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Publication Date
2009-02-01

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2007-08 Technical Completion Report for the UC Salinity/Drainage Taskforce
Water Resources Center, UC Riverside
PRO10 February 2009

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Abstract and Summary

Twelve, 19.5 acre test plots arranged in a randomized complete block design are set within two 155 acre fields to provide a realistic production environment. These blocks of well-drained Panoche clay loam were formerly irrigated with California Aqueduct water and sprinklers for the last 30 years. Overall the field electrical conductivity (EC) ranged from 0.5 to 4.5, averaging 1.57 dS/m to a 3-foot depth. Saturation extract boron was 0.6 ppm. The area is underlain by a semi-saline aquifer that has been made worse over the decades by contamination from oilfield leachate water. Several production wells were drilled in fall 2003 to begin using this water. A drip tape irrigation system was set up to allow the planting of 6 rows of cotton every 22 feet the first year of the project (2004) followed with the planting of 1 year old pistachio seedling rootstocks March 2005 in 22 foot rows interplanted with 4, 38 inch rows of pima cotton. Salinity of the shallow groundwater for the test fields has varied from 4 to 7.5 dS/m with 8 to 11 ppm B. Three treatments were imposed: AQUEDUCT/CONTROL: EC ~ 0.4 dS/m (Aqueduct water only), BLEND: EC ~ 2.5 dS/m (50/50 mix) and WELL: EC ~ 5 dS/m.

Chloride and boron contents in late season cotton petioles and pistachio leaf tissues were significantly higher in the WELL treatment compared to the Control. Saturation extract EC and B in the top three feet of rootzone were significantly increased in the BLEND and WELL treatments over the Control at the end of the season, with most salts increasing significantly to 3 feet with a significant increase in Cl to 5 feet.

Cotton yield and tree development: Pima cotton lint yields were nearly 4 bale/acre in 2004, but crashed to about 2 bale/acre in 2005 due to very cool spring conditions that made for poor stand establishment. Cotton yields and plant height were unaffected by salinity. Spring 2006 provided excellent conditions for cotton growth, but excessive salts accumulated in the top 4 inches of the Well treatment beds reduced cotton emergence by 14% (statistically insignificant) and lint yield from the saline Well treatment was reduced by 275 lb/ac compared to the Aqueduct water. However, the Well treatment yield was still excellent at 3.12 bale/ac.

Increase in pistachio rootstock diameter and general tree development was unaffected by salinity for both rootstocks for the first three years, but PG1 rootstocks showed a significant 7% decrease at the end of 4th leaf (Figure 1). However, Photoshop® pixel counts of green foliage down the row show an equal amount of green foliage for all treatments as of 10/18/08.

Salinity and sustainability: At the end of 2006, after three seasons of cotton irrigation this program applied about 6,600, 32,500 and 54,000 lb/ac of salt in the Aqueduct, Blend and Well treatments, respectively. Rootzone salinity to 5 feet in the wettest part of the profile (between the two hoses) measured by Spring and Fall soil samples has remained surprisingly stable at about an ECe of 2.5 dS/m for the Aqueduct and about 5 to 6 dS/m for the Well treatment. However, in-season ECe in the top two feet is much higher as water and salts sub up from the buried drip tape. Without 6 to 10 inches of effective rainfall or fresh water winter irrigation for efficient leaching this system may not be sustainable. Due to the decrease in cotton yield in 2006, combined with a 50% increase in the Well water EC over the last four years we reduced the salinity of the Well treatment (by blending with Aqueduct water) down to 4.5 dS/m. This is about the salinity of the Well at the start of the test in 2004. After one year of cotton and four years of drip tape irrigation in the pistachios a total of 73,823 lb salt/wetted acre (about a 9.5 foot wide zone of subbing) was applied in the active rootzone of the Well treatment compared to 8,050 lb salt/wetted acre for Aqueduct water.

At an average pima price of $1.08/lb, an economic analysis of cotton production and yields for the year prior to and first two years after planting pistachios shows a net return of $2,120 for Aqueduct water @ $120/ac-ft and $2,249 for Well water @ $45/ac-ft for this system.

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 with an electroconductivity (EC) up to 8 dS/m for irrigating these trees without a reduction in yield. 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. In contrast to these studies, Sepaskhah and Maftoun (1981) found that pistachio nut production under greenhouse conditions was reduced by 38% with a 7-day irrigation interval and 4.5 dS/m water, but when water was not limiting, shoot growth (which should be more sensitive than nut yield) was not reduced until soil salinity reached an EC of 12.5 dS/m.

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). But despite many small-scale field trials over the last 30 years almost no marginally saline water in the San Joaquin Valley is used for long-term production. Over this same period water costs have increased four to tenfold while acala cotton prices have actually declined to those seen in the early 1960's. Farmers are looking for less expensive, more secure water supplies and more profitable crops. This project attempts to determine the economic and physiologic viability of establishing a large-scale pistachio orchard interplanted with cotton and irrigated with buried drip tape using marginally saline groundwater.

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.

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 fully supply water for the planted acreage or additional water supplies must be found. In water short years growers must often buy water from the Kern County Water Bank or other sources.

OBJECTIVES

1. Assess the viability of large-scale cotton production over four years using saline shallow groundwater (EC 4 to 5 dS/m and B @ 8 to 10 ppm) and optimal irrigation scheduling with SDI.
2. Using the same water, establish a new pistachio orchard interplanted with cotton starting the second year. Determine crop ET for this system and impact of salinity.
3. Maintain acceptable soil salinity levels for cotton stand establishment/production and maximum growth of young pistachios.
4. Compare total project profitability under SDI using 3 different levels of salinity: saline water, non-saline CA Aqueduct water and a 50/50 blend. Compare the economics of drip tape SDI with typical Belridge Water District cotton production using sprinklers.

Procedures

Counting on the salt tolerance of cotton and pistachios, 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 $45/ac-ft compared to $120+/ac-ft for California Aqueduct water. The regional salinity of this groundwater varies from 3 to 15 dS/m with 8 to 18 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). (See Figure 1) 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.

Treatments: 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. Due to contamination of the aquifer by oil field leachate water, the average salinity of the Well water eventually increased to 7.5 dS/m by July 2007. At this time we began blending some Aqueduct water into the Well treatment and increased the amount of Aqueduct water in the Blend treatment to return to the salinity levels at the start of the trial; being 4.5 dS/m for the Well treatment and 2.5 dS/m for the Blend. EC over the last four years we reduced the salinity of the Well treatment (by blending with Aqueduct water) down to 4.5 dS/m starting July 2007. 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 from August 12-19. 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 were grown for 2008.

Irrigation system: T-Tape TSX 708-12-220, 0.875 inch diameter drip tape with emitters every 12 inches was injected at 9 to 10 inches below field grade in January 2004. Designed for a final tree spacing of 22 feet, the tape was installed under 4 contiguous 38 inch rows followed by a 56 inch skip, 2 more 38 inch rows and a second 56 inch skip (see Figure 1). A separate underground manifold connected to the two hoses with the 56 inch spacing to either side was installed for irrigating pistachios and to allow for separate scheduling from the cotton. At this spacing the cotton receives 1.99 inches/day and the pistachios receive 0.57 inches/day from the two adjacent hoses.

