9/15/05				**Pistachio 2005**			**10/18/05**	**10/19/05**		**Pistach'05**
Aque	63	160	580	1.02	222	**0.27**	**194**	**2.87**	2.31		1,742
50/50	55	128	545	1.06	220	**0.27**	****492**	**4.12**	2.17		8,570
Well	65	148	500	1.08	314	****0.38**	****673**	***4.44**	2.18		14,782
2006	**Petioles 9/21/06**				**Cotton 2006**			**10/30/06**	**9/21/06**	**10/27/06**	**Cotton'06**
Aque	125	55	635	2.15	885	1.95	48	**1.01**	44.9	**1835**	1,967
50/50	168	65	495	1.90	937	1.91	55	***3.61**	45.0	**1615**	11,046
Well	83	63	413	1.97	1143	2.21	*56	****4.63**	40.9	***1560**	15,832
	Kerman Leaves 10/31/06				**Pistachio 2006**				**10/19/06**		**Pistach'06**
		N (%)	**P (%)**	**K (%)**	**Na (ppm)**	**Cl (%)**	**B (ppm)**	**10/30/06**			
Aque		1.19	0.08	2.67	171	0.52	531	**2.65**	2.58		1,022
50/50		1.36	0.08	2.83	140	*0.58	**954	**4.34**	2.55		8,994
Well		*1.55	0.09	2.99	201	*0.62	**1096	***4.61**	2.49		11,104
	Kerman Leaves 6/19/07				**Pistachio 2007**				**10/18/07**		**Pistach'07**
Aque		2.56	0.14	1.69	99	0.24	167		4.65		1,390
50/50		*2.67	0.14	1.76	108	0.28	**315		4.59		7,571
Well		*2.80	0.15	1.75	*133	0.30	**384		4.45		13,197

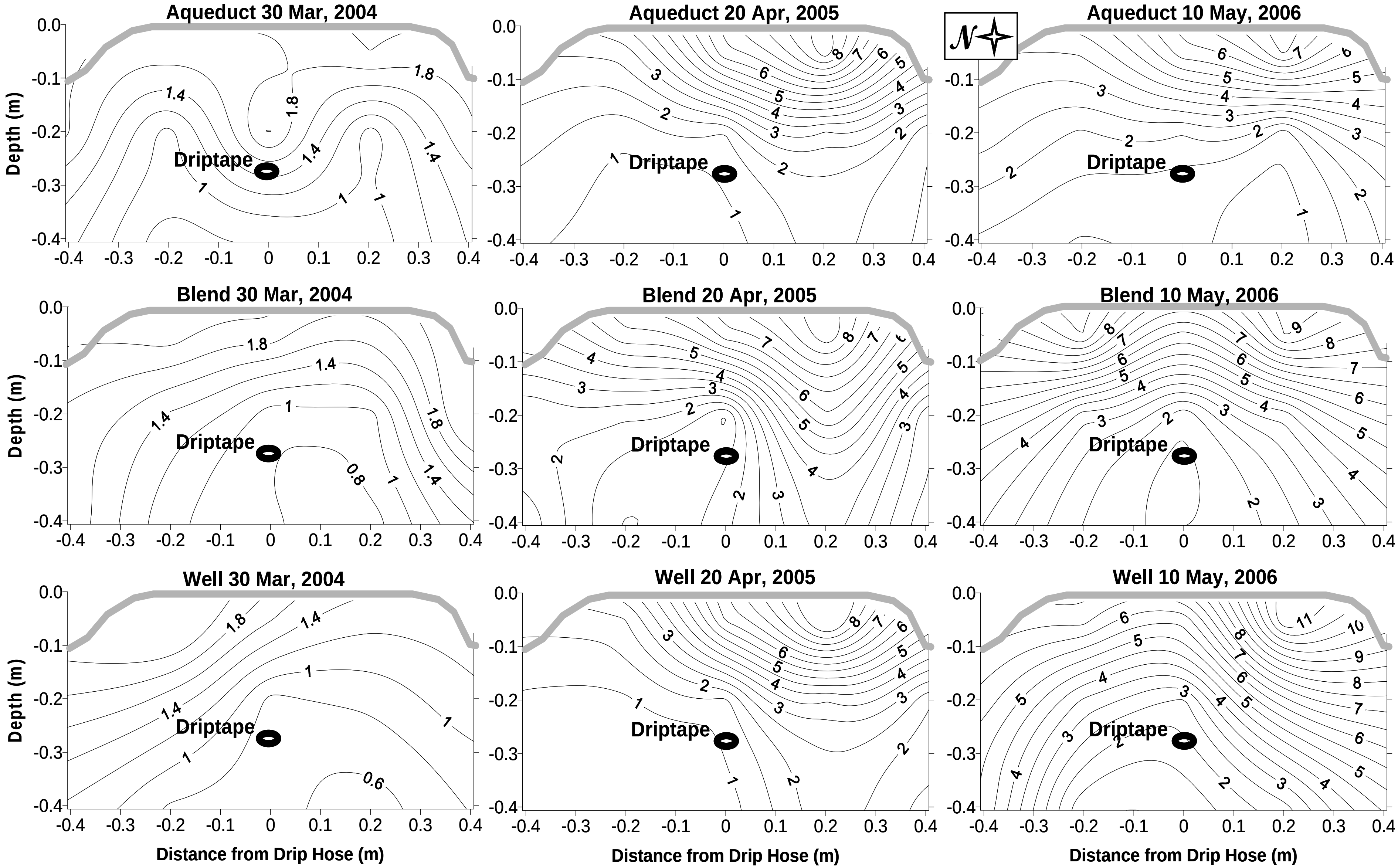
*Significantly different from Aqueduct @ 0.05, **Significant @ 0.01
[1]Cotton height @ irrigation cuttoff.
[2]Cotton cover = 12.7 feet/tree row Pistachio drip subbing = 9.5 feet/tree row

