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

2006 Progress Report for the California Pistachio Commission
December 15, 2006

AUTHOR LISTING:

Blake Sanden – Irrigation and Agronomy Advisor, UCCE Kern County
1031 S. Mt. Vernon Ave.
Bakersfield, CA 93307
Phone: (661) 868-6218 Fax: (661) 868-6208 blsanden@ucdavis.edu
http://cekern.ucdavis.edu

Louise Ferguson – UCCE Pomology Specialist, Kearney Ag. Center
9240 S. Riverbend Ave.
Parlier CA, 93648
Phone: (559) 646-6541 Fax: (559) 646-6593 louise@uckac.edu
http://pom.ucdavis.edu/

Craig Kallsen – Subtropical Crops and Pistachio Advisor, UCCE Kern County
1031 S. Mt. Vernon Ave.
Bakersfield, CA 93307
Phone: (661) 868-6218 Fax: (661) 868-6208 cekallsen@ucdavis.edu
http://cekern.ucdavis.edu

Brian Marsh – Agronomy Farm Advisor, UCCE Kern County
1031 S. Mt. Vernon Ave.
Bakersfield, CA 93307
Phone: (661) 868-6218 Fax: (661) 868-6208 brmarsh@ucdavis.edu
http://cekern.ucdavis.edu, http://danrrec.ucdavis.edu/shafter/home_page.html

Bob Hutmacher – UCCE/AES Cotton Specialist, Shafter Research & Extension Center
17053 Shafter Ave.
Shafter CA, 93263
Phone: (661) 746-8020 Fax: (661) 746-1619 rbhutmacher@ucdavis.edu
http://danrrec.ucdavis.edu/shafter/home_page.html

Special Collaboration, ECa Survey:
Dennis Corwin – Soil & Environmental Scientist USDA George E. Brown, Jr. Salinity Laboratory
450 West Big Springs Road
Riverside, CA 92507-4617
Phone: 909-369-4819 Fax: 909-342-4962 dcorwin@ussl.ars.usda.gov
http://www.ussl.ars.usda.gov/

Research Staff:

Michael Mauro, Lab Assistant II

SUMMARY

Cotton has long been known as a salt tolerant crop, but despite many small-scale field trials over 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. Work in Iran, salt tank studies at the USDA Salinity Lab, Riverside, and a small plot study in NW Kern County indicate pistachios may tolerate an ECe up to 8 dS/m, but this has not been proven on a commercial scale in CA.

This project utilizes twelve, 19.5 acre test plots arranged in a randomized complete block design set within two 155 acre fields to provide a realistic production environment to demonstrate the economic viability of using marginally saline water for cotton production and development of a new pistachio orchard. These blocks of well-drained Panoche clay loam were formerly irrigated with California Aqueduct water and sprinklers for the last 30 years. Overall field EC's ranged from 0.5 to 4.5, averaging 1.57 dS/m to a three 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 (as measured by electroconductivity, EC) of the shallow groundwater for test fields varies from 4 to 5 dS/m (1 dS/m ~ 640 mg/l) with 8 to 10 ppm boron (B). Three treatments were imposed: AQUEDUCT/CONTROL: EC ~ 0.4 dS/m (Aqueduct water only), BLEND: EC ~ 3 dS/m (50/50 mix) and WELL: EC ~ 5 dS/m. Chloride (Cl) content in late season cotton petioles and average seasonal soil water content were significantly higher in the WELL treatment compared to the Control. Saturation extract EC and B in the top three feet of rootzone increase significantly in the BLEND and WELL treatments over the Control by the end of the season, with a significant increase in Cl to 5 feet. Total measured salt increase (as EC) to a depth of 5 feet for 2004 was 176, 69.1 and 77.8% of the mass applied in the irrigation water for the Control, BLEND and WELL treatments, respectively. Cl increased by 287, 92.9 and 84.4% of the mass applied for the same respective treatments. Alternatively, most of the B added in the WELL treatment becomes fixed in the soil – becoming insoluble under the drip irrigation regime. Average pima cotton lint yield has varied from 2 to 4 bale/ac, depending on the year; showing no salinity impacts on yield for the 2004 and 2005 crops. However, 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 has been 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 have a full set of Kerman scaffolds by the end of 2006. However, UCB rootstocks are significantly larger than the PG1 rootstocks. Shoot length is the same at about 31 inches.

After three seasons of cotton irrigation this program results 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 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. The current trial is scheduled to run through 2008. Cotton will be grown one more season (2007) and, with the continued help of the CA Pistachio Commission, the pistachios will be monitored at least until 10 years of age (2014).

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.

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.

PROCEEDURES

SITE: Located in the Belridge Water District in southwestern Kern County, soils are primarily Panoche clay loam and have been planted to a cotton/alfalfa/fallow rotation for more than 20 years and irrigated with California Aqueduct water and hand-move sprinklers. Drainage is excellent with a marginally saline aquifer of 4 to 5 dS/m starting at a depth of 50 feet below the ground surface and going down to 500 to 600 feet. Seven ag wells, each producing 1,200 to 2,000 gpm, were drilled between fall 2002 and fall 2003. The grower has installed shallow subsurface drip tape on six quarter sections, with plans for another 6 to follow. Drip tape has been installed at spacings that allow for the interplanting of cotton and pistachios. The project site for this study consists of two adjacent quarter sections (9-1 and 9-3) containing three treatments replicated four times, divided into a Randomized Complete Block Design as illustrated by Figure 1.

IRRIGATION SYSTEM and CROPPING PATTERN: 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. 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.

In 2004 the entire field was planted to pima cotton and irrigated up from 3/11-25 (variety, Delta Pine 340). The average application rate of the six hoses over the 22 foot spacing was 1.76 inches/day. In

2005, Pioneer Gold rootstocks were planted March 5-11 at an18 x 22 foot spacing. Blocks of 20 UCB rootstocks were planted adjacent to the replicated PG trees at all monitoring sites to allow for evaluation of differential vigor/salt impacts from a rootstock interaction. Four, 38 inch rows of DP340 pima cotton were interplanted and irrigated up between March 25 and April 15. At this spacing the cotton receives 1.99 inches/day and the pistachios receive 0.57 inches/day from the two adjacent hoses. All pistachio trees were budded with Kerman buds from August 12-19.

TREATMENTS: Aqueduct water (a 6 to 9 inch depth) was used for the cotton germination irrigation and for "heeling in" pistachio rootstocks for optimal stand establishment in all subunits. Subsequent irrigation was applied in 24 hour sets as required over the season using the following treatments with four replications (Figure 1):

AQUEDUCT/CONTROL: Aqueduct water only EC ~ 0.4 dS/m
BLEND: 50/50 mix of Aque and WELL EC ~ 2.5-4.0 dS/m
WELL: Shallow groundwater only EC ~ 5.5 dS/m
(Note: Well water salinity and flow fluctuate slightly.)

MONITORING and ANALYSIS: 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 UCDavis 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.

Seedbed salinity: 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.

GIS / ECa / Aerial survey: Both fields were surveyed for EC_a 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. These two surveys will be repeated at the end of the trial.