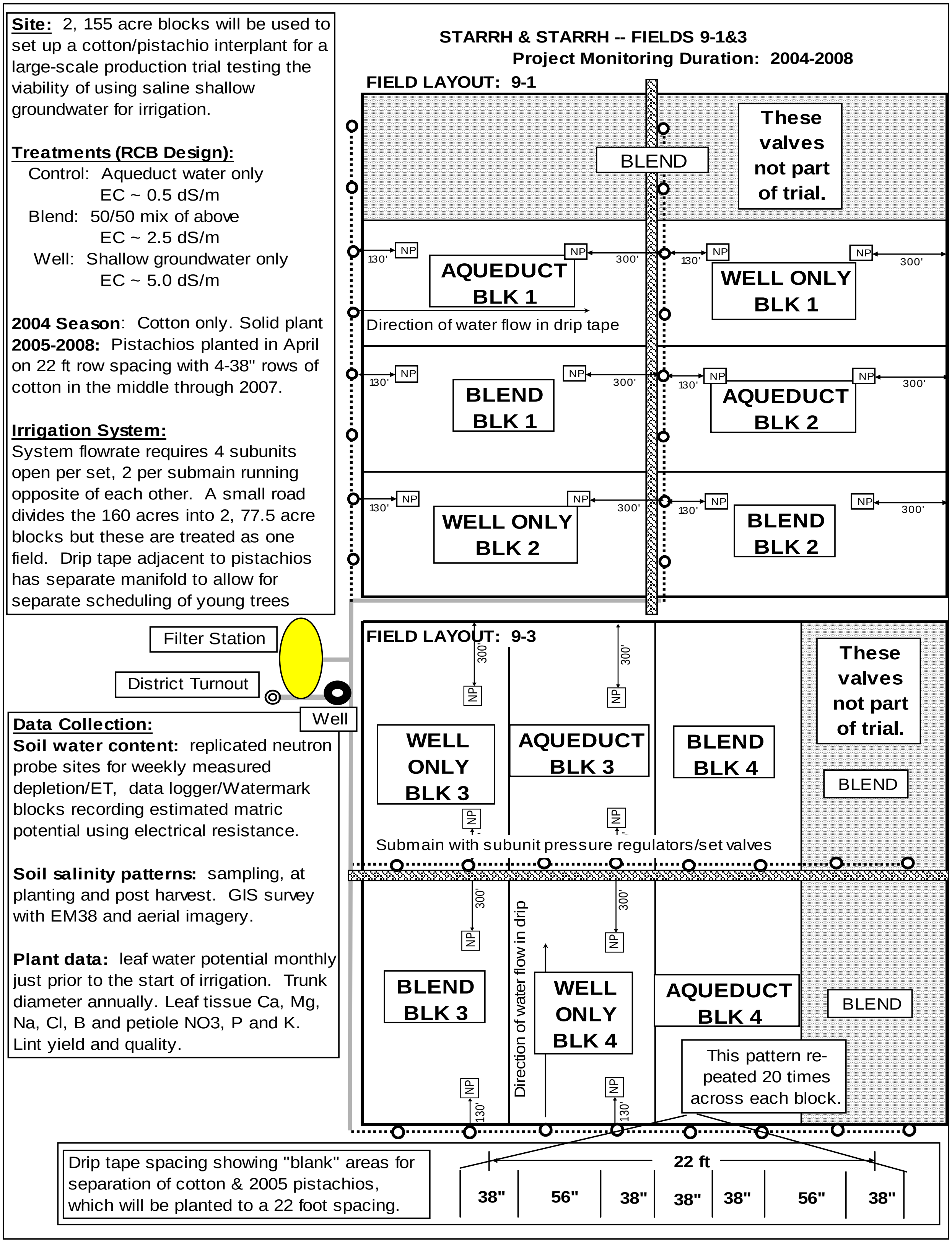

Fig.1. Experimental design and data collection.

Hose runs are 1280 feet long with the manifold connected at the high side of the field with the outlets connected to a common flush line. Each block has 16 separate pressure regulating subunit valves. Sixty hoses are served by a single cotton manifold tied to each subunit valve that also delivers water to 30 hoses connected to the manifold serving the interplanted pistachios. The grower's booster and filter station are designed to irrigate 8 subunits at a time (78 net acres); making for 4, 24 hour set changes during irrigation. Flow from the well, however, is not sufficient to meet this demand when no additional canal water is blended for irrigation. Therefore, the "WELL" only treatment is irrigated in two sets to maintain pressure uniformity. The system is operated @ 15 psi at the subunit regulators, yielding 0.27 gpm/100 feet of drip tape. All irrigations are scheduled for a 24 hour duration due to restrictions on canal water delivery. Randomized, replicated treatments are applied to 19.5-acre plots (2 adjacent subunit valves each, 440 feet wide by 1280 feet long). Valves have been color coded to indicate the appropriate treatment water and are operated by farm staff.

Monitoring and analyses: *Soil water content and applied water:* For the 2004 cotton season, neutron probe access tubes for weekly measured soil water content were installed in Blocks 1, 2 and 3 to a depth of 6 feet @150 feet from the head and 300 feet from the tail ends of the drip tape. In Block 1, 6 electrical resistance blocks (Watermarks®) are used to estimate matric potential at the 12, 24 and 48 inch depths adjacent to neutron probe access. A Hanson AM400 data logger records these readings every 8 hours. These loggers allow the grower a quick graphic check on moisture status trends over five weeks and help with optimal irrigation scheduling. Small flow meters were installed at the entrance to each replicated run of drip tape adjacent to neutron probe access tubes. For the 2005 season, a similar network of access tubes and resistance blocks was set up for the newly planted pistachios and reinstalled in the cotton after planting. "Tail" end monitoring of soil water was deemed unnecessary for the 2005 season due to the high uniformity of the system and lack of real differences between the head and tail ends. Eliminating these sites allowed for the installation of access tubes in the head end of Block 4 to increase replication.

Soil and water salinity: Replicated soil samples are taken at germination and post harvest each year from the area adjacent to access tube locations from the 0-6, 6-18, 18-36 and 48-60 inch depths and analyzed by the ANR Lab at UC Davis for EC, Ca, Mg, Na, Cl, HCO3, and B. Treatment water samples are collected in June and the end of August (near irrigation cutoff) and analyzed for the same constituents. In addition, weekly to biweekly (June – Aug) the EC of treatment water samples are checked with a portable EC meter in our Kern County office. For each treatment, a transect of closely spaced samples taken at the time of cotton emergence (about one week after the end of irrigation) and perpendicular to the drip tape will be used to characterize EC and B patterns at the time of stand establishment for each treatment. A similar transect will be done for pistachios but with wider spacing. To improve the characterization of an "average" transect, individual samples representing a given distance from the drip hose(s) will be obtained by compositing separate samples of the same distance from 5 separate transects along 50 to 100 feet of the same drip hose near, but not adjacent to, a "head" access tube.

Plant data: Leaf water potential (LWP) was measured biweekly once cotton plants were about 12 inches high. Petiole NO3, P, K, Na, Cl and B was determined for the end of June and again just before defoliation in September. Foliage was rated visually for leaf burn. Plant mapping was done in July and just before defoliation. Cotton lint was determined using a 2-row and 4- row commercial picker harvesting over the 1280 foot length of the row and weighed in a separate “boll buggy”. Lint quality was be determined by subsampling each plot and using HVI automated classing. Starting in 2006, LWP and N, P, K, Na, Cl and B will be determined for the Kerman scion that was budded into all trees 8/12-19/05. Trunk circumference in pistachios will be measured annually in late fall, starting 2005. Three extra trees per plot were planted in 2005 and will be sacrificed at the end of the experiment to determine shoot, scaffold and trunk weights and B accumulation in the woody tissue. Replicated Photoshop pixel counts of total “down the row” green foliage were made starting 2007 and 2008.

GIS / ECa / Aerial survey: Both fields were surveyed for ECa (apparent soil salinity) using a tractor mounted dual dipole EM38 from the USDA Salinity Lab in Riverside, CA with GPS (Section 9-1, on May 14,26-27 and field 9-3, May 5-6). GPS way points for anchoring aerial imagery and field mapping were done with HGIS and a hand-held NavMan GPS unit mounted to an IPAQ pocket PC. This data was compared to field aerial imaging analysis (Ag Recon of Davis, CA) shot on 7/29/04. Reflectance is digitally recorded for three different band widths: visible red light (VIS 0.4 to 0.7 µm), near infrared (NIR, 0.7 to 1.1 µm) and far (thermal IR, 6 to 15 µm) infrared. The relative intensity of thermal IR and the Normalized Difference Vegetation Index (NDVI = (NIR — VIS)/(NIR + VIS)) was calculated for each plot where 1 pixel equals a 2 meter diameter. As plots are 440 feet wide by 1280 feet long (6.71 x 390.1m) this equals 1308 pixels per plot – providing a much greater number of pixels for analysis than is often available for replicated studies. Aerial NDVI was again measured 8/14/06. The final ECa survey is scheduled for 2009.

