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

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SUMMARY

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.

This current large-scale began March 2004. Twelve 19.5 acre test plots were set up 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. The fields were well reclaimed (salinity averaged 1.57 dS/m to 3 feet) and had good drainage. We used fresh (Aqueduct), blended (Blend) and saline Well water treatments (average EC of 0.4, 3.3 and 5.1 dS/m and boron @ 0.3, 6 and 11 ppm, respectively, from 2005-9). The highest salinity treatment is more than 4 times as saline as most irrigation waters currently used in the SJV. The field was planted to solid pima cotton in 2004. In 2005, pistachio rootstocks (PG1 and UCB1) were planted in March, 17 feet apart on a 22 foot row spacing and interplanted with four 38 inch rows of pima cotton. Pistachios were budded with a Kerman scion in July. Every winter/early

spring all treatments received 8 to 12 inches of fresh water for leaching/preirrigation and cotton germination, followed by 21 to 26 inches of treatment water, depending on seasonal demand. Pistachios receive about 18 inches total based on a 9.5 foot wide area (7.8 inches for the 22 foot row spacing). Cotton was not inter-planted for 2007 or 2008 as the grower stopped all his Westside cotton production due to a severe shortage of canal water. The water shortage continues and the trees now shade too much area for profitable cotton production.

The salinity of the well water has been slowly increasing up to 8 dS/m by 2008. So as of August 2007, it was necessary to use additional aqueduct water to return the Well and Blend treatment salinity to 3 and 5 dS/m, respectively. As the drought continued into 2009 with reduced supplies and Emergency Pool water costs as high as $400/ac-ft, the grower could no longer afford to apply aqueduct water to this field. The irrigation system was connected to another well ½ mile to the east with a steady EC of 3.3 dS/m. This water has now been used as the sole supply for all irrigation starting June 2009 with the exception of intensively monitored Aqueduct treatment rows (2 adjacent rows, 1.33 acres, in each of the four replicated blocks). Thus, we have maintained a sufficient number of control trees receiving only fresh water to compare to the trees irrigated with saline water. This means we are now reduced to only two levels of differing irrigation salinity. For the past 3 years, however, there has been little difference in the sampled root-zone soil salinity of the Well and Blend treatments (6.9 and 7.1 dS/m, as of 7/30/09). Average Aqueduct soil salinity to 5 feet is now 3.5 dS/m.

<u>Results:</u> For the first two years of cotton, plant tissue analysis showed a significant 0.5 to 3 fold increase in chloride and boron levels in both cotton and pistachio tissues, but produced no toxicity symptoms. 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. 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). Cotton plant height under saline irrigation was significantly reduced early in the season, but this difference was insignificant by the end of July. Comparing aerial imagery and the Normalized Difference Vegetation Index (NDVI) for August 2004 and 2006 also showed no treatment impacts. But 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. PG1 rootstocks showed a significant 7% decrease at the end of 4^{th} leaf while UCB was unaffected. From 10/22/08 to 10/31/09 average trunk circumference increased by 50% with no statistical difference between the Well and Aqueduct treatments for PG1, but for 2009 the trunk circumference for UCB was a statistically significant 7% greater for the Aqueduct treatment. However, Photoshop pixel estimates of green foliage down the row show no difference between treatments. It is too early to tell if there will be sufficient fruiting buds for a commercial harvest in the 6^{th} leaf (2010).

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.

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 (total) of salt in the Aqueduct, Blend and Well treatments, respectively. By the end of 2009 this total is up to 15,000, 59,000 and 92,000 lb/ac of salts deposited in the wetted rootzone for the same treatments. This equals a maximum increase in EC of 1.2, 4.6 and 7.2 dS/m if averaged over the whole rootzone. But salts from drip irrigation don't like to cooperate in this way. At this time the salinity in the top 0-15 inches is more than twice that of the lower depths for all treatments and is over the EC tolerance limit of 8.4 dS/m established by Sanden and Ferguson. This is caused by the fact that the 2 drip tapes are buried about 10 to 12 inches deep on either side of the tree; causing the salt to move to the middle of the tree row/crown in our sampling zone. This effect can also create toxic NO3 levels around the crown with certain soils and water quality. This concentration effect increases leaf burn during mid to late season forcing more water to be taken up deeper in the profile. **Without 6 to 10 inches of effective rainfall or fresh water winter irrigation for efficient leaching this system may not be sustainable.**

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.