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 ($LSD_{0.05}$) 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

Irrigation water quality and system performance: Average EC (dS/m), SAR and B (ppm) for the 2004 season were, respectively, 4.5, 5 and 10.2 for the WELL treatment, 3.0, 4 and 5.7 for the BLEND and 0.41, 2 and 0.2 for the AQUEDUCT treatment. The EC of grab samples of well water varied from a low of 4.04 to a high 5.69 dS/m. Irrigation system application distribution uniformity (DU) was 95.6 % for an evaluation on 9/7/04. Two more evaluations were conducted on 7/16/05 and 8/29/05. Out of 36 emitters unearthed for the test (different locations from 2004) one was found to be plugged – either by silt in the hose or a manufacturing defect. Root intrusion was not a problem. Final DU was 94.2% without the plugged emitter, 85.1% when included. It is doubtful that 3% of the emitters in the field are plugged. The average application from the catch test was 2.32 inches/day for a 38" row spacing. This is 15% higher than the manufacturer's specifications, but may be an artifact of errors in the evaluation. The average tape flowrate measured by the small flowmeters serving one of the hoses in the manifolds that were evaluated was 1.91 inches/day. These same meters recorded most irrigation applications of 1.9 to 2.1 inches/day throughout the season.

Water use and salt load (Table 1): Due to early variability in subunit regulator pressures, 6.1 to 8.4 inches of Aqueduct water were used to establish the cotton at the start of the 2004 season. The young cotton plants were well established by April 1, after which time only the appropriate treatment water was applied; for a total of 32 (+/-0.5) inches for the season. Using the Belridge CIMIS station estimate of ETo and published crop coefficients (Pruitt, et al., 1987) the calculated ET for the 2004 season was 38.2 inches. Neutron backscatter estimates of soil moisture for the AQUEDUCT treatment measured an additional 3 inches of depletion beyond the total applied irrigation for the season; exhausting all available soil moisture to 6 feet by the end of the season. For the BLEND there was 10% (1.2 inch) available water remaining and 44% (5.3 inch) remaining in the WELL treatment at the end of the season. The whole season average available soil water content to 6 feet (from weekly measurements) in the AQUEDUCT and BLEND treatments was significantly less than the WELL at 68, 70 and 95%, respectively; indicating the increased osmotic potential of the WELL water restricted ET. Figure 2 confirms this finding as the changes in soil matric potential are less dynamic and less negative as salinity increases.

The increase in average soil saturation extract EC to 5 feet was used to calculate the increase in the mass of soluble salts remaining in the profile at the end of the season (using 640 ppm = 1 dS/m EC and an average soil extract saturation percentage, SP = 40.7%). This number divided by the mass of salts applied in the respective irrigation water treatments provides an indication of irrigation efficiency. This increase, expressed as a percentage, was 175, 69 and 78% for the AQUEDUCT, BLEND and WELL treatments, respectively. A more accurate estimate of the leaching can be obtained from the chloride mass balance. Again expressed as a percentage of the increase over applied this number was 287, 92.9 and 84.4% for the AQUEDUCT, BLEND and WELL treatments, respectively (Table 1); meaning that the leaching fraction (LF) was 0% for the AQUEDUCT treatment, 7.1% for the BLEND and 15.6% for the WELL. While there is no logical way to explain where the large excess of Cl came from for the AQUEDUCT treatment (other than sampling error) these ratios support the general trends shown in the water content and matric potential data. Indeed, an analysis of projected steady state salinity of the cotton rootzone using a Windows-based WATSUIT model (Wu, 2004 and Oster and Rhodes, 1990) calculated a steady-state average soil water EC of 1.91 dS/m @ a 5% LF for the AQUEDUCT treatment. Using the average SP of 40.7% reduces this number to 0.78 dS/m saturation extract salinity (EC_e); far less than the 2.71 dS/m EC_e found at the end of the season. The same calculation for the BLEND with a 10% LF yields a final average EC_e of 3.15 dS/m and for the WELL treatment, a 20% LF resulted in a final calculated average EC_e of 4.63 dS/m. These model numbers corroborate the field findings and the above estimates of LF determined for the end of the 2004 season.

Seedbed salinity: Table 2 shows average saturation extract EC and boron concentrations at the beginning and end of the 2004 season, and then for the beginning of the 2005 season. The critical issue at stake is to insure a seedbed salinity suitable for establishing the young cotton seedlings. Spring 2005 was much colder than 2004. Because of this the decision was made to apply 4.5 to 5 inches of Aqueduct water from 2/25 – 3/10 to wet the soil to both mellow the seed bed, store more heat in the beds and to add to about 1.5 inches of effective rainfall in January and February to maximize leaching of salts out of the beds. This caused a two week delay in planting cotton with final true "establishment" of seedlings delayed about one month until April 25, and a total application of Aqueduct water of 9.3, 7.7 and 9.0 inches for the AQUEDUCT, BLEND and WELL, respectively. The final result was a two- to three-fold decrease in seedbed EC_e, depending on the treatment, compared to the end of the 2004 season to an average of 2.79 dS/m in the 0-6 inch depth for all treatments – a very acceptable salinity level for the germination of cotton. Figure 3 on the other hand, indicates that salinity levels were much higher in some specific locations. (Contours generated from data from one bed per treatment only.) According to these data, the EC_e in the 0-2 inch (0-0.5m) depth runs about 6 dS/m in the seed row and about 4 dS/m for the 0-6 inch depth. The replicated data in Table 2 is more representative as stand establishment did not appear to suffer from salinity treatments, but was overall less dense than 2004 due to the incidence of seedling diseases brought on by the cold weather. It should be noted, however, that salts appear concentrated to the right side of the graphs for all three treatments. This was the south side of the bed with the greatest sun exposure and, hence, evaporation and movement of salts toward the surface. Saturation extract B concentration ranged from 0.9 to 3.7 ppm in the top 2 inches.

Plant characteristics and yield: For 2004, Table 3 shows that plant height trended taller for the AQUEDUCT treatment but was not statistically different. Only Cl levels in the petioles sampled 8/27 were significantly elevated in the BLEND and WELL treatments over the AQUEDUCT. There was no difference in Na or B. Nor was there any difference in fiber quality or lint yield among treatments. Average lint yield was 1,718 lb/ac for the total acreage. Calculated on planted acreage only, the average yield was 1,959 lb/ac with the WELL treatment yielding highest @ 4.03 bales/ac.

Except for the last 3 weeks of the season for the BLEND, biweekly treatment leaf water potentials were greater (less negative) than -18 bars and averaged around -15 bars for most of the season (Figure 4), indicating that the cotton was able to grow without any significant stress. There was no significant difference between treatments.