Data analysis: All data was tested for significance using a 2-way ANOVA for a completely randomized block design. Some tables are presented with a Fisher’s least significant difference (LSD0.05) means separation. Adobe Photoshop was used to analyze average plot gray-scale pixel intensity of a modified NDVI calculation of spectral data for significant differences between treatments and field variability. In a similar manner, average plot values of the vertical electromagnetic conductance (EMv in milliSeimens/meter) were calculated from filled contours generated from the EM38 survey and regressed against mean values of plot NDVI.

Results and Discussion

As the well water quality in this trial has degraded over time we have attempted to maintain the original salinity treatment targets by adjusting the Blend and Well treatments to the appropriate EC using a small field EC tester. The average water quality over the last five years is given in Table 1.

Table 1. Average treatment water quality from 2004-2008

WATER SOURCE	pH	EC	SAR	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	Cl (meq/l)	B (ppm)	HCO3 (meq/l)	CO3 (meq/l)	SO4 (meq/l)	NO3-N (ppm)
Aqueduct	8.0	**0.55**	2.5	1.2	1.0	**2.6**	**2.2**	**0.3**	1.3	<0.1	0.7	0.3
Blend	7.6	**3.41**	4.1	14.1	7.8	**13.6**	**21.2**	**6.3**	1.4	<0.1	9.9	2.9
Well	7.6	**5.15**	5.2	22.7	12.7	**21.8**	**33.5**	**10.4**	1.5	<0.1	19.6	6.8

Despite the high salinity of this water, it is atypical of most Westside saline waters in that the calcium and sodium are about equal in ionic strength. This ratio is usually more in the range of three to five times the sodium to calcium. Therefore, this water may provide some buffering effect against sodium ion toxicity that may not be found in sodium dominated waters of the same salinity.

Cotton yields for 2004 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 2). 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 2), but produced no toxicity symptoms in 2005. Comparison of digital aerial analysis of the Normalized Difference Vegetation Index (NDVI, Figure 2) for August 2004 and 2006 showed a very slight decrease in NDVI with increasing salinity that was not statistically significant. However, correlation of the average NDVI and season end rootzone salinity to five feet in 2004 (the solid cotton planting) was highly significant (Figure 3). 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, but UCB rootstocks were significantly larger than the PG1 rootstocks.

For the Well treatment, total applied salts were 54,251 lb/ac for three seasons of cotton. For one year of cotton and four years pistachios the wetted area applied salts was 73,823 lb/ac. Cotton and pistachio tissues had significantly greater accumulation of chloride and boron for the Well treatment; showing some marginal burn by the end of 2006, but some leaf burn was also observed in the Aqueduct treatment. Pistachio marginal burn by the end of the 2008 season was much greater than 2006. Rootstock circumference for the Well treatment was 7% less than the rootstock circumference for the Aqueduct treatment(Figure 4).

In 2007 a method was designed using Adobe Photo-shop® to isolate and count pixels of leaves in the pistachio canopy. Thus, provided a very quick, inexpensive quantitative estimate of the comparative canopy development for all treatments. The results of this analysis (Figures 5 and 6) for 2008 show no reduction in can-opy development.

Table 2. Summary of plant tissue data, cotton height/lint yield, PG1 rootstock circumference and total applied salts.

	NO3-N (ppm)	NH4-N (ppm)	PO4-P (ppm)	K (%)	Na (ppm)	Cl (%)	B (ppm)	Rootzone EC_e to 5 ft (dS/m)	[1]Cotton Ht, Pistachio Circum (inch)	Cotton Lint Yield (lb/ac)	[2]Total Salts Applied in Irrigation (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**						
		N	**P**	**K**	**Na**	**Cl**	**B**	**10/30/06**	**10/19/06**		**Pistach'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 (PG1)					**Pistachio 2007**					
Aque		2.56	0.14	1.69	99	0.24	167				
50/50		*2.67	0.14	1.76	108	0.28	**315				
Well		*2.80	0.15	1.75	*133	0.30	**384				
	Kerman Leaves 10/19/07 (PG1)					**Pistachio 2007**		**10/18/07**	**10/18/07**		**Pistach'07**
Aque		1.94	0.15	2.51	98	0.26	342	3.23	4.65		1,390
50/50		2.04	0.14	2.71	106	*0.33	**730	4.68	4.59		7,571
Well		**2.24	0.14	2.76	111	0.30	**915	*6.53	4.45		13,197
	Kerman Leaves 10/19/07 (UCB1)					**Pistachio 2007**			**10/18/07**		Pistach'07
Aque		1.97	0.13	2.02	82	0.26	253		4.51		1,390
50/50		2.01	0.13	2.19	80	0.29	**626		4.59		7,571
Well		1.97	0.12	2.15	78	0.25	**682		4.59		13,197
	Kerman Leaves 8/26/08 (PG1)					**Pistachio 2008**		**4/25/08**	**10/22/08**		**Pistach'08**
Aque		2.29	0.13	2.91	80	0.12	301	2.60	7.81		1,553
50/50		2.36	0.13	2.87	84	0.12	**684	*4.69	7.55		8,185
Well		2.33	0.13	3.15	79	0.15	**870	**5.64	*7.23		13,296
	Kerman Leaves 8/26/08 (UCB1)					**Pistachio 2008**		**11/11/08**	**10/22/08**		**Pistach'08**
Aque		2.32	0.13	2.41	83	0.14	269	2.84	7.83		1,553
50/50		2.41	0.13	*2.73	75	0.13	**606	*5.05	7.66		8,185
Well		2.37	0.13	2.50	68	0.14	**733	**6.44	7.49		13,296

*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

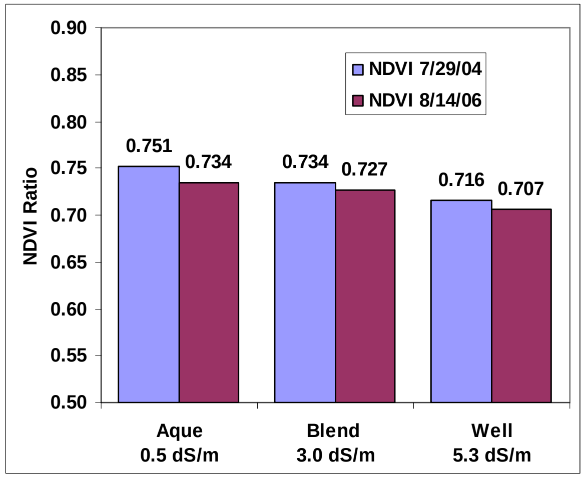

Fig. 2. Normalized Difference Vegetation Index (NDVI) for 2004 solid cotton and 2006 cotton/pistachio interplanting.

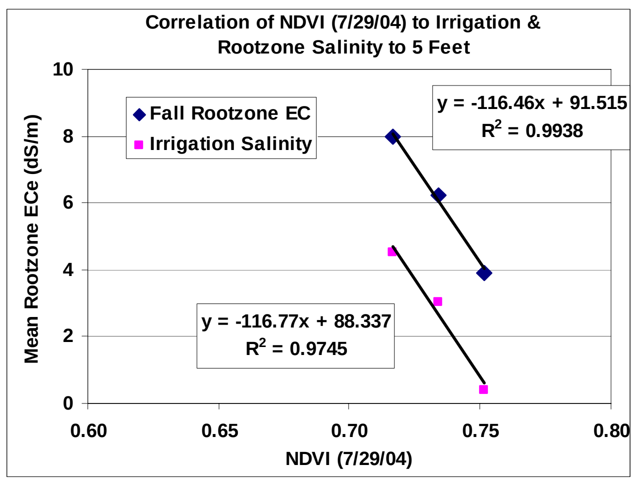

Fig. 3. Correlation of average treatment NDVI with irrigation and season end rootzone salinity.