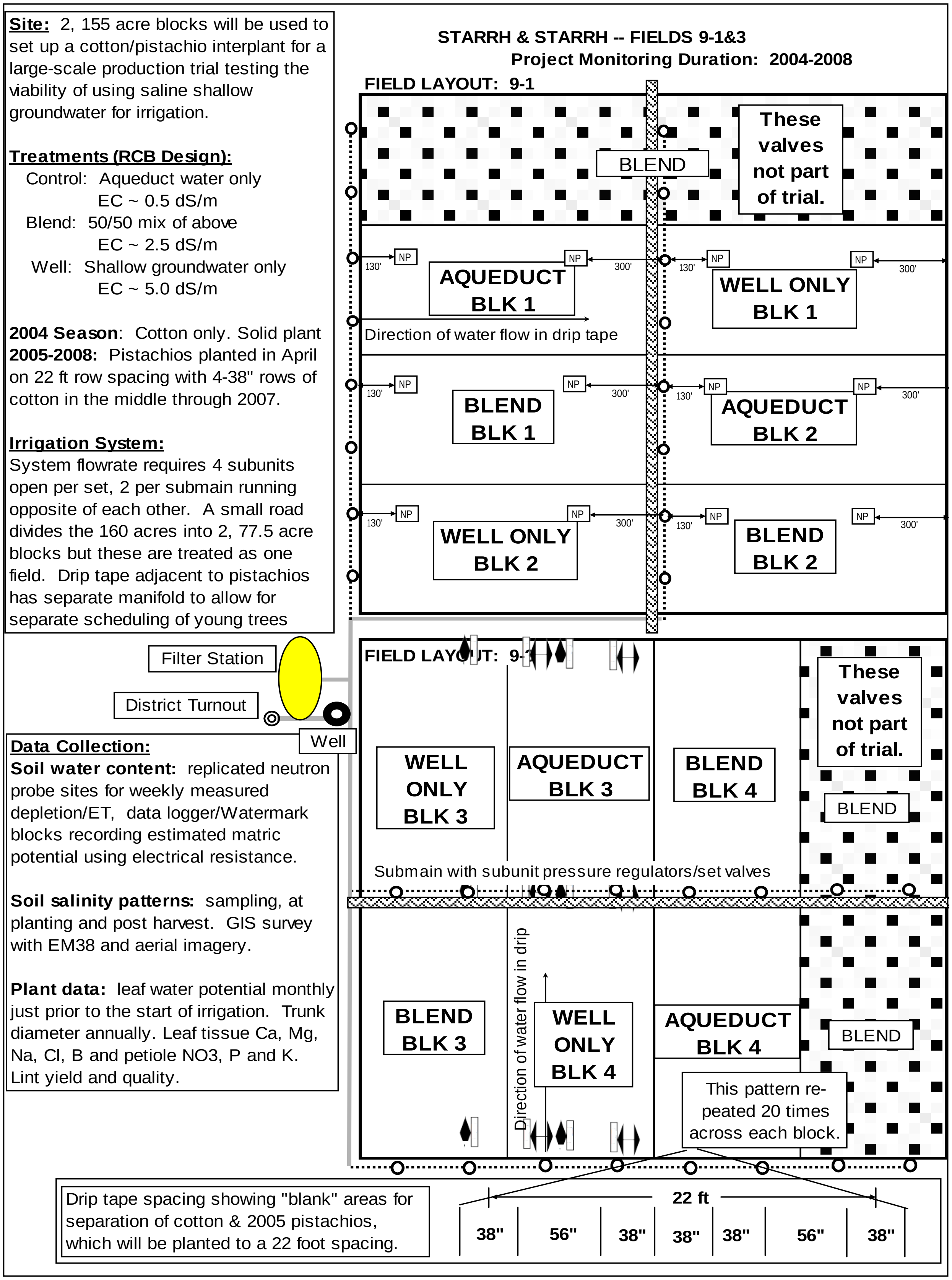


Fig.1. Experimental design and data collection.

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.

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..

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 has not been completed at this time.

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 is given in Table 1.

Table 1. Average treatment water quality from 2004-2009

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	**0.50**	2.5	1.2	1.0	**2.6**	**2.2**	**0.3**	1.3	<0.1	0.7	0.5
Blend	7.6	**3.42**	4.2	14.1	7.8	**13.8**	**20.9**	**6.5**	1.4	<0.1	9.9	2.5
Well	7.6	**5.02**	5.2	22.2	12.2	**21.4**	**32.3**	**10.3**	1.5	<0.1	19.6	6.6

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 for 2005 and 2006 (Table 2), but produced no toxicity symptoms in 2005. From 2006 on only boron has been consistently higher in Kerman leaves irrigated with saline water. Marginal leaf burn has slowly increased in severity (up to ½ inch of outer leaf boundary necrosis) since 2006. By the end of 2007 scaffold development was essentially the same for all treatments and rootstocks.

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.

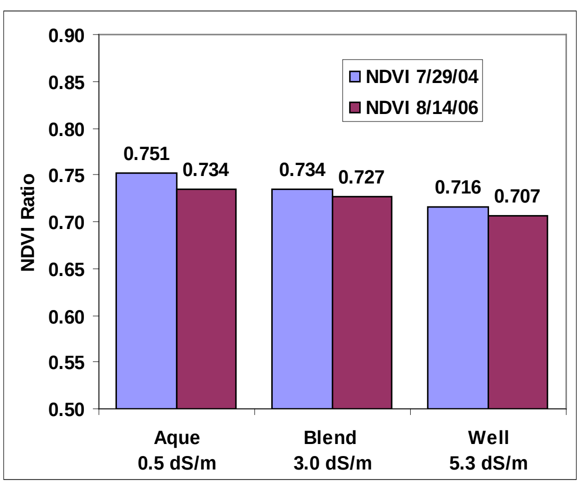


Fig. 2. Normalized Difference Vegetation Index (NDVI) for 2004 solid cotton and 2006 cotton/pistachio interplanting.

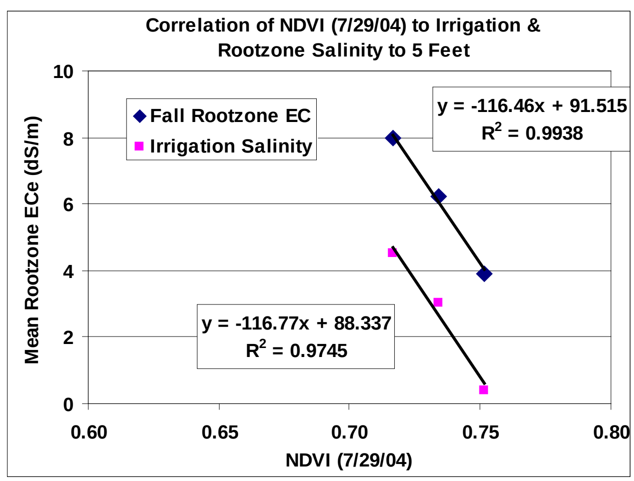


Fig. 3. Correlation of average treatment NDVI with irrigation and season end rootzone salinity.