For the 2005 season, there have been no observed toxicity symptoms or differential stress to either cotton or pistachios related to any treatment and all cotton yields were low (Table 3). In 2006, however, a significant decline was seen in cotton emergence in the WELL and BLEND treatments compared to the AQUEDUCT, resulting in marginal stand densities of 29,288, 31,982 and 33,414 plants/acre and the WELL treatment lost ½ bale/ac compared to the AQUEDUCT (3.12 and 3.68 bale/ac, respectively). No real correlation was seen between cotton lint yield, and aerial imagery using Normalized Difference Vegetation Index (NDVI, Figure 5). B concentration in pistachio tissues is two and three times that of the AQUEDUCT in the BLEND and WELL treatments, respectively, but apparently tolerable to the pistachio at nearly 700 ppm. More marginal burn was seen on Kerman leaves by the end of 2006 in the WELL treatment, but was also seen in some trees in the AQUEDUCT. However, neither rootstock circumference or Kerman shoot length was affected by salinity (Figure 6). UCB trunk circumference continues to be significantly greater than PG1, but full scaffold development is superior on PG1 compared to UCB (Figure 6). This has nothing to do with salinity, but soley due to poor bud take in the UCB trees in 2005.

Electromagnetic conductance (EC_a): Transects of EM38 readings were taken in an effort to calibrate EC_a estimates to actual soil EC_e. For field 9-1 a total of 11,521 horizontal and vertical EM readings were acquired across 89 transects. The field average vertical and horizontal readings were 61.0 and 40.3 mS/m, with standard deviations of 11.6 and 6.2 mS/m, respectively. The minimum to maximum observed readings were 28.9 to 102.9 for the vertical and 20.5 to 61.0 for the horizontal. Both signal data distributions appeared to be approximately symmetric. The horizontal / vertical signal correlation was 0.695. For field 9-3, a total of 13,409 horizontal and vertical EM readings were acquired across 86 transects. The field average vertical and horizontal readings in field 9-3 were 56.8 and 41.8 mS/m, with standard deviations of 8.8 and 5.6 mS/m, respectively. The minimum to maximum observed readings were 36.5 to 89.3 for the vertical and 24.4 to 64.6 for the horizontal. Both signal data distributions appeared to be slightly right-skewed. The horizontal / vertical signal correlation was 0.749. The relatively low EM average levels and lower than normal signal correlation show that both fields are well reclaimed and basically non-saline, and that the spatial EM signal pattern may have been significantly influenced by within-field textural and/or water content variation.

Thirty-six soil samples (identified by GPS coordinates to represent the random variability of salinity in the field as determined by the EM38) were collected in 30 cm increments to a depth of 1.2 meters for both fields in between the two drip hoses. Saturation extract salinity (ECe, dS/m) and Boron (ppm) measurements were performed on each soil sample, with reported accuracies of 0.01 (ECe) and 0.1 (Boron), respectively. Duplicate samples were also acquired at six locations so that the local scale variation in these two soil properties could be quantified. A few sample sites were excluded from the final analysis due to missing data and two outliers with extremely high EC. Values for other missing data observations were estimated using a regression-based expectation algorithm (i.e., missing data for a specific depth were estimated using the measured data in adjacent depths). The depth-specific average ECe ranged from 1.44 to 2.67 dS/m for field 9-1 and from 2.00 to 2.64 dS/m for 9-3. The maximum ECe readings over the four sampling depths for both fields ranged from 3.5 to 7.2 dS/m.

The optimal regression model structures for each field were found by performing a standard jack-knifing analysis (Lesch et al., 2005). The best model was deemed to be the model exhibiting the smallest jack-knifed prediction error. In field 9-1 this regression model included both EM signal readings and a second order trend surface equation. Table 4 shows that the correlation of EM readings with ECe was marginal for the 0 to 2 foot depths (likely due to greater differences in water content and soil structure), but highly significant for the 2 to 4 foot depths and the overall 0 to 4 foot average ECe. Thus, the predicted values of ECe for a given site agreed well with the actual sample means. Figure 7 compares the ECa readings with the regression model bulk ECe for field 9-1. Regression modeling of 9-3 produced statistically significant correlations for the same depths as field 9-1, however, R^2 values were 0.32 or less and deemed unsuitable for accurate bulk mapping, but still suitable for describing general field salinity. The corresponding range interval estimates suggest that both fields exhibit both non-saline (ECe < 2 dS/m) and mildly-saline ($2 <$ ECe < 4 dS/m) areas. With respect to the bulk average (0-120 cm) estimates, about 47.8% of the soil in field 9-1 can be classified as non-saline and 50.5% mildly-saline. In field 9-3, 35.7% would be classified as non-saline and 63.4% as mildly-saline.

The lack of a strong salinity / conductivity correlation in either field is disappointing, but perhaps not that surprising given the sample duplication variability estimates. In general, the root MSE of the optimal regression model can not be any smaller than the micro-scale salinity (site duplication) variation, which was 0.76 and 0.96 dS/m for fields 9-1 and 9-3, respectively. This level of variability is statistically equivalent to the 0-30, 30-60, and 60-90 cm root MSE estimates in the regression models. From this perspective, one would not expect to find a strong correlation. Finally, in both fields the EM survey data may have been strongly influenced by spatial texture and/or water content variations. Incorporation of laboratory SP (saturation percentage) and/or gravimetric water content readings into the regression model could greatly improve the correlation with bulk ECe (Lesch & Corwin, 2003). Some water content data is available but has not yet been incorporated into the model.

Aerial imagery/spectral analysis: Two-way analysis of variance of the relative intensity of long-wave (thermal) infrared radiation (IR) and the Normalized Difference Vegetation Index (NDVI) on 7/29/04 showed no significant difference between treatments. The relative mean canopy temperature (Figure 8) was 96.6% of the field average for the AQUEDUCT treatment, 97.9% for the BLEND and 105.5% for the WELL. The NDVI (Figure 9), which has a maximum range of -1 to +1, was 0.751 for the AQUEDUCT, 0.734 for the BLEND and 0.716 for the WELL treatment. Correlation analysis of plot values of NDVI with the EMv values generated with the EM38 probe for the same plots yielded a weak R^2 of only 0.414 and only 0.352 for correlation of NDVI and 2004 lint yield and a -0.245 for the 2006 lint yield. Figure 10 is the enhanced NDVI image for 8/14/06 clearly showing fhe rows of two year old pistachios. Figure 11 is the gray scale image and grids used to process the analysis, which yielded similar values to 2004 of 0.734 for the AQUEDUCT, 0.727 for the BLEND and 0.707 for the WELL treatment.

CONCLUSIONS and PRACTICAL APPLICATIONS

Season-long irrigation with saline water @ 5.5 dS/m significantly increased average rootzone salinity by nearly two to three-fold above that of fresh water to 4.7 to 7 dS/m ECe. This level is still well below the threshold tolerance of cotton and, as expected, produced no measurable adverse impacts on the crop. ET in the WELL treatment was reduced by 15.6% by Cl mass balance. Eight to nine inches of fresh water in the spring of 2005, delivered through drip tape buried at a depth of 9 inches, was sufficient to leach salts below the seedbed, recharge depleted soil moisture to 5 feet and establish the second year cotton crop as well as newly planted pistachio rootstocks. No adverse treatment impacts to either the second year cotton crop or pistachios has been seen as of the end of August 2005. In 2006, sufficient leaching was achieved with winter irrigation in the deeper rootzone but excess salinity in the upper cotton seedbed decreased the stand density in the WELL treatment. 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 have a full set of Kerman scaffolds by the end of 2006. However, UCB rootstocks are significantly larger than the PG1 rootstocks. Shoot length is the same at about 31 inches. After three seasons of cotton irrigation this program results in about 6,600 lb/ac applied salt in the Aqueduct treatment and about 54,000 lb/ac in the Well treatment (Table 1). Cotton and pistachio tissues 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. The current trial is scheduled to run through 2008. Cotton will be grown one more season (2007).