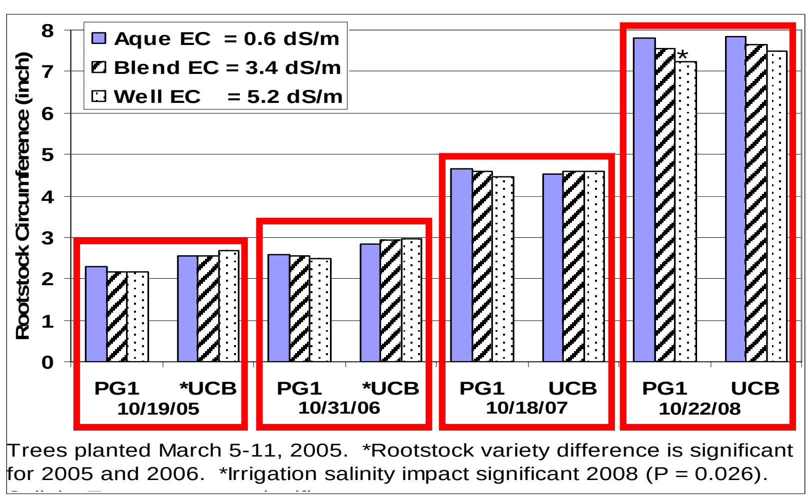

Fig. 4. Change in pistachio rootstock circumference over 4 years.

		Leaf Pixels	Mean Green
Aque	**V 6 W**	1,779,489	74.46
Blnd	**V 4 W**	1,699,659	81.55
Well	**V 6 E**	1,785,752	89.93
Aque	**V 4 E**	1,643,387	63.32
Blnd	**V 2 E**	1,684,789	66.59
Well	**V 2 W**	1,804,652	76.21
Aque	**V 4 N**	1,928,077	105.13
Blnd	**V 2 S**	1,809,587	97.47
Well	**V 2 N**	1,719,525	93.16
Aque	**V 6 S**	1,570,771	87.15
Blnd	**V 6 N**	1,795,931	99.62
Well	**V 4 S**	1,778,227	112.94

AVERAGE LEAF PIXEL TOTALS

	Leaf Pixels	% of Aque	Mean Green
AQUEDUCT	1,730,431	**100.0%**	82.52
BLEND	1,747,492	**101.0%**	86.31
WELL	1,772,039	**102.4%**	93.06

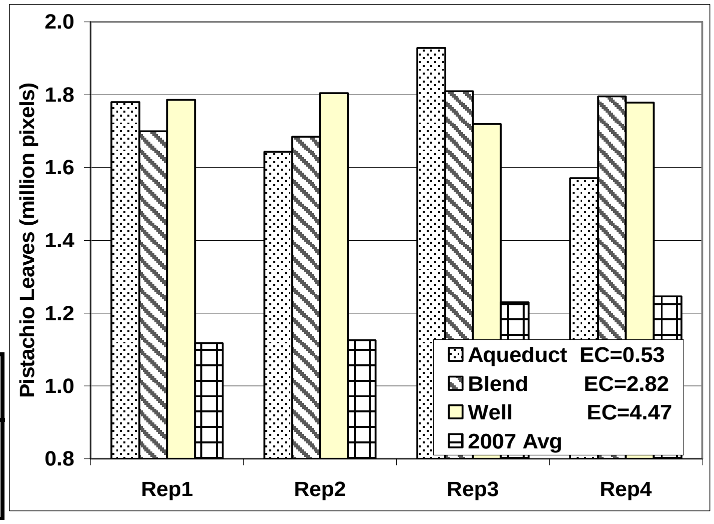

Fig. 5. Comparison of leaf pixel totals by treatment and replication (10/3/07 average only and 10/18/08, Camera Aspect 16wide:4tall, PicSize 5.5MB, Quality 7 dots) and 2008 average water quality.

The Belridge Water District allocation was only 35% for 2008. In order to conserve water the pre-irrigation was only one inch with a total season application of around nine inches (Table 3). This level of irrigation provided adequate soil moisture according to Watermark® matric potential readings (Figure 7). However, neutron probe soil water content readings (Figure 8) revealed that total stored soil moisture to a six foot depth slowly declined starting in July, indicating a slight deficit in applied irrigation and no leaching. This undoubtedly increased marginal leaf burn in 2008 as soil salts concentrated and may have contributed to the decrease in rootstock growth in the Well treatment. All irrigations were 24 hours in duration with some penetration to the 48 inch depth.

Salinity increase, distribution and sustainability: At the end of 2006, after three seasons of cotton irrigation this program applied about 6600, 32500 and 54000 lb/ac of salt in the Aqueduct, Blend and Well treatments, respectively (Table 2) and a cumulative application of 8050, 44710 and 73823 lb/ac in the wetted area for one year of cotton and four years of pistachios (Table 3). Spring and fall average rootzone salinity to 5 feet in the wettest part of the profile (between the two hoses about two feet from the tree) has remained surprisingly stable at an ECe of 2.8 dS/m for the Aqueduct, 4.5 dS/m for the Blend and 5.0 dS/m for the Well treatment (see Table 4 for seasonal data).

Table 3. Applied irrigation (total acreage) and cumulative salt loading for pistachios.

Irrigation Treatment	2004 (Cotton) Irrig (in)	2004 (Cotton) Salt (lb/ac)	2005 Irrig (in)	2005 Salt [1](lb/ac)	2006 Irrig (in)	2006 Salt (lb/ac)	2007 Irrig (in)	2007 Salt (lb/ac)	2008 Irrig (in)	2008 Salt (lb/ac)	TOTAL Irrig (in)	TOTAL Salt (lb/ac)	[2]EC+ Max (dS/m)
Aque	32.3	2343	10.4	1742	8.3	1022	12.0	1390	8.8	1553	71.7	8050	0.6
50/50	33.1	11390	10.4	8570	8.7	8994	10.8	7571	8.7	8185	71.6	44710	3.5
Well	33.1	21444	11.8	14782	7.9	11104	10.7	13197	9.6	13296	73.1	73823	5.8

[1]Irrigation inches for total tree spacing, salt totals (lb/ac) calculated for a 9.5 foot wide subbing area centered on the tree row. Assumes 640 ppm soluble salt = 1 dS/m and a 5 ac-ft depth of soil = 20 million lbs.

[2]Maximum increase in soil saturated paste EC for a 5 foot rootzone with no precipitation of salts and no leaching past the 5 foot depth.