produced no toxicity symptoms in 2005. Comparison of digital aerial analysis of the Normalized Difference Vegetation Index (NDVI) for August 2004 and 2006 showed no treatment impacts on crop vigor across the field. However, final 2006 cotton yields showed a half bale loss for the Well compared to the Aqueduct treatment (3.12 and 3.68 bale/ac, respectively). Pistachio development was unaffected by salinity, but due to small caliper rootstocks at planting and extremely high July temperatures, a significant number of trees needed to be rebudded in Fall 2005 and only 40% of the PG1 and 4% of the UCB trees had a full set of Kerman scaffolds by the end of 2006. However, UCB rootstocks were significantly larger than the PG1 rootstocks. Shoot length was the same for both varieties at about 31 inches.

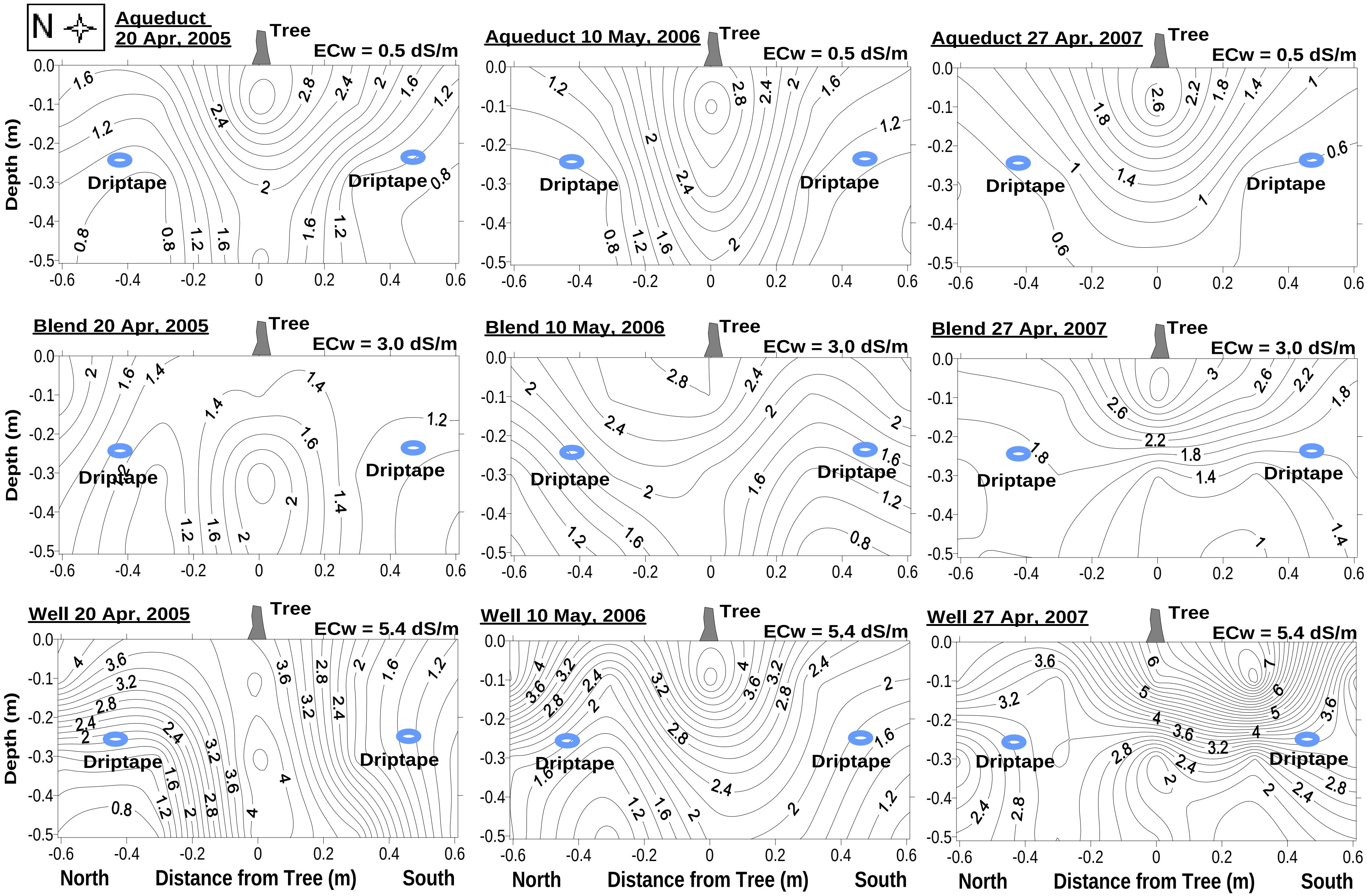
After three seasons of cotton irrigation this program resulted in about 6,600 lb/ac applied salt in the Aqueduct treatment and about 54,000 lb/ac in the Well treatment. Cotton and pistachio tissues continue to show significantly greater accumulation of chloride and boron for the Well treatment; showing some marginal burn at the end of the 2006 season, but some leaf burn was also observed in the Aqueduct treatment. Contours of cotton seed bed and pistachio berm salinity and boron (figures following) show that much of this salt load gets concentrated toward the surface due to evaporation and upward subbing from the drip. Much salt and boron also appear to drop out of solution, especially boron as it becomes adsorbed to native clays.

An economic analysis shows an estimated return to the project of $1,779/ac net return above cash costs from the 3 years of cotton production. Projected forward over 20 years @ 5% interest this is a return on investment of $4,719/ac.