To this one grower, the eventual savings in water costs will be about $120/acre for mature tree ET. This equals $37,000/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. At this writing there are about 4,000 additional acres of pistachios planted or scheduled for 2007 in Buttonwillow and NW Kern County on saline ground with marginal well water that would not have been developed three 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. 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

I owe a tremendous debt to Starrh & Starrh farming for their vision, cooperation and willingness to entrust a large-scale orchard development to my recommendations and testing.

LITERATURE CITED

Ayars, J.E., R.B. Hutmacher, R.A. Schoneman, S.S. Vail, T. Pflaum. 1993. Long term use of saline water for irrigation. Irrigation Science 14(1):27-34.

Ayers, R.S. and D.W. Westcott. 1985. Water quality for agriculture. United Nations FAO Irrig & Drainage Paper No. 29, Rev.1.

CalFed. 2000. *CALFED Water Use Efficiency, DRAFT Details of Quantifiable Objectives*. Calif. Dept. of Water Resources, http://calwater.ca.gov/Archives/WaterUseEfficiency/adobe_pdf/qo_appendixA_19.pdf.

Fardooel, A.R. 2001. Evaluation of salt and drought resistance of two pistachio species (Pistacia chin-up and P. musica) in terms of growth and ecophysiological characteristics. Ph.D. dissertation. University of Ghent, Belgium.

Ferguson, L., B. Sanden, S. Grattan, 2003. Salinity tolerance of pistachio rootstocks. Annual Report, UC Salinity/Drainage Program Water Resources Center and Prosser Trust, 2002-2003, pp. 13-27.

Ferguson, L., P.A. Poss, S.R. Grattan, C.M. Grieve, D. Want, C. Wilson, T.J. Donovan and C. T. Chao. 2002. Pistachio rootstocks influence scion growth and ion relations under salinity and boron stress. J. Amer. Soc. Hort. Sci. 127(2):Pp.194-1999.

Fulton, A.E., J.D. Oster, B.R. Hanson, C.J. Phene, and D.A. Goldhamer. 1991. Reducing drainwater: Furrow vs. subsurface drip irrigation. California Agriculture 45(2):4-7, March/April 1991.

Grattan, S., C. Grieve, J. Poss, D. Suarez. 2003. Does saline drainwater affect crop tolerance to boron. Annual Report, UC Salinity/Drainage Program Water Resources Center and Prosser Trust, 2002-2003, pp. 58-69.

Lesch, S.M. and Corwin, D.L. 2003. Predicting EM / soil property correlation estimates via the Dual Pathway Parallel Conductance model. Agron J. 95:365-379.

Lesch, S.M., Corwin, D.L., and Robinson, D.A. 2005. Apparent soil electrical conductivity mapping as an agricultural management tool in arid zone soils. Com. & Electron. in Ag. 46, 351-378.

Oster, J.D., and J.D. Rhoades. 1990. Steady-state rootzone salt balance . K.K. Tanji (ed), Agricultural Salinity Assessment and Management. ASCE Manuals and Reports on Engineering Practice No. 71. ASCE, New York. pp 469-481.

Pruitt, W.O., Fereres, E., Kaita, K. and Snyder, R.L. 1987. Reference Evapotranspiration (ETo) for California. UC Bulletin 1922.

Sanden, B.L., L. Ferguson, H.C. Reyes, and S.C. Grattan. 2004. Effect of salinity on evapotranspiration and yield of San Joaquin Valley pistachios. Proceedings of the IVth International Symposium on Irrigation of Horticultural Crops, Acta Horticulturae 664:583-589.

Shennan, C., S.R. Grattan, D. M. May, C. J. Hillhouse, D. P. Schactman, M. Wander, B. Roberts, S. Tafoya, R. G. Burau, and L. Zelinski. 1995. Feasibility of cyclic reuse of saline drainage in a tomato-cotton rotation. J. Environ. Qual. 24 (3):476-486.

Wu, L. 2004. Windows-based water suitability determination model (WATSUIT). Univ. CA, Riverside. http://envisci.ucr.edu/index.php?file=faculty/wu/wu.html