For the Well treatment, total applied salts were 54,251 lb/ac for three seasons of cotton. For one year of cotton and five years pistachios the wetted area applied salts was 92,267 lb/ac.

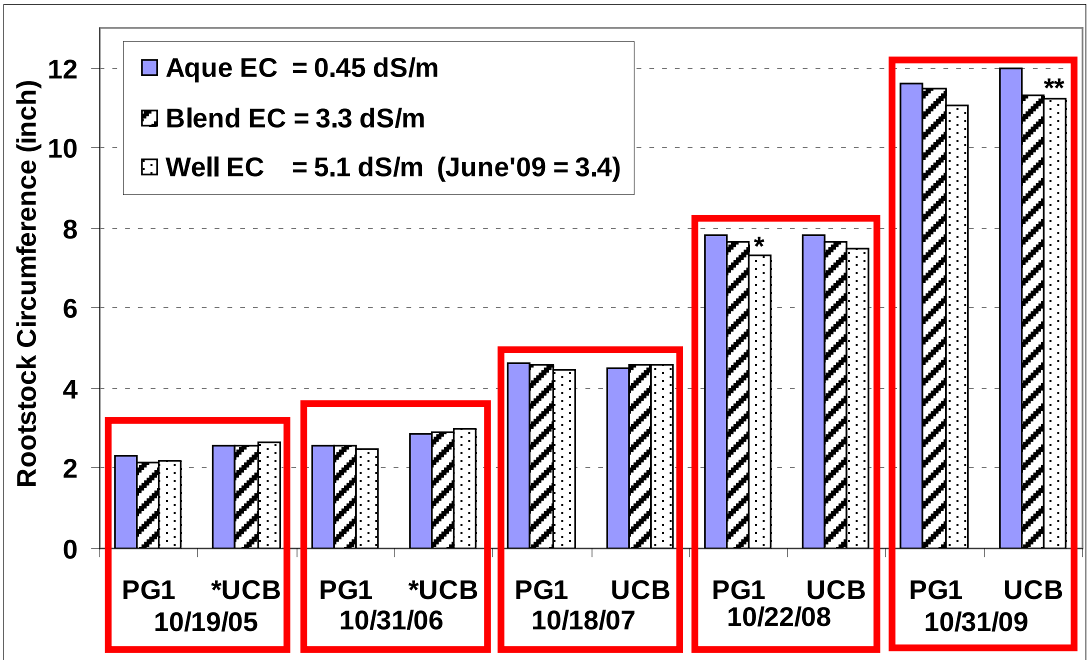
Table 2. Summary of plant tissue data, cotton height/lint yield, rootstock circumference and total applied salts.

	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**(ppm)	**Cl** (%)	**B**(ppm)	**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**		
Aque		1.97	0.13	2.02	82	0.26	253		4.51		
50/50		2.01	0.13	2.19	80	0.29	**626		4.59		
Well		1.97	0.12	2.15	78	0.25	**682		4.59		
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**		
Aque		2.32	0.13	2.41	83	0.14	269	**2.84**	7.83		
50/50		2.41	0.13	*2.73	75	0.13	**606	***5.05**	7.66		
Well		2.37	0.13	2.50	68	0.14	**733	****6.44**	7.49		
Kerman Leaves 7/31/09 (PG1)						**Pistachio 2009**		**7/30/09**	**10/22/08**		**Pistach'09**
Aque		2.68	0.13	2.69	100	0.20	378	**3.52**	11.6		7,022
50/50		2.63	0.13	2.83	94	0.22	**831	***7.08**	11.5		14,399
Well		2.53	0.13	2.79	90	0.22	**780	***6.90**	11.1		18,444
Kerman Leaves 7/31/09 (UCB1)						**Pistachio 2009**			**10/22/08**		
Aque		2.69	0.14	2.08	80	0.16	318		12.0		
50/50		2.67	0.14	2.17	81	0.17	**616		11.3		
Well		2.70	0.14	2.28	91	0.19	**716		*11.2		

*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

PG1 rootstock circumference for the Well treatment was a significant 7% less than the rootstock circumference for the Aqueduct treatment in 2008, but not significantly different in 2009. In 2009, however, UCB rootstock circumference in the Well treatment was significantly less by 7% compared to the Aqueduct (Figure 4).



Trees planted March 5-11, 2005. *Rootstock variety difference is significant for 2005 and 2006. *Irrigation salinity impact significant PG1 2008 (P = 0.048), UCB 2009 (P=0.023).

Fig. 4. Change in pistachio rootstock circumference over 5 years.

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 2009 show no reduction in canopy development.

			Leaf Pixels	Mean Green
Aque		V 6 W	1,784,985	76.36
Blnd	Rep1	V 4 W	1,777,483	81.58
Well		V 6 E	1,864,260	73.34
Aque		V 4 E	1,640,283	63.44
Blnd	Rep2	V 2 E	1,960,303	80.57
Well		V 2 W	1,942,731	62.89
Aque		V 4 N	1,805,648	80.71
Blnd	Rep3	V 2 S	1,532,577	79.64
Well		V 2 N	1,948,508	84.98
Aque		V 6 S	1,851,314	75.54
Blnd	Rep4	V 6 N	1,940,991	88.92
Well		V 4 S	1,816,979	81.2

AVERAGE LEAF PIXEL TOTALS

	Leaf Pixels	% of Aque	Mean Green
AQUEDUCT	1,770,558	**100.0%**	74.01
BLEND	1,802,839	**101.8%**	82.68
WELL	1,893,120	**106.9%**	75.60