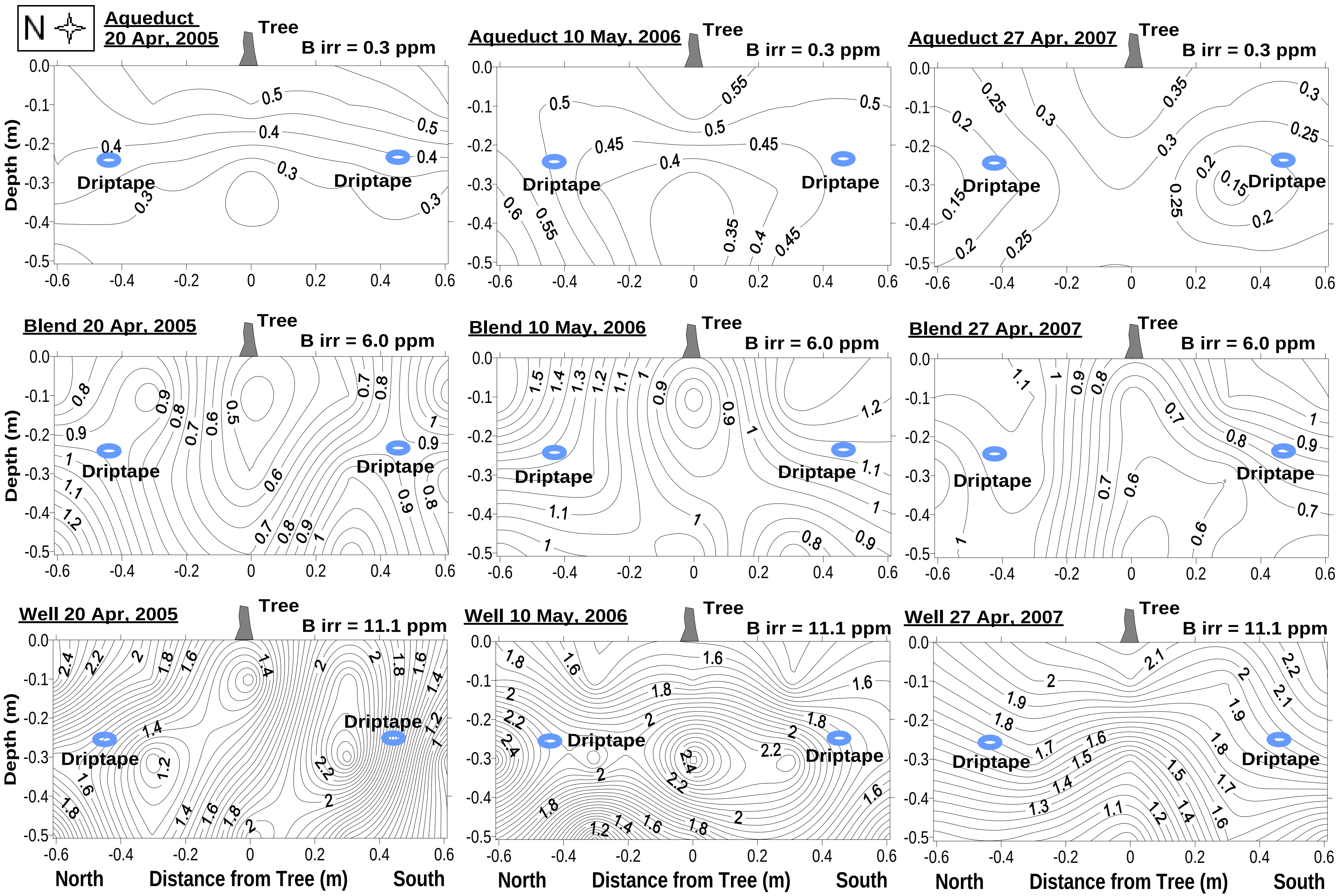
The grower elected not to plant cotton in 2007 due to severe restrictions in water allocation on the Westside. Only pistachios were grown in the test area. Salinity of the pumped groundwater has slowly increased over the years of the trial, reaching 7.3 dS/m by July. This is a 37% higher salt load than the average 5.5 dS/m for the 2005 and 2006 seasons and 67% more salt than the 4.5 dS/m average for 2004. In light of this large increase, salinity treatments were reduced after 7/11/07 so that the WELL treatment is now about 4 dS/m (50/50 blend of well and



Contours of saturation extract **soil salinity (ECe, dS/m)** in **cotton** beds (0.96m, 38 inches) at emergence after spring recharge and post-plant irrigation of 200 mm (8 inches) low salinity canal water (Aqueduct, 0.5 dS/m). Kerman rootstock planted 5-11 March, 2005 following cotton irrigated with the same treatment waters.



Contours of **soil salinity (ECe, dS/m)** in **pistachio** beds after spring recharge of 200 mm (8 inches in the wetted area 2 m wide) low salinity canal water (Aqueduct, 0.5 dS/m). Kerman rootstock planted 5-11 March, 2005 following 2004 cotton irrigated with the indicated treatment waters. Tree spacing 6.7 x 5.2m (22 x 17ft).