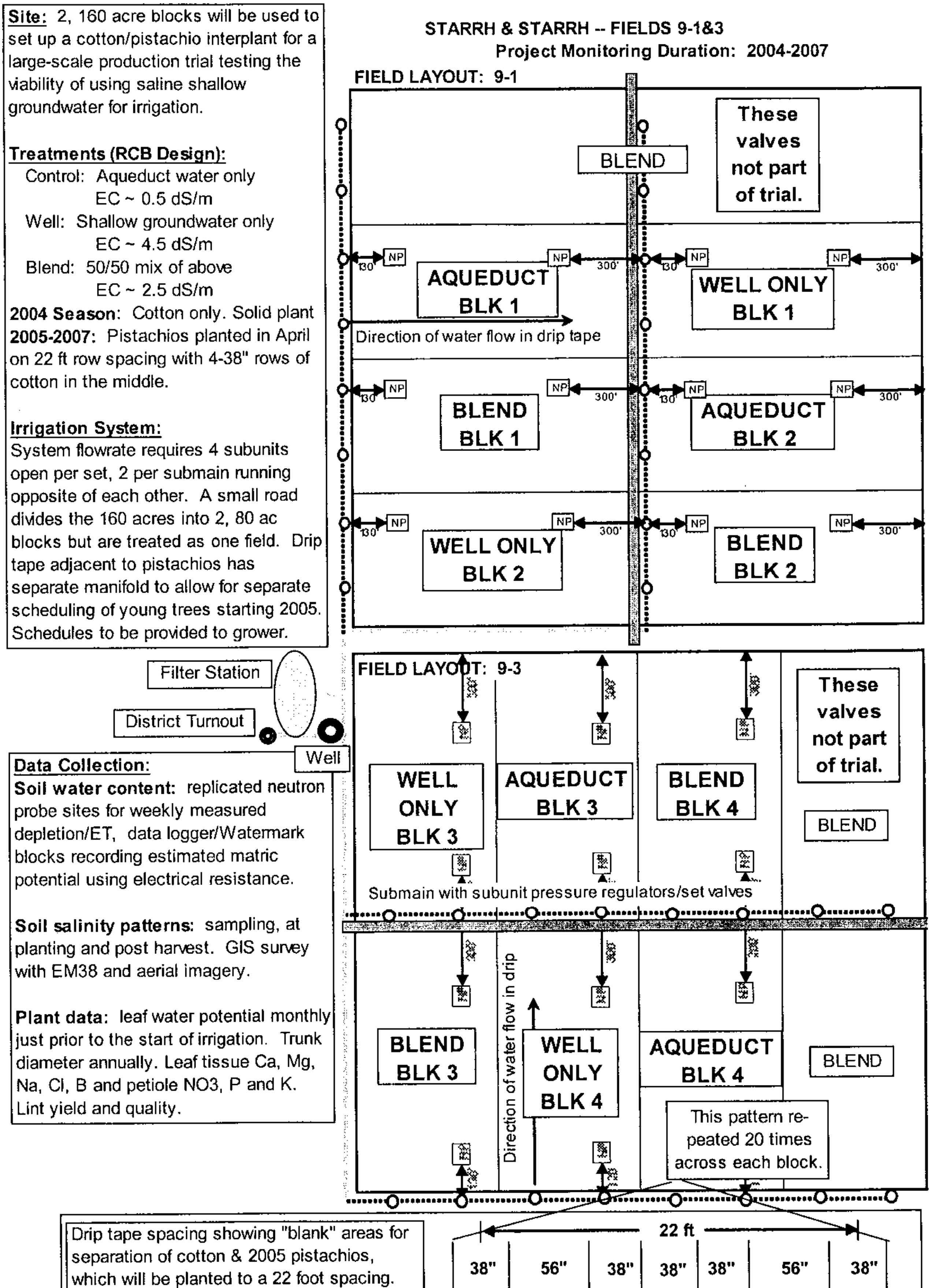


Fig. 1. Project site design.

Table 1. Applied water, mean soil water content/matric potential, rootzone EC and salt balances for the 2004 season.

Treat-ment	Aqueduct Water to Establish (inch)	Season Total (inch)	[1]Mean Available Water Content (%)	[2]Mean Matric Potential 0-4 foot (cb)	[3]Mean Soil EC to 5 Feet 3/22/04 (dS/m)	Mean Soil EC to 5 Feet 10/6/04 (dS/m)	[4]Total Increase in Soluble Salts (lb/ac)	Total Salts Applied in Irrigation (lb/ac)	Measured Salt Increase / Applied (%)	Measured Chloride Increase / Applied (%)
Aque	7.6	31.5	68%	-37	2.07	2.71	3334	1898	175.7%	287.0%
Blend	8.4	32.2	70%	-33	2.53	*4.08	8075	11680	69.1%	92.9%
Well	6.1	32.3	*95%	*-22	2.10	*4.68	13441	17285	77.8%	84.4%

*Significantly different at the 0.05 level.

[1]To 6 feet as determined by neutron backscatter. Based on a refill water content of 1.1 in/ft and a field capacity of 3.1 in/ft.

[2]As determined by Watermark electrical resistance blocks @ 12, 24 and 48" depths.

[3]Weighted average of the saturation extract EC of four soil samples taken from the following depths 0-6, 6-18, 18-36 and 36-60 inches.

[4]Increased mass of salt = increase in EC*(640ppm/dS/m) * 5 feet * 4 million lbs soil/ft * 0.407, the average SP%.

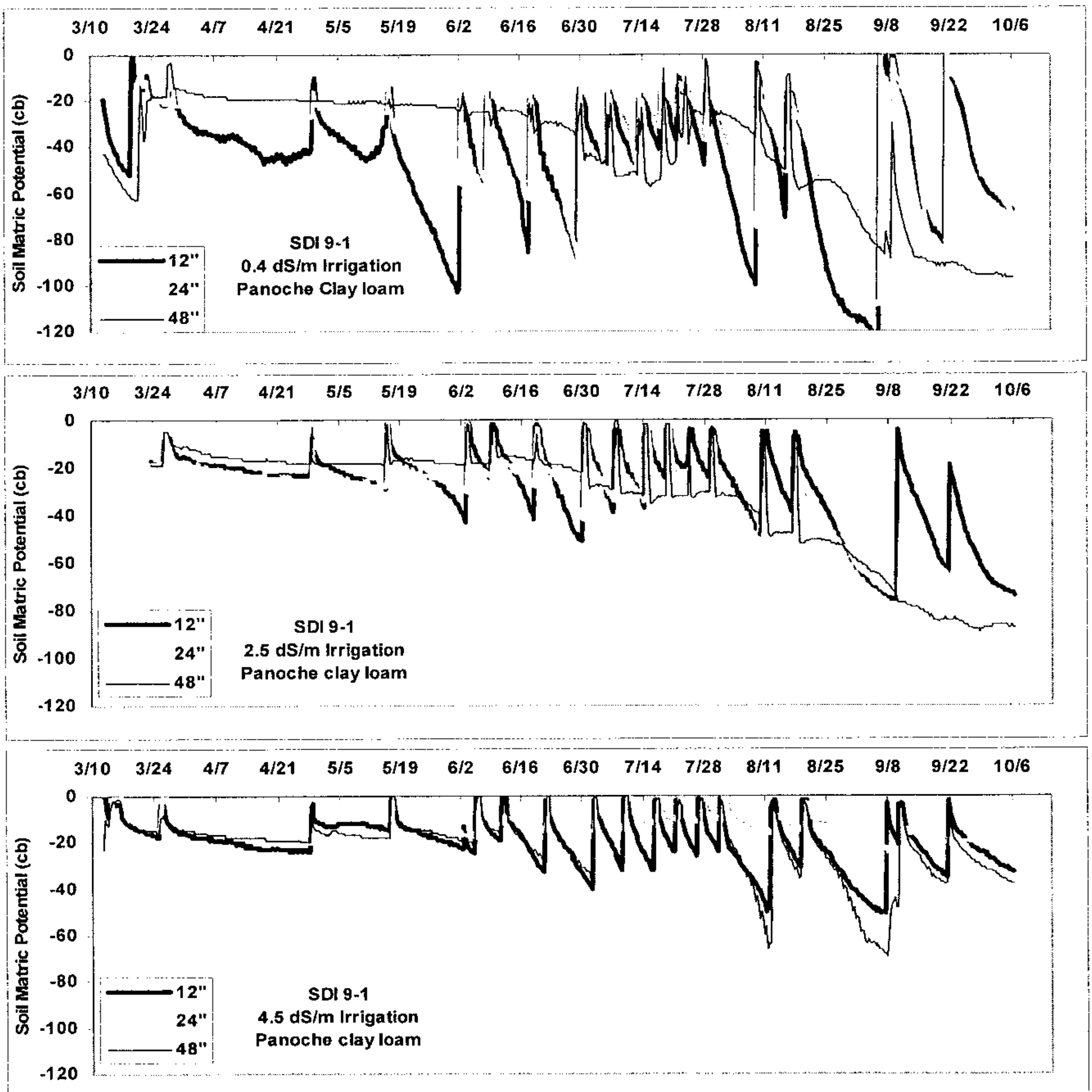


Fig. 2. Changes in soil matric potential over the season for the AQUEDUCT (0.4 dS/m), BLEND (2.5 dS/m) and WELL (4.5 dS/m) irrigation treatments as measured by Watermark® electrical resistance blocks, recorded every 8 hours with a Hanson AM400 logger.