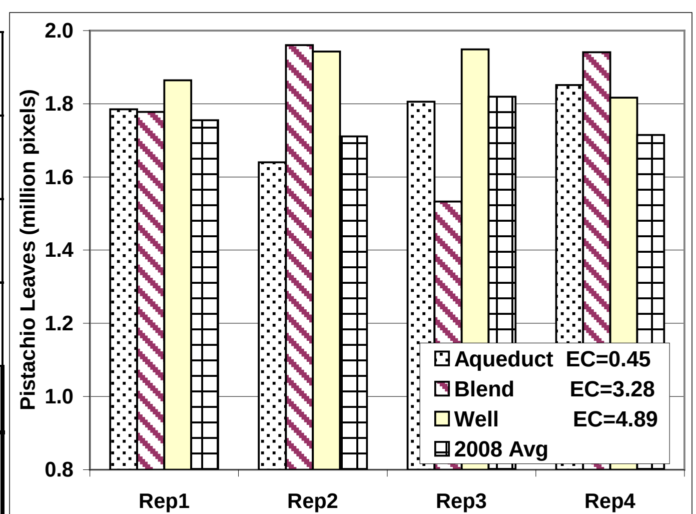


Fig. 5. Comparison of leaf pixel totals by treatment and replication (10/18/08 average only and 10/29/09, Camera Aspect 16wide:4tall, PicSize 5.5MB, Quality 7 dots) and 2004-09 average water quality.

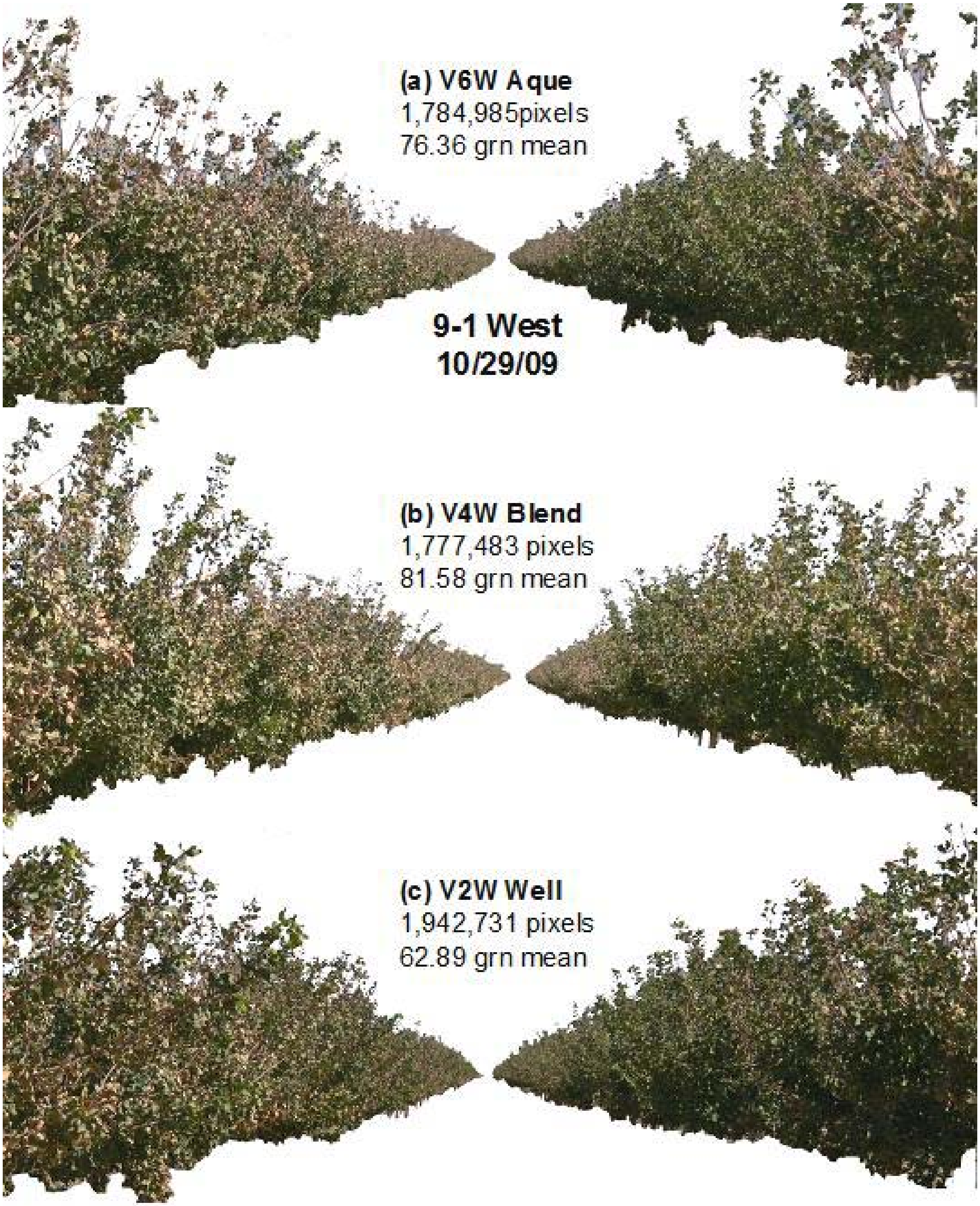


Fig. 6. Canopy leaf pixels isolated from color digital pictures on 10/29/09. Above images created using pictures taken with a Panasonic Lumix DMC-FZ30 and aspect ratio of 16wide:4tall, picture size of 5.5MB, JPEG quality high (7 dots). Image processed with Adobe Photoshop® by first selecting and excising 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.