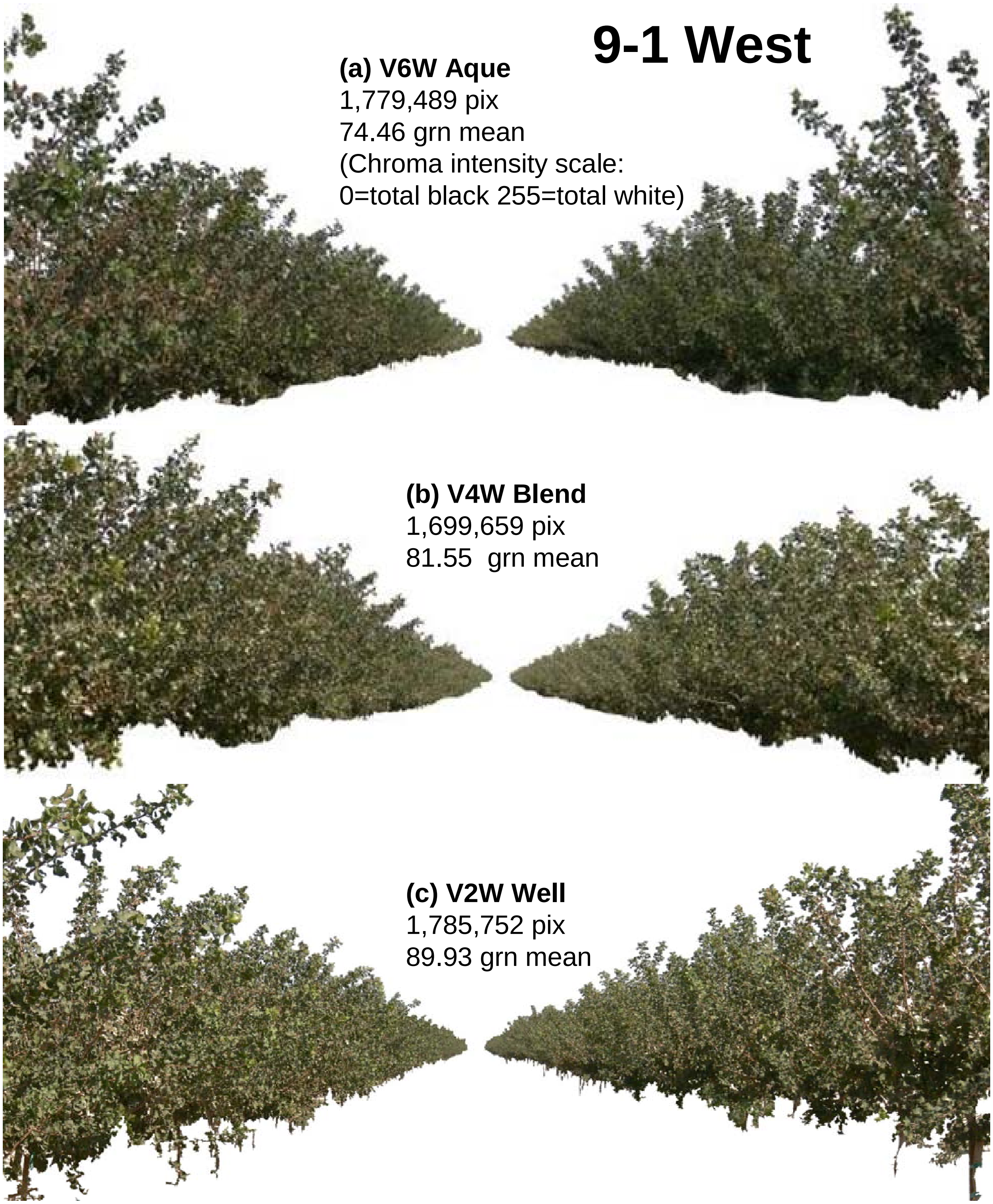

Fig. 6. Canopy leaf pixels isolated from color digital pictures on 10/18/08. Above images created using pictures taken with a Panasonic Lumix DMC-FZ30 and aspect ratio of 16wide:4tall, picture size of 5.5MB, JPEG quality high (7 dots). Image processed with Adobe Photoshop® by first selecting and excising bare soil using "Magic Wand" (Tolerance 50) and then selecting green foliage (Tolerance 50). Total foliage pixel count and "Average Green" (0 is total green, 256 total white) is obtained by selecting "Histogram" from the "Image" pull-down menu.

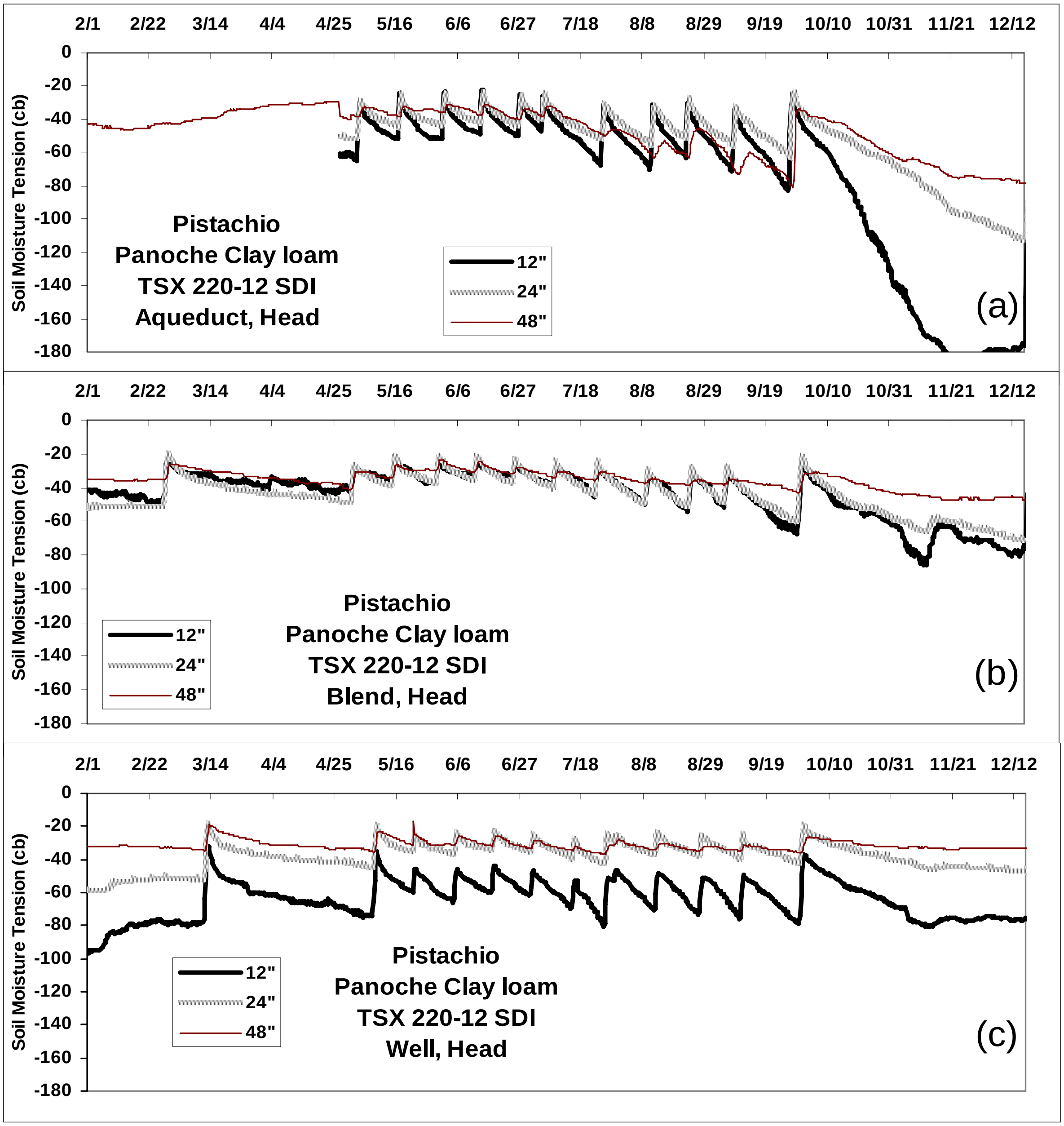

Fig. 7. Soil matric potentials for 2008 for the 12, 24 and 48 inch rootzone depths as determined by Watermark® electrical resistance sensors logged every 8 hours for the Aqueduct (a), Blend (b) and Well (c) treatments.