Table 2. Seedbed and rootzone saturation extract EC and B levels by depth for the beginning and end of the 2004 season and the beginning of the 2005 season.

2004 Saturation Extract EC (dS/m)

3/22/04	0-6"	6-18"	18-36"	36-60"
Aque	1.95 ab	1.15 a	2.38 b	2.33 a
Blend	2.33 b	1.60 a	1.01 a	4.18 a
Well	1.81 a	1.00 a	0.94 a	3.58 a
$LSD_{0.05}$	*0.14*	*0.65*	*1.09*	*2.14*
10/6/04	**0-6"**	**6-18"**	**18-36"**	**36-60"**
Aque	4.02 a	1.61 a	1.96 a	3.49 a
Blend	5.73 b	3.12 b	4.13 b	4.1 a
Well	7.61 c	3.64 b	4.18 b	4.83 a
$LSD_{0.05}$	*0.34*	*0.79*	*0.99*	*1.62*
Change	**0-6"**	**6-18"**	**18-36"**	**36-60"**
Aque	2.07 a	0.46 a	-0.42 a	1.16 a
Blend	3.40 b	1.52 ab	3.12 b	-0.08 a
Well	5.80 c	2.64 b	3.24 b	1.25 a
$LSD_{0.05}$	*1.33*	*1.19*	*1.3*	*1.98*

2004 Saturation Extract B (ppm)

3/22/04	0-6"	6-18"	18-36"	36-60"
Aque	0.8 a	0.5 a	1.0 b	1.5 a
Blend	0.8 a	0.5 a	0.4 ab	2.0 a
Well	0.7 a	0.4 a	0.3 a	1.3 a
$LSD_{0.05}$	*0.2*	*0.2*	*0.6*	*1.6*
10/6/04	**0-6"**	**6-18"**	**18-36"**	**36-60"**
Aque	1.1 a	0.6 a	1.0 a	2.9 a
Blend	1.6 a	2.0 b	1.9 a	2.2 a
Well	3.2 b	3.2 c	3.1 b	2.1 a
$LSD_{0.05}$	*1.0*	*0.6*	*1.0*	*2.7*
Change	**0-6"**	**6-18"**	**18-36"**	**36-60"**
Aque	0.3 a	0.1 a	0.1 a	1.4 a
Blend	0.8 a	1.5 b	1.5 b	0.2 a
Well	2.5 b	2.8 c	2.7 c	0.8 a
$LSD_{0.05}$	*1.1*	*0.9*	*1.1*	*2.3*

2005 Saturation Extract EC (dS/m)

4/26/05	0-6"	6-18"	18-36"	36-60"
Aque	2.78 a	2.70 a	1.47 a	1.21 a
Blend	3.21 a	2.88 a	1.96 a	3.07 b
Well	2.39 a	3.23 a	1.65 a	3.49 b
$LSD_{0.05}$	*0.89*	*2.34*	*1.72*	*1.47*

2005 Saturation Extract B (ppm)

4/26/05	0-6"	6-18"	18-36"	36-60"
Aque	0.6 a	0.9 a	0.5 a	1.7
Blend	1.3 ab	1.0 a	1.1 ab	1.6
Well	2.3 b	2.0 a	2.3 b	1.7
$LSD_{0.05}$	*1.1*	*1.84*	*1.69*	*2.82*

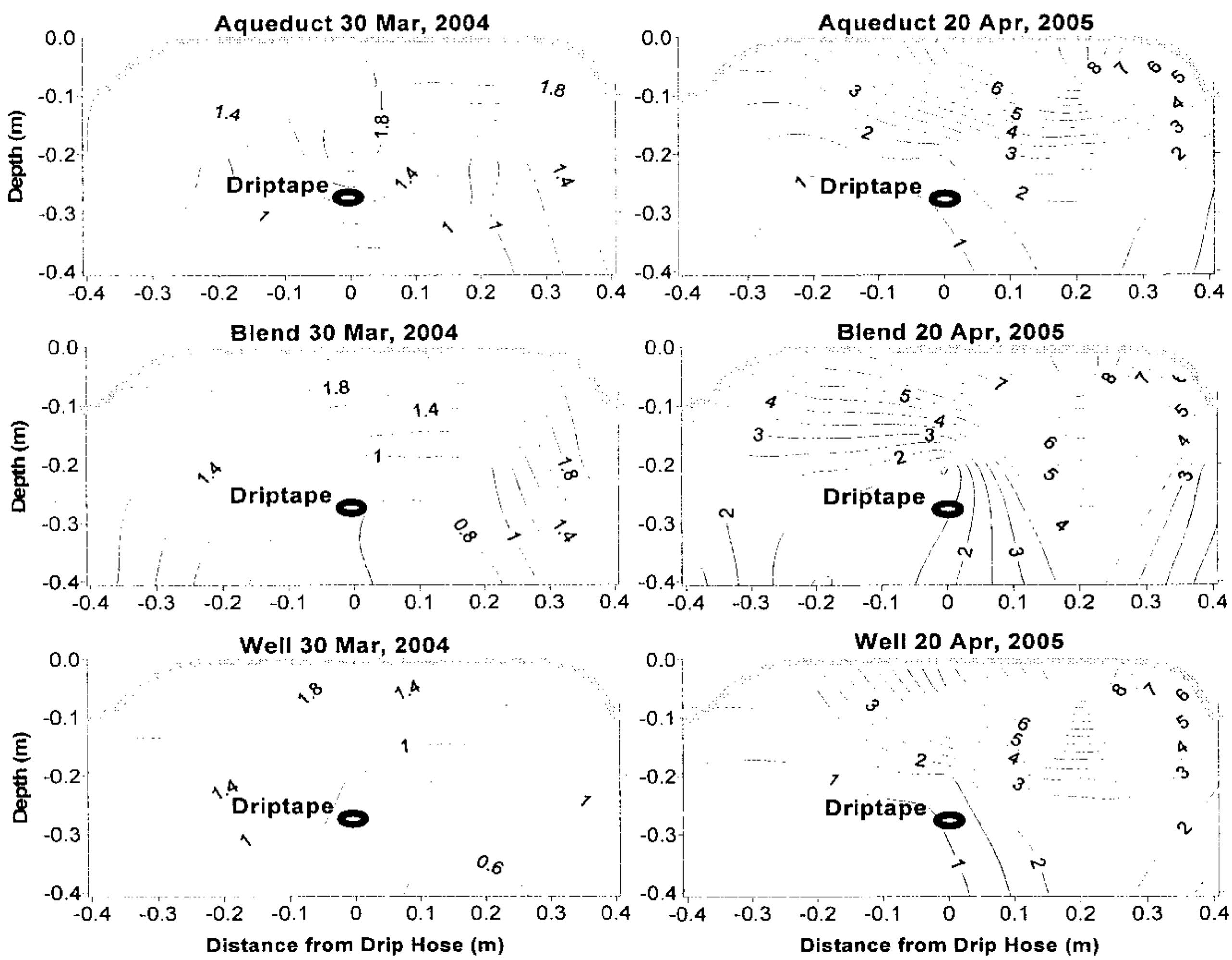


Fig. 3. Contours of seedbed salinity comparing the start of the 2004 and 2005 seasons. Contours generated from composite samples from three different transects across one bed for each treatment.