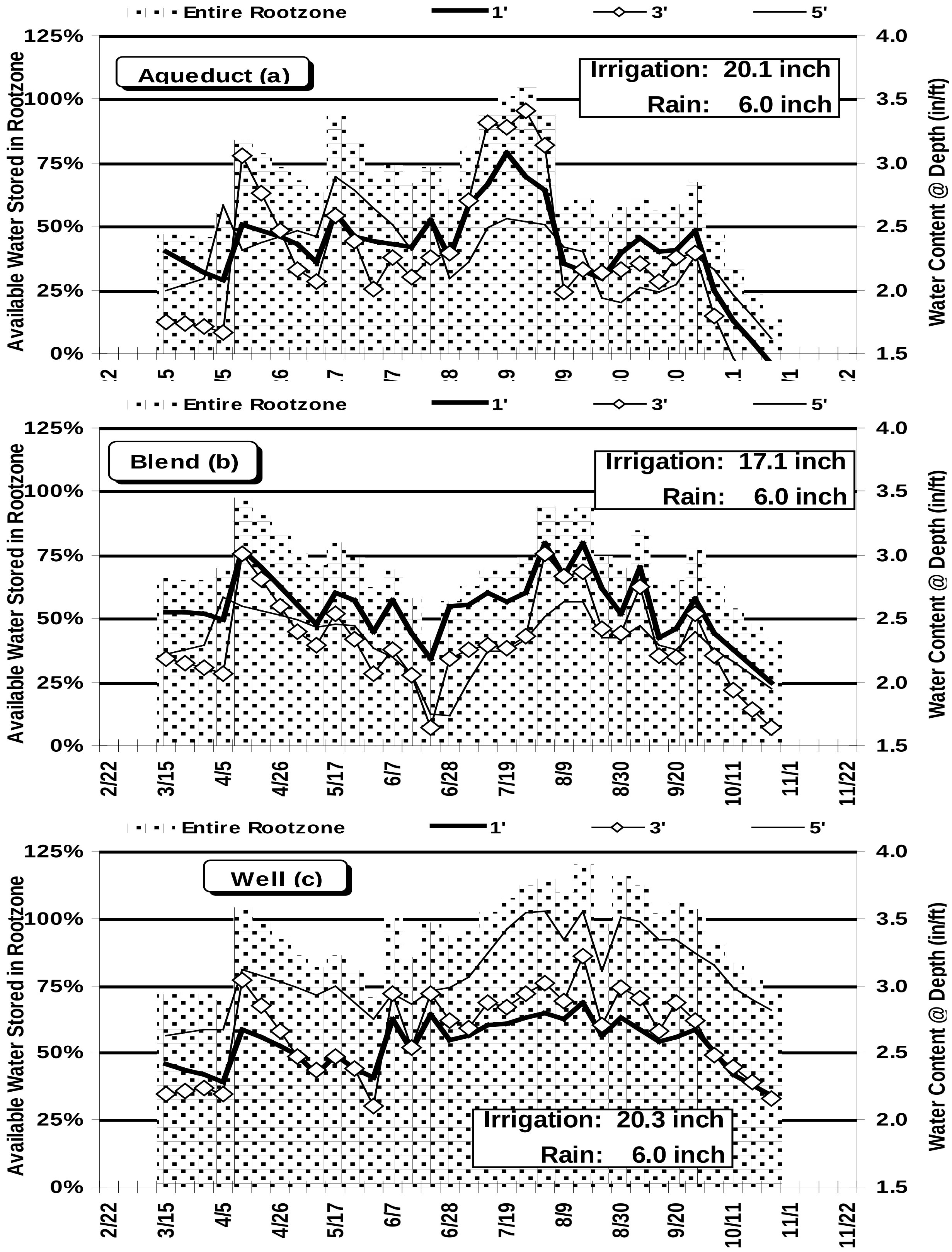


Fig. 7. Weekly neutron probe measurements of soil water content for the Aqueduct (a), Blend (b) and Well (c) treatments. Cross-hatched area indicates integrated water content to 6 feet as % Available Water (3.1 in/ft as 100%, 1.1 in/ft as 0%). Total water content for the 1, 3 and 5 foot depths indicated on right hand axis.

The Belridge Water District allocation was only 35% for 2008 and 2009. In order to conserve water no pre-irrigation water was applied, and spring bud push commenced using stored soil moisture from 2.95 inches of winter rainfall. Rain plus irrigation totaled about 17 inches (Table 3). Neutron probe soil water content readings (Figure 7) showed that total stored soil moisture to a six foot depth was about 75% available at the start of the season and was increased to 100% with the start of irrigation the end of March. Except for one plumbing problem in the Aqueduct treatment in July, adequate soil moisture should have been available to the trees. However, midday stem water potential measurements indicated that the trees were experiencing significant stress starting the end of June (Figure 8). Osmotic stress due to increased rootzone salinity in the blend and well treatments undoubtedly contributed to this stress. But it is unclear as to why the Aqueduct treatment appeared to show nearly the same level of stress. All this increased marginal leaf burn in 2009 as soil salts concentrated and may have contributed to the decrease in rootstock growth in the Well treatment. Most irrigations were 48 hours in duration with penetration to four to five foot depth.