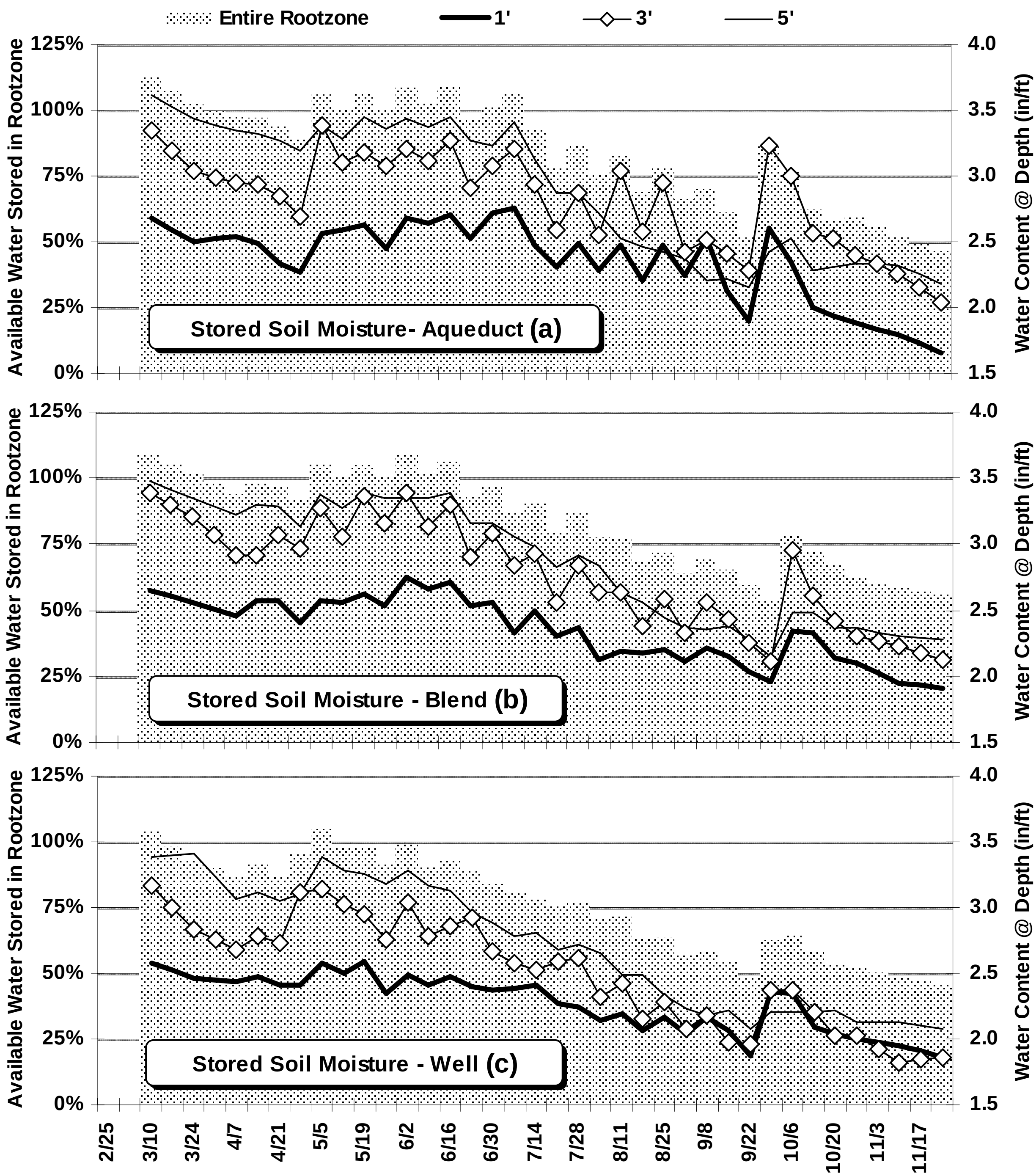

Fig. 8. Weekly neutron probe measurements of soil water content for the Aqueduct (a), Blend (b) and Well (c) treatments. Cross-hatched area indicates integrated water content to 6 feet as % Available Water (3.1 in/ft as 100%, 1.1 in/ft as 0%). Total water content for the 1, 3 and 5 foot depths indicated on right hand axis.

Table 4. Average saturation extract rootzone soil salts from 4 continuous samples to 5 feet for spring and fall pistachio soil samples taken from replicated monitoring sites corresponding to neutron probe water content measurement.

WEIGHTED AVERAGES TO 5 FEET Soil sampled 3/23/04										
Aque	44	7.8	2.07	11.7	2.1	9.1	5.7	1.9	1.1	Nitric
Blend	47	7.8	2.53	13.0	2.3	11.4	7.0	1.9	1.1	Acid
Well	46	7.7	2.10	14.2	1.9	9.3	4.9	1.9	0.8	Total B
WEIGHTED AVERAGES TO 5 FEET Soil sampled 10/7/04										(ppm)
Aque	45	7.8	2.71	11.3	2.5	13.0	9.9	1.8	1.7	17.6
Blend	47	7.7	4.08	21.6	4.2	16.4	18.2	1.4	2.0	
Well	47	7.7	4.68	25.8	5.4	17.2	23.6	1.3	2.7	20.7
WEIGHTED AVERAGES TO 5 FEET Soil sampled 4/10/05										
Aque	44	7.7	3.22	16.3	3.3	15.2	11.9	1.4	1.7	
Blend	48	7.6	4.47	27.6	5.7	17.6	21.3	1.2	1.3	
Well	47	7.6	4.52	29.2	5.5	14.6	23.2	1.1	1.5	
WEIGHTED AVERAGES TO 5 FEET Soil sampled 10/18/05										
Aque	44	8.0	2.88	16.1	3.7	10.8	11.7	1.5	1.5	
Blend	47	7.9	4.12	25.3	5.3	14.1	20.0	1.8	1.5	
Well	47	7.9	4.43	28.1	6.0	14.5	24.2	2.5	1.7	
WEIGHTED AVERAGES TO 5 FEET Soil sampled 5/10/06										
Aque	46	7.9	2.15	10.5	2.2	9.4	5.4	2.8	1.6	
Blend	51	7.7	4.18	27.6	5.1	14.1	16.1	2.0	1.3	
Well	48	7.7	3.99	25.4	5.2	12.5	17.5	2.0	1.5	
WEIGHTED AVERAGES TO 5 FEET Soil sampled 10/30/06										
Aque	44	7.8	3.59	20.5	5.9	13.1	15.9	2.0	1.3	
Blend	48	7.7	5.84	39.7	9.6	17.0	32.3	1.6	1.5	
Well	45	7.7	6.06	39.8	9.5	18.4	35.1	1.7	2.0	
WEIGHTED AVERAGES TO 5 FEET Soil sampled 4/27/07										
Aque	41	7.8	2.55	13.3	3.2	10.3	6.3	2.5	1.4	Nitric
Blend	47	7.7	3.91	24.3	4.7	13.4	17.5	1.6	1.4	Acid
Well	46	7.7	3.99	23.2	5.0	14.2	19.3	1.6	1.9	Total B
WEIGHTED AVERAGES TO 5 FEET Soil sampled 10/18/07										(ppm)
Aque	40	7.8	3.23	17.9	4.3	12.5	10.7	3.1	1.6	27.8
Blend	45	7.7	4.68	29.8	6.0	16.0	24.0	2.1	2.1	28.6
Well	42	7.6	6.53	42.7	9.3	20.8	36.3	2.2	2.6	26.9
WEIGHTED AVERAGES TO 5 FEET Soil sampled 4/25/08										
Aque	42	7.9	2.60	13.4	3.3	10.7	8.2	2.4	1.2	
Blend	47	7.6	4.69	32.5	5.9	15.3	22.8	1.8	1.5	
Well	46	7.7	5.74	37.2	7.9	19.9	35.4	1.7	2.1	
WEIGHTED AVERAGES TO 5 FEET Soil sampled 11/24/08										
Aque	41	7.8	2.84	16.1	3.9	9.0	10.6	2.0	0.6	
Blend	46	7.8	5.05	28.2	7.7	17.3	29.0	1.6	2.6	
Well	43	7.7	6.44	35.6	9.8	23.2	42.9	1.5	3.8	

In-season ECe in the top three feet is much higher as water and salts sub up from the buried drip-tape at the 10 to 12 inch depth due to tree water demand and surface evaporation. With the high level of calcium found in this water we are probably precipitating some lime during drying cycles. For cotton, with a drip hose every 38 inches, contours of soil ECe generated from samples taken after emergence (Figure 9) show that water and salts roughly distribute evenly over the profile of this fine sandy clay loam with excellent lateral subbing. The lowest soil salinity with the lowest salinity directly beneath the tape. In contrast, contours of pistachio soil ECe (Figure 10) take on a concentric pattern around the tree as water is applied by two buried drip tapes about 19 inches on either side of the tree and these young trees will have the greatest root concentration within a two to three foot radius of the trunk. The water required to meet ET, along with the evaporation from this wetted zone thus concentrates the salts around the crown of the tree. Eventually, denser rooting farther away from the trunk as roots mature should carry salts in the opposite direction, away from the tree. Contours of **soil saturation extract boron** (Figure 11) show only a moderate increase of 2 to 3 ppm in the Well treatment compared to the Aqueduct treatment rootzone, despite the very high irrigation water concentration of 8 to 11 ppm. Table 4 shows even less increase as an average to five feet, but also provides an indication of the cause for this result. Total soil B in the top two feet of soil as determined by nitric acid digestion in 2004 showed that most of the native B in this soil is in an unavailable "adsorbed"/ insoluble phase at a concentration of 17 to 20 ppm. A similar digestion performed on all sample sites Fall 2007 showed total B to two feet at 27 to 28 ppm regardless of treatment. Theoretically, there should have been a significant increase in total B for the Well treatment over total B in the Aqueduct treated plots, but these results show the highly variable nature of native B concentrations within many of these Westside soils and the huge potential to sequester irrigation water B into the soil matrix. Still, this ability provide only marginal help to safeguard the tree from uptake of excess B as confirmed by the noticeable leaf burn and tissue levels of excess B in the Well treatment.

Without 6 to 10 inches of effective rainfall or fresh water winter irrigation for efficient leaching every one to two years the use of 4.5 to 6 dS/m EC irrigation water may not be sustainable. Compounding this problem is the continuing increase in salinity of the local groundwater, a not uncommon problem in areas plagued by poor groundwater quality. A regression of all EC data for the well water used in this study indicates a steady increase in EC by about 1 dS/m every 500 days.