Table 3. 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)	[1]Cotton Ht, Pistachio Circum (inch)	Cotton Lint Yield (lb/ac)	Total Salts Applied in Irrigation (lb/ac)
	Petioles 8/27/04			**Cotton 2004**				**9/14/04**	**10/6/04**	**Cotton'04**
Aque	170	75	368	1.84	570	2.58	34	42.2	1933	2,343
Blend	273	95	463	1.73	712	**3.23	37	*35.8	1928	11,390
Well	548	108	413	1.72	574	*3.00	37	38.8	2016	21,444
	Petioles 9/15/05			**Cotton 2005**				**9/15/05**	**10/19/05**	**Cotton'05**
Aque	403	53	760	2.06	605	2.71	42	41.6	954	2,305
Blend	158	40	573	1.79	539	*3.13	46	43.1	1129	10,144
Well	288	85	593	1.91	546	**3.38	**50	42.1	999	16,975
	Rootstock Leaves 9/15/05				**Pistachio 2005**			**10/19/05**		**Pistach'05**
Aque	63	160	580	1.02	222	0.27	194	2.31		1,742
Blend	55	128	545	1.06	220	0.27	**492	2.17		8,570
Well	65	148	500	1.08	314	**0.38	**673	2.18		14,782
	Petioles 9/21/06			**Cotton 2006**				**9/21/05**	**10/19/05**	**Cotton'06**
Aque	Lab Data Still Being Processed							41.6	1835	1,967
Blend								43.1	1615	11,046
Well								42.1	*1560	15,832
	Rootstock Leaves 9/21/06				**Pistachio 2006**			**10/19/05**		**Pistach'06**
Aque	Lab Data Still Being Processed							2.58		1,022
Blend								2.55		8,994
Well								2.49		11,104

*Significantly different from Aqueduct @ 0.05, **Significant @ 0.01
[1]Cotton height @ irrigation cuttoff.

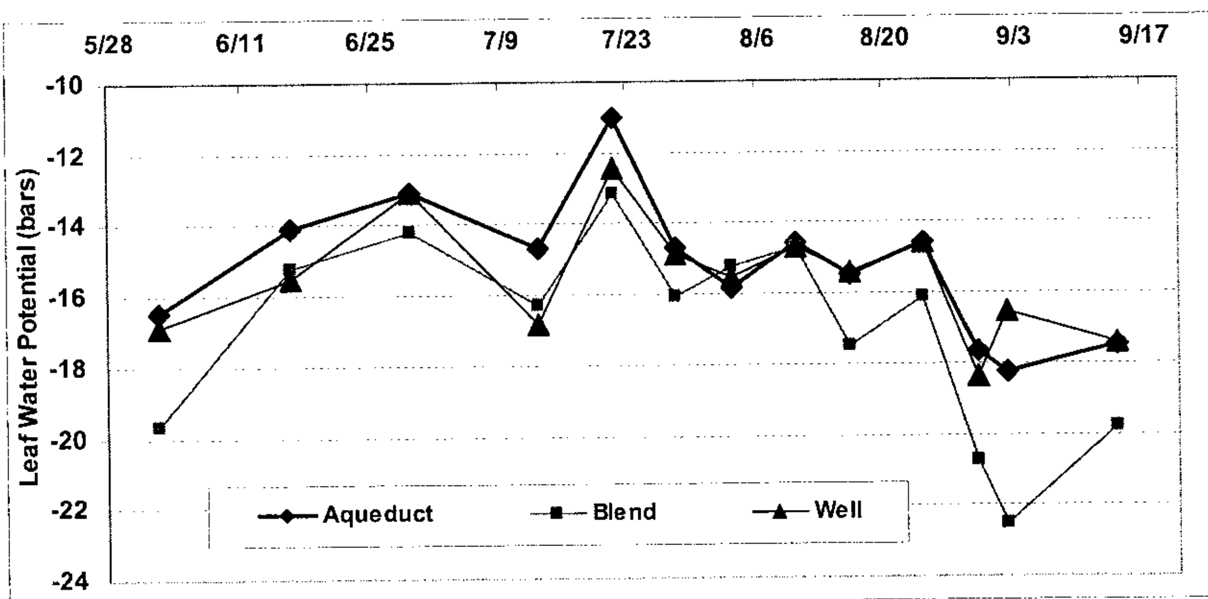


Fig. 4. Biweekly mean leaf water potential for all treatments for the 2004 season.

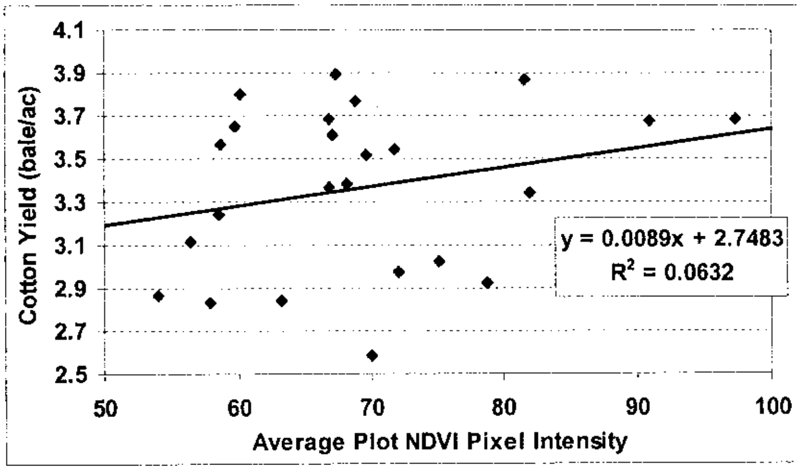
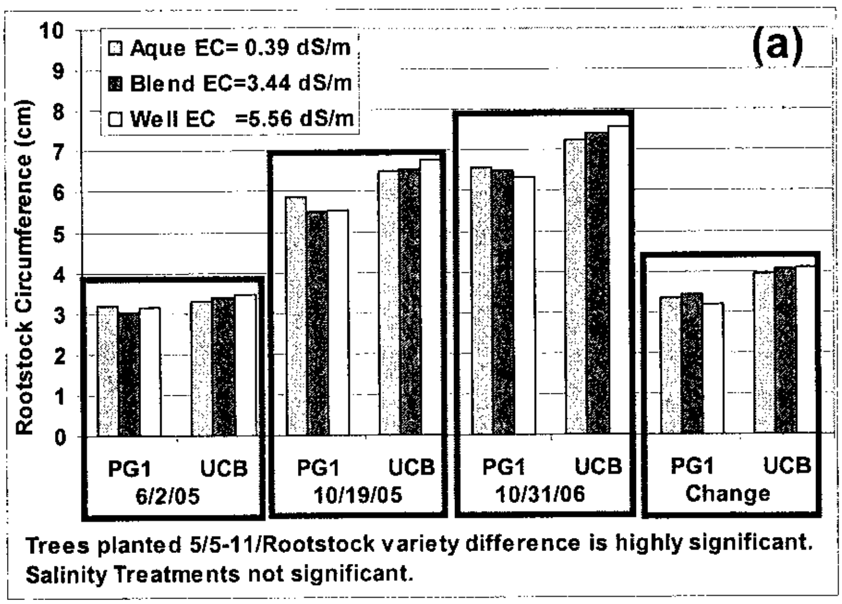


Fig. 5. Correlation of 2004 cotton Normalized Difference Vegetation Index (NDVI) values (7/29/04) and lint yield (10/6/04) and 2006 NDVI (8/14/06) and lint yield 10/27/06.