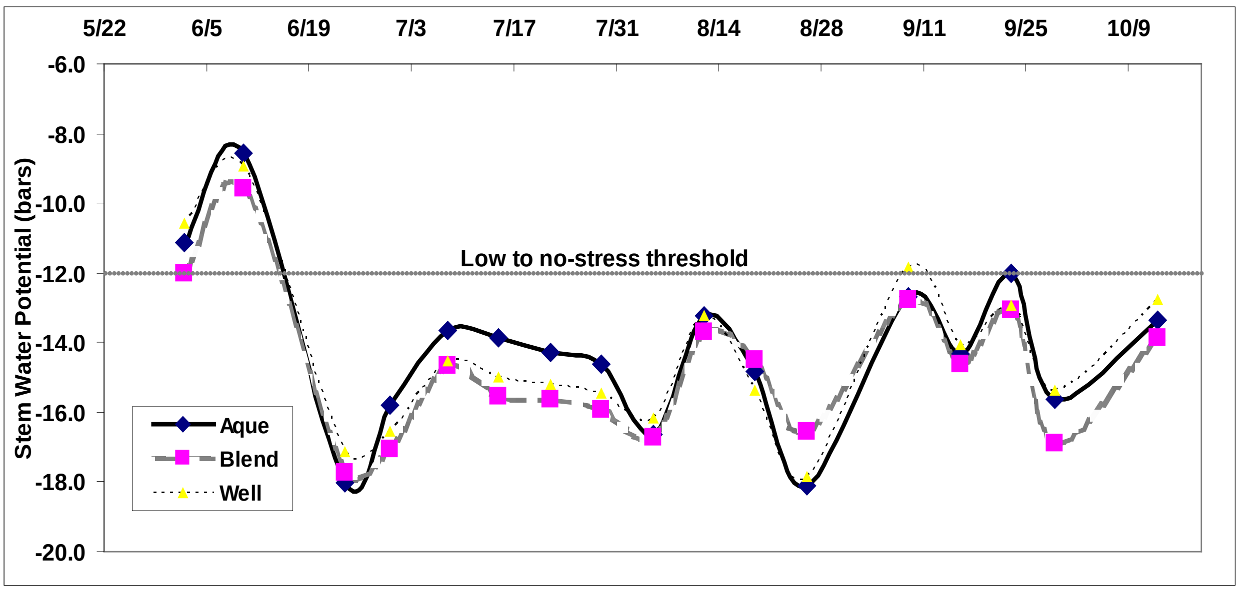


Fig. 8. Midday stem water potential measurements for all treatments using shaded bagged leaves in a PMS pressure chamber.

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 15,072, 59,109 and 92,267 lb/ac in the wetted area for one year of cotton and five 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).

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 distribute fairly evenly over the profile of this fine sandy clay loam with excellent lateral subbing. The lowest soil salinity is directly beneath the tape. The highest concentration is on the south side of the bed due to sun angle.

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

	2004 (Cotton)		2005		2006		2007		2008		2009		TOTAL		[2]EC+ Max
Irrigation Treatment	Irrig (in)	Salt (lb/ac)	Irrig (in)	Salt [1](lb/ac)	Irrig (in)	Salt (lb/ac)	Irrig (in)	Salt (lb/ac)	Irrig (in)	Salt (lb/ac)	Irrig (in)	Salt (lb/ac)	Irrig (in)	Salt (lb/ac)	(dS/m)
Aque	32.3	2343	10.4	1742	8.3	1022	12.0	1390	8.8	1553	17.5	7022	71.7	15072	1.2
50/50	33.1	11390	10.4	8570	8.7	8994	10.8	7571	8.7	8185	15.6	14399	71.6	59109	4.6
Well	33.1	21444	11.8	14782	7.9	11104	10.7	13197	9.6	13296	16.6	18444	73.1	92267	7.2

[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.

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. Over the last 5 years, continuing root development creates a gradient that pulls salts and water farther away from the trunk and evens out the salinity pattern over the 4 foot wide zone shown by the transect contours. However, salt is still concentrated to the south side due to sun angle.

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 may 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. Until 2009, contours of **soil saturation extract boron** (Figure 11) showed 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. But this year may have been the "time bomb" point at which most of the adsorption sites become saturated and more boron remains soluble as shown in the Well treatment contours for 2009. Figure 12 gives a direct comparison of the soluble and total boron.

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 groundwater, a not uncommon problem in areas plagued by poor groundwater quality. A regression of all EC data for the well water used for the first five and one-half years of this study indicates a steady increase in EC by about 1 dS/m every 500 days. We are lucky that the well just one-half mile to the east has not been degraded in the same fashion. Time will tell.

Table 4. Average saturation extract rootzone soil salts from 4 continuous samples to 5 feet for spring and fall (2004-8, mid-season only starting 2009) pistachio soil samples taken from replicated monitoring sites corresponding to neutron probe water content measurement.

	SP %	pH	EC dS/m	Ca (SP) meq/l	Mg (SP) meq/l	Na (SP) meq/l	Cl (SP) meq/l	HCO3 meq/l	B (SP) ppm	
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	Nitric
Blend	46	7.8	5.05	28.2	7.7	17.3	29.0	1.6	2.6	Acid
Well	43	7.7	6.44	35.6	9.8	23.2	42.9	1.5	3.8	Total B
WEIGHTED AVERAGES TO 5 FEET Soil sampled 7/30/09										(ppm)
Aque	43	7.7	3.52	19.8	5.3	10.8	13.1	1.9	0.8	18.6
Blend	45	7.6	7.07	42.5	9.4	23.3	39.1	1.6	2.3	21.6
Well	45	7.7	6.89	41.8	9.3	22.7	40.0	1.5	2.7	21.8
WEIGHTED AVERAGES TO 5 FEET Soil sampled 7/21/10										(ppm)
Aque	45	7.7	5.62	37.0	8.0	16.2	26.0	1.4	0.7	17.8
Blend	47	7.7	8.55	52.1	11.5	29.9	53.1	1.3	2.6	21.4
Well	47	7.7	7.82	43.8	10.4	31.8	51.7	1.3	4.6	24.7