Economic analysis: The irrigation requirement of pistachios for the first 4 years under drip irrigation is equal to about one season of cotton irrigation requirement. For the Well treatment in this trial, we used 10.3 inches of fresh water for winter pre-irrigation 29.7 inches of well water during the season. At an average price of $120/ac-ft for Aqueduct water from 2004-2008 and a Well water price of $45/ac-ft this is a savings of $186/ac. **Table 5** (following) breaks down the economics of the cotton production for the Aqueduct and Well treatments by year. At an average pima price of $1.08/lb, this analysis of cotton production and yields for the year prior to and first two years after planting pistachios shows a net return of $2,120 for Aqueduct water @ $120/ac-ft and $2,249 for Well water @ $45/ac-ft for this system.

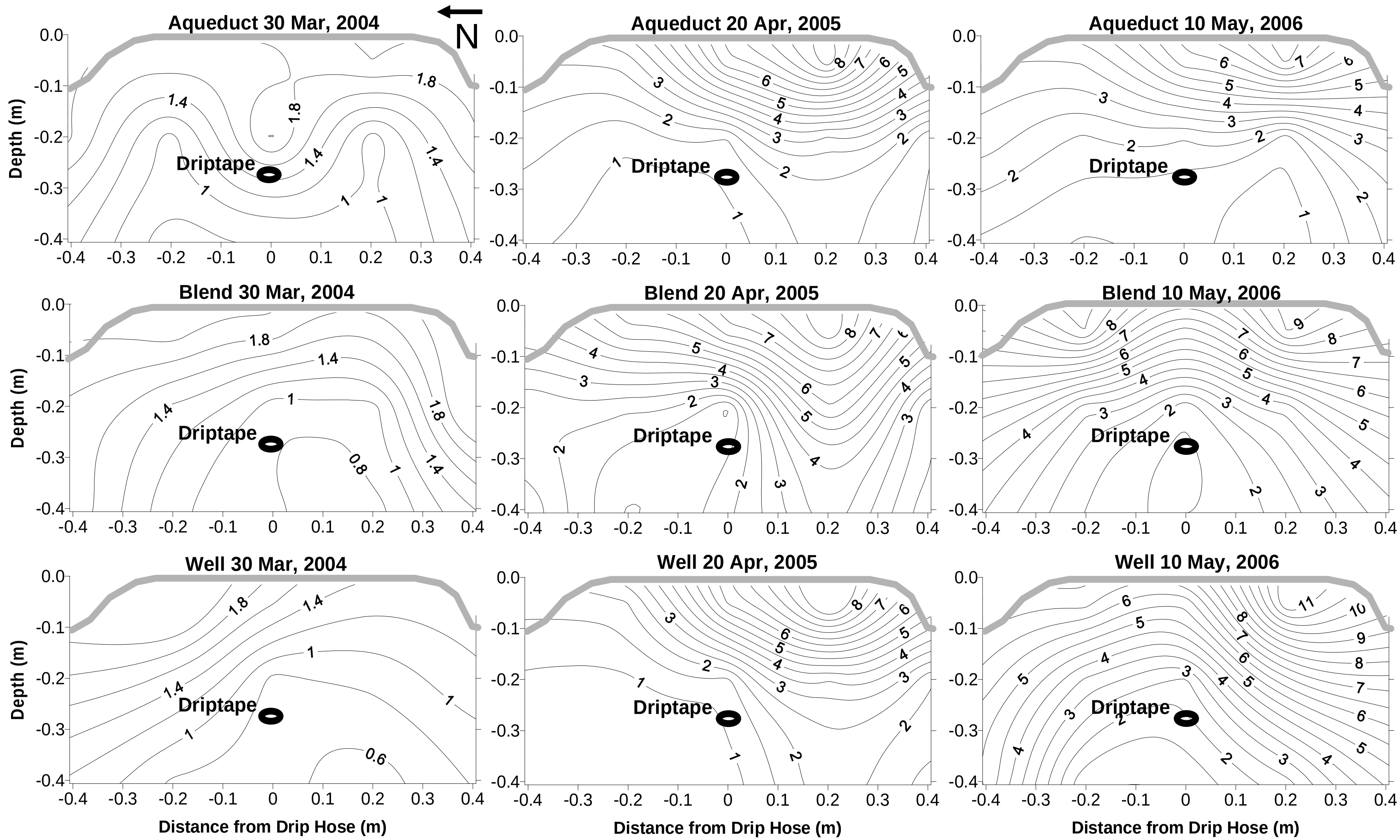

Fig. 9. Contours of saturation extract **soil salinity (ECe, dS/m)** in **cotton** beds (0.96m, 38 inches) at emergence after spring recharge and post-plant irrigation of 200 mm (8 inches) low salinity canal water (Aqueduct, 0.5 dS/m). Kerman rootstock planted 5-11 March, 2005 following cotton and irrigated with the same treatment waters.

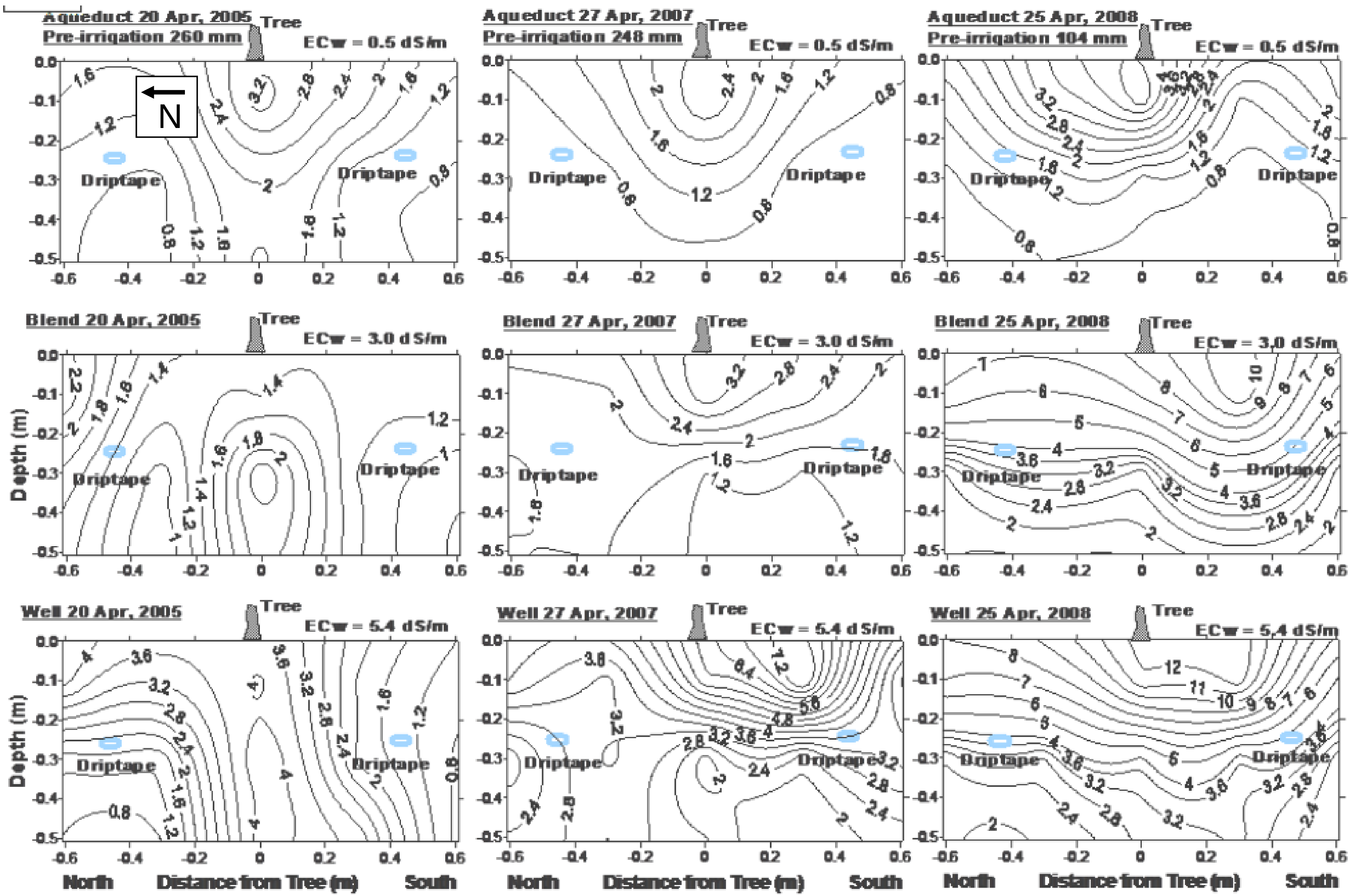

Fig. 10. Contours of **soil salinity (ECe, dS/m)** in **pistachio** beds after spring recharge with low salinity canal water (Aqueduct, 0.5 dS/m, depth of water applied over 2 m width). Kerman rootstock planted 5-11 March, 2005 following 2004 cotton irrigated with the indicated treatment waters. Tree spacing 6.7 x 5.2m (22 x 17ft).