Contours of **soil saturation extract boron (ppm)** in **pistachio** beds after spring recharge of 200 mm (8 inches in the wetted area 2 m wide) low salinity canal water (Aqueduct, 0.5 dS/m). Kerman rootstock planted 5-11 March, 2005 following 2004 cotton irrigated with the indicated treatment waters. Tree spacing 6.7 x 5.2m (22 x 17ft).

Aqueduct water) and the BLEND treatment runs about 2.3 dS/m (25/75 Well to Aqueduct water). This actually returns irrigation treatment salinity levels close to where they were intended at the start of the trial.

After three seasons in the pistachios we have applied 4,154 (Aqueduct), 25,135 (Blend) and 39,083 (Well) lb/ac of salt along a 9.5 foot band (the extent of subbing from the buried drip tape) down the tree row in about 25 inches of applied water. Tree development has been unaffected by salinity with tree circumference almost doubling from the 2006 levels to average 4.56 inches. At the end of this third season there are no apparent differences in tree size between the UCB and PG1 rootstocks (Figure 1). Average soil salinity to 5 feet at the end of 2006 was 4.8 dS/m for the Well treatment (2007 data pending).

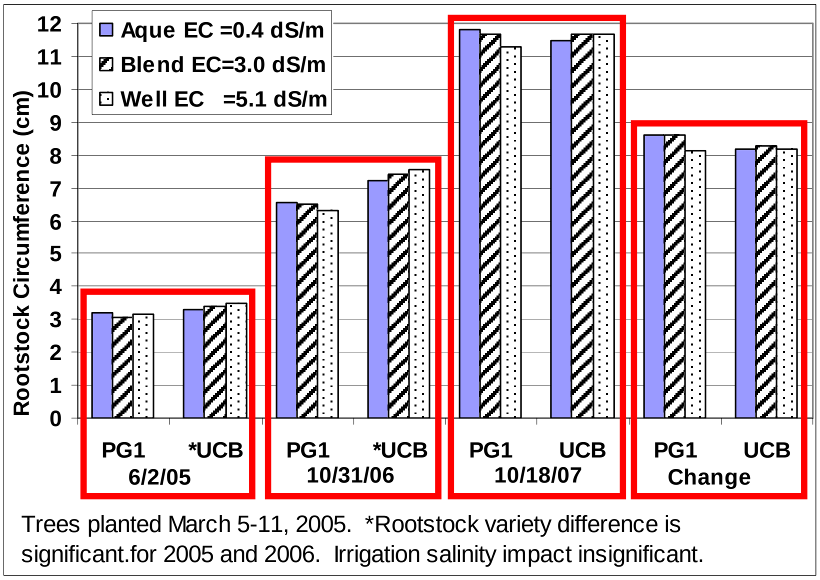


Fig. 1. Rootstock circumference since 2005 by variety and irrigation water salinity.

The current trial is scheduled to run through 2008 to assess the impact of salinity on the trees during the first four critical years of orchard development. With the continued help of the Western Pistachio Association, the pistachios will be monitored till we reach mature bearing.

CONCLUSIONS AND PRACTICAL APPLICATIONS

To this one grower, the eventual savings in annual water costs can exceed $200/acre for mature tree ET. This equals $62,000/year for the 310 acre orchard. This doesn't even take into account the fact that planting this acreage would be impossible without using the "substandard" water. An economic analysis shows an estimated $1,779/ac net return above cash costs from the 3 years of cotton production.

At this writing there are about 15,000 additional acres of pistachios planted along the Westside since 2006 on ground that would not have been developed five years ago. Between marginal groundwater and blended drainwater there is more than 150,000 ac-ft/year of additional "alternative" water supply on the Westside that appears suitable for pistachios. Pistachio growers in Westlands Water District will be relying heavily on this water for 2008. The aggregate value of this water and the potential development of 30 to 40,000 acres of pistachios replacing cotton and wheat rotations could easily exceed a benefit of $30 million/year over the value of the field crops.

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