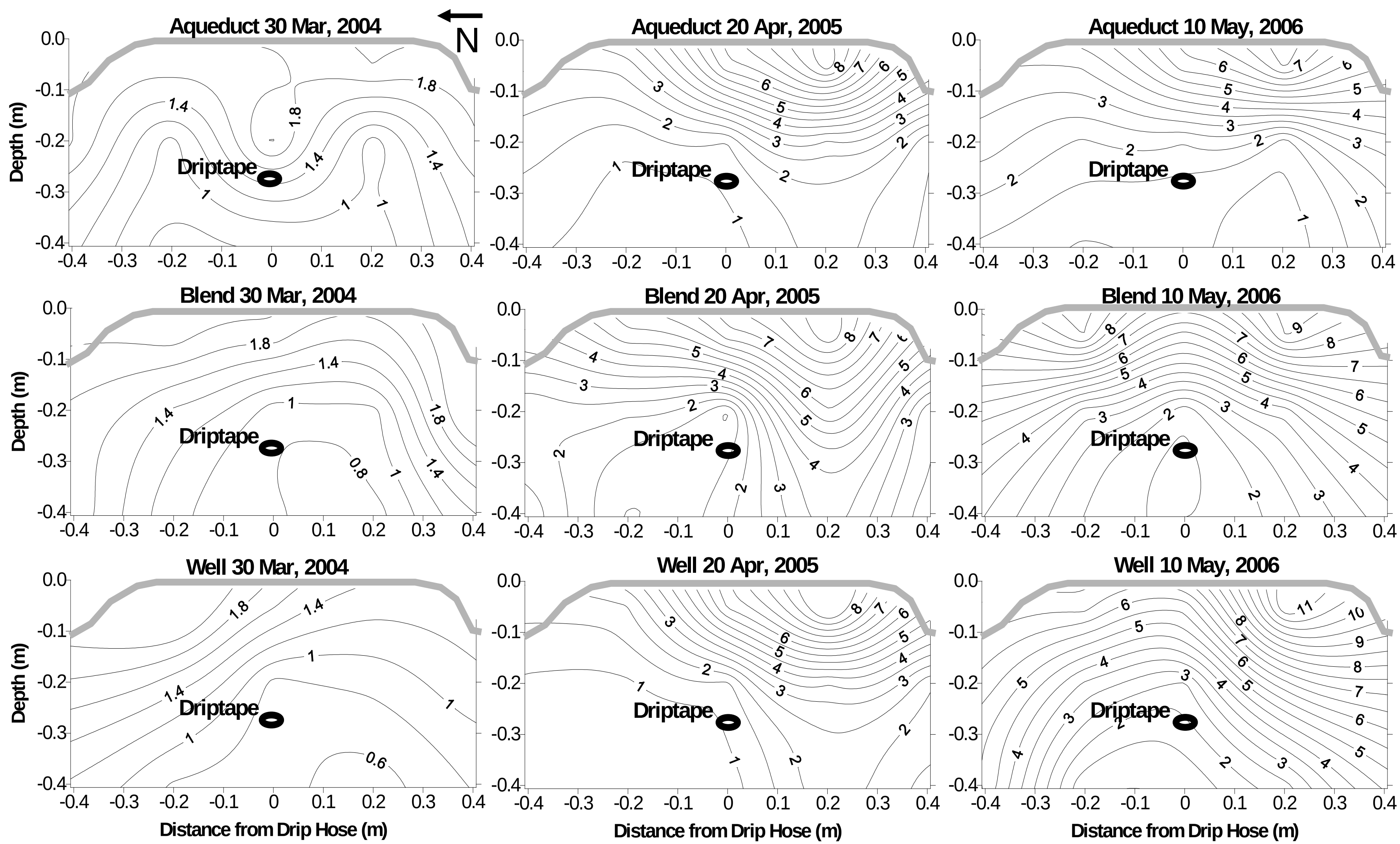


Fig. 9. Contours of saturation extract **soil salinity (ECe, dS/m)** in **cotton** beds (0.96m, 38 inches) at emergence after spring recharge and post-plant irrigation of 200 mm (8 inches) low salinity canal water (Aqueduct, 0.5 dS/m). Kerman rootstock planted 5-11 March, 2005 following cotton and irrigated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