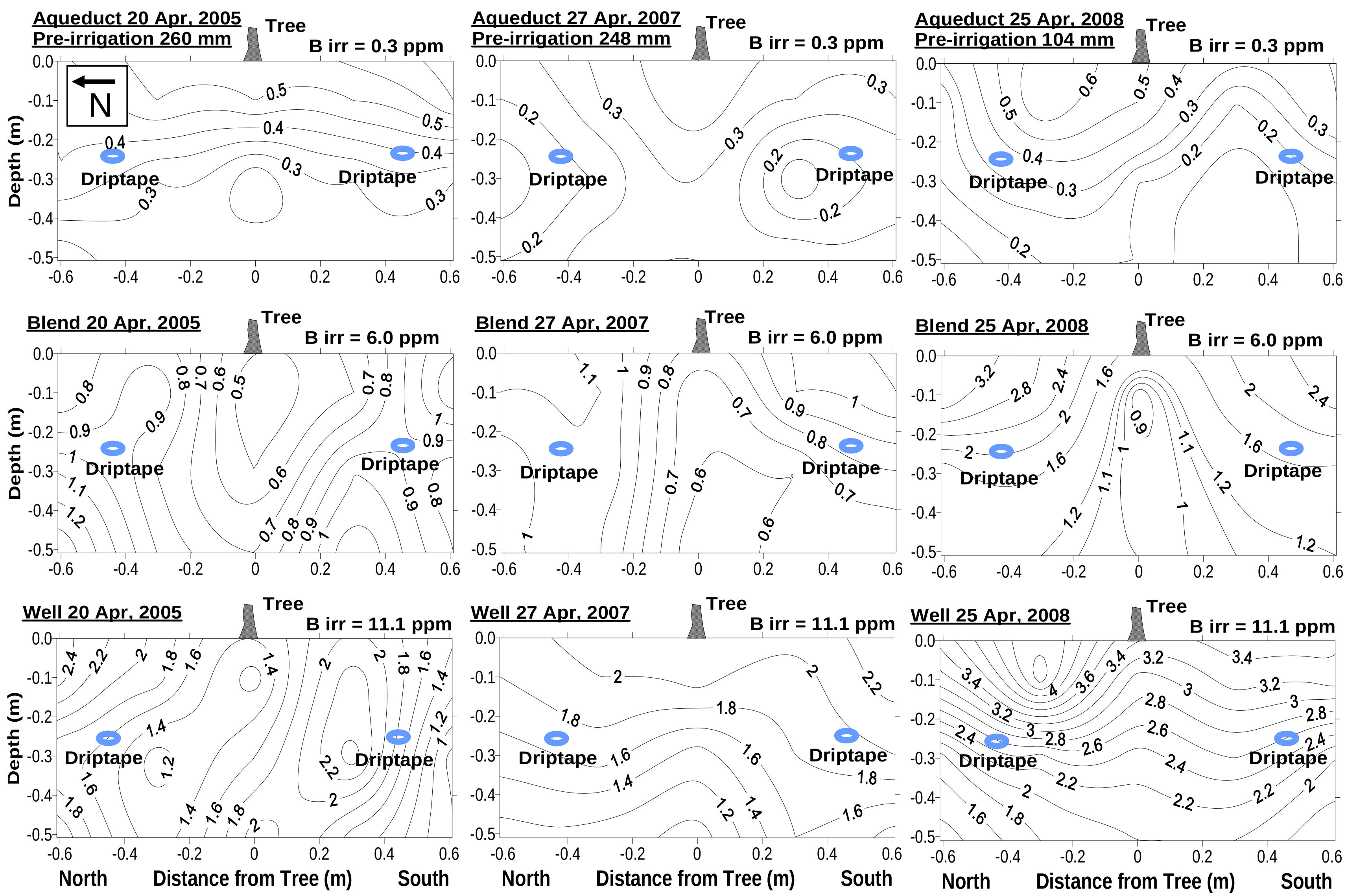

Fig. 11. Contours of **soil saturation paste extract boron (ppm) in pistachio** beds after spring recharge with low salinity canal water (Aqueduct, 0.5 dS/m, depth of water applied over 2 m width). Kerman rootstock planted 5-11 March, 2005 following 2004 cotton irrigated with the indicated treatment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

Table 5. Economic analysis for Net Return from three years of cotton production for both Aqueduct and Well water treatments.

Cotton	[1]Yield (lb/ac)	[2]Gross $/ac	[3]AQUE Treatment Irrig (in)	Salt (lb/ac)	Net Return	[4]WELL Treatment Aque (in)	Well (in)	Salt (lb/ac)	Net Return
2004	1959	$1,861	32.3	2,343	**$877**	6.1	27.0	21,444	**$1,038**
2005	1028	$1,233	31.8	2,305	**$254**	9.0	21.0	16,975	**$403**
Aque'06	1835	$2,019	36.8	1,967	**$990**				
Well'06	1560	$1,716				17.8	18.5	15,832	**$808**
Total	**4821**	**$5,112**	100.9	6,615	**$2,120**	32.9	66.5	54,251	**$2,249**
[5]Pistachios 2005-2008			39.4	8,050	--	10.3	29.7	73,823	**$186**

[1]Average field yield of all treatments for 2004 & '05 cotton as there was no treatment difference. 2006 yields and returns separated due to treatment effect.

[2] Pima price for 2004 - $0.95, 2005 - $1.20, 2006 - $1.10

[3]Total applied water, salts and net return based on irrigation + system depreciation cost of $261/ac, $400/ac other cultural/harvest costs and water cost of $120/ac-ft of CA Aqueduct water.

[4]Above costs apply except WELL water was $45/ac-ft. The indicated depth of Aqueduct water was used for spring pre-irrigation and germination of cotton.

[5]Total applied water and salt load (based on a 9.5 foot wide wetted area) from planting to the end of the 4th year. The $186 net return equals the money saved using the less expensive WELL water.

Conclusions and practical application

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 $2,100 to $2,200/ac net return above cash costs from the 3 years of cotton production with an additional savings of $186/ac savings using Well water @ $45/ac-ft compared to Aqueduct water @ $120/ac-ft to irrigate pistachios for the first four years. But the Well water also added an additional 74,000 lbs/ac of salt (0.35% by weight for a five foot depth of soil) to the wetted area of the crop rootzone. If sufficient fresh water is available for less than $150/ac-ft this would be the safest irrigation supply, but if long-term allocations to the Westside are greatly reduced on the average, then the use of saline drain water up to an EC of 5 to 6 dS/m allows for continued production with occasional leaching and probably some long-term yield impact.

At this time there are probably 30,000 additional acres of pistachios planted along the Westside since 2004 that would not have been developed five years ago without our current understanding of pistachio salt tolerance. Between marginal groundwater and blended drainwater there is more than 150,000 ac-ft/year of additional "alternative" water supply on the Westside that is at least partly 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.

Acknowledgements

This project would not have been possible without the generosity and cooperation of Starrh & Starrh Cotton Growers. The pistachio and irrigation industry owe a big debt of gratitude to Fred Starrh in particular to have the vision and "cussedness" to implement this project on such a production scale. I would also like to thank Marciano for accommodating our irrigation scheduling and my field techs Mike Mauro and Beau Antongiovanni for getting most of the work done.

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