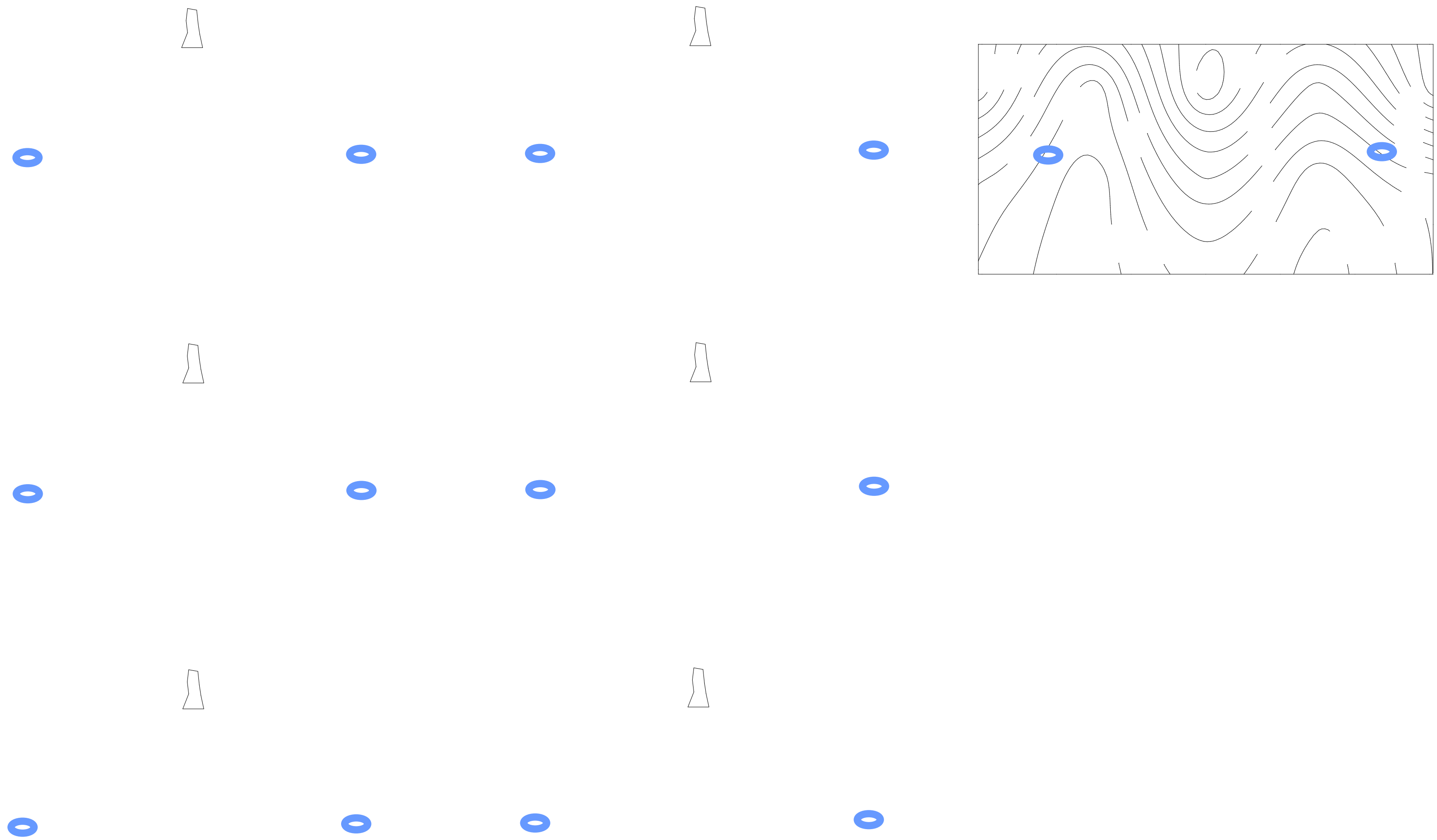


Fig. 10. Contours of **soil salinity (ECe, dS/m) in pistachio** beds after spring recharge with low salinity canal water (Aqueduct, 0.5 dS/m, depth of water applied over 2 m width, 2004-8). Kerman rootstock planted 5-11 March, 2005 following 2004 cotton irrigated with the indicated treatment waters. Tree spacing 6.7 x 5.2m (22 x 17ft). Mid-season salinity 2009.

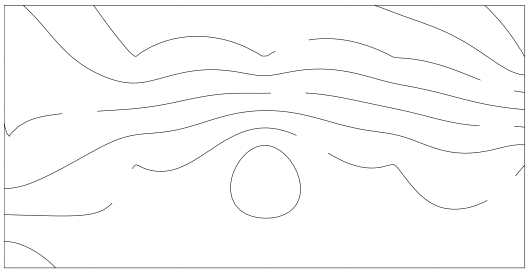


Fig. 11. Contours of **soil saturation paste extract boron (ppm) in pistachio** beds after spring recharge with low salinity canal water (Aqueduct, 0.5 dS/m, depth of water applied over 2 m width, 2004-8). Kerman rootstock planted 5-11 March, 2005 following 2004 cotton irrigated with the indicated treatment waters. Tree spacing 6.7 x 5.2m (22 x 17ft). Mid-season salinity 2009.

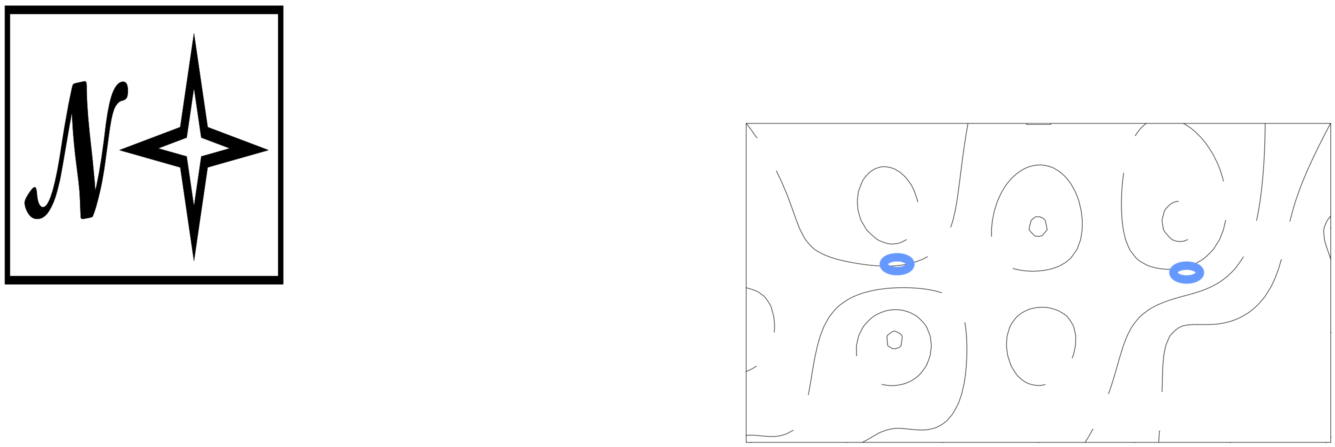


Fig. 12. Soluble boron from soil saturated extract paste compared to total boron from nitric acid extraction after six years of applied irrigation at the indicated average B concentration.

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 and 40 inches of well water during the seasons. At an average price of $160/ac-ft for Aqueduct water from 2005-2009 and a Well water price of $50/ac-ft this is a savings of $367/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.

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	40.0	92,267	**$367**

[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 4th year. The $186 net return equals money saved using the less expensive WELL water @ an average $50/ac-ft and district water at $160/ac-ft.

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 $367/ac savings using Well water compared to Aqueduct water. But the Well water also added an additional 92,000 lbs/ac of salt (1.06% 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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