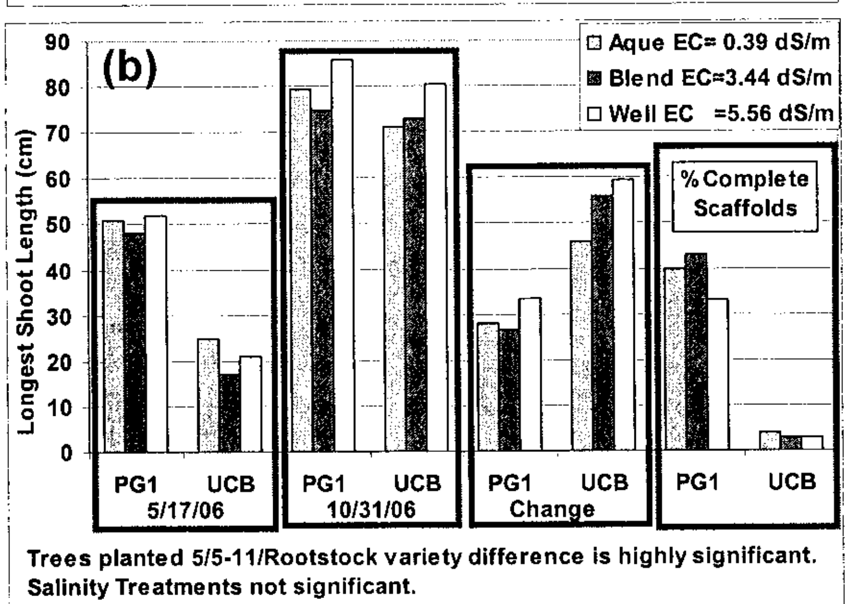


Fig. 6. (a) Comparison of rootstock circumference and (b) Kerman shoot length for 2005 and 2006.

Table 4. Regression model and summary statistics for estimating ECe with EM38 readings for field 9-1

$$ECe = b_0 + b_1(EMv) + b_2(EMh) + b_3(x) + b_4(y) + b_5(xy) + b_6(x^2) + b_7(y^2)$$

Depth	R-square	Root MSE	F-value	Prb > F
0-30	0.268	0.625	1.36	0.265
30-60	0.339	0.530	1.9	0.109
60-90	0.643	0.808	6.69	0.001
90-120	0.582	1.331	5.16	0.001
0-120	**0.630**	**0.553**	**6.31**	**0.001**

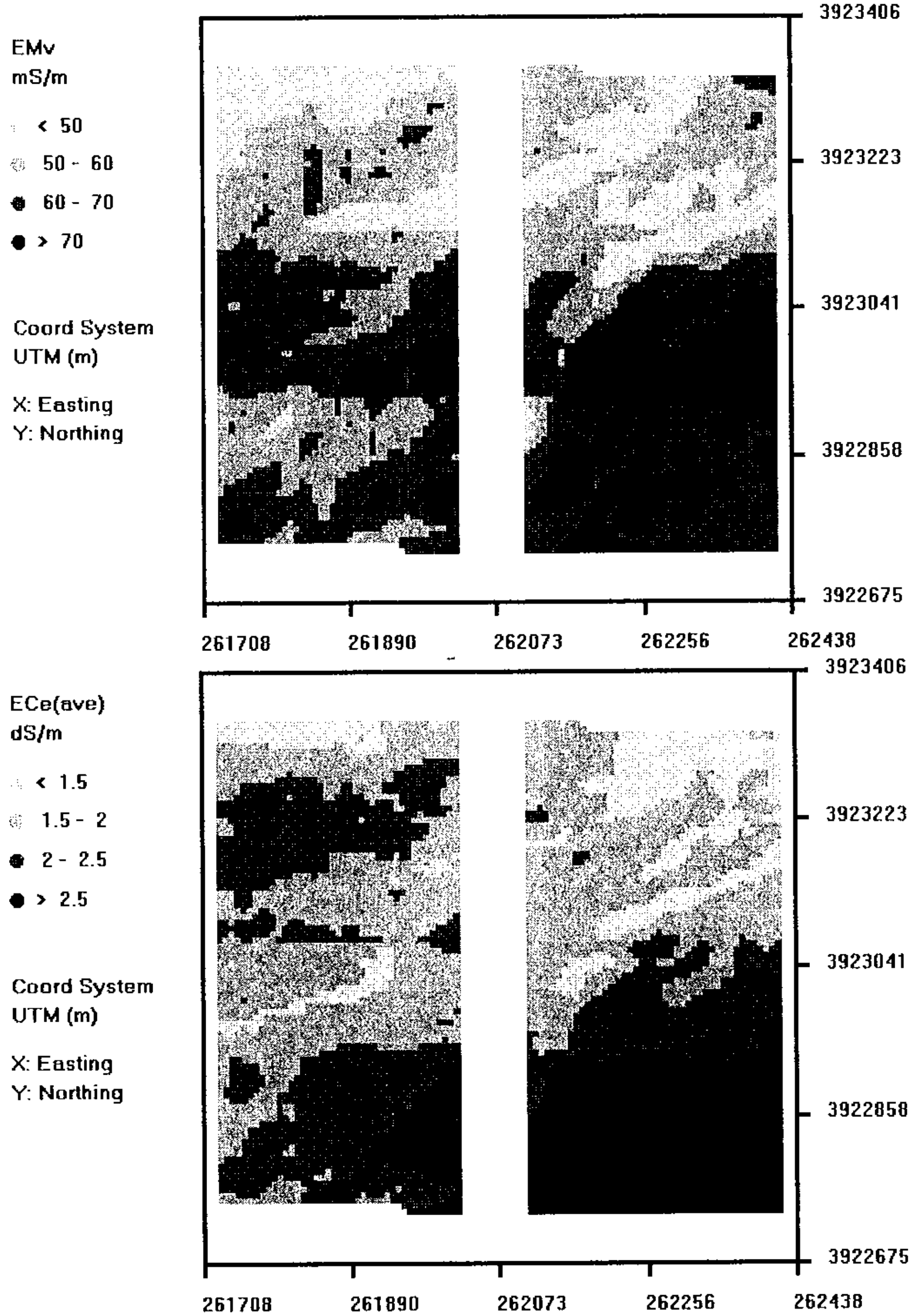


Fig. 7. EM38 readings as ECa (mS/m, above) and calibrated bulk average ECe as estimated by regression model for field 9-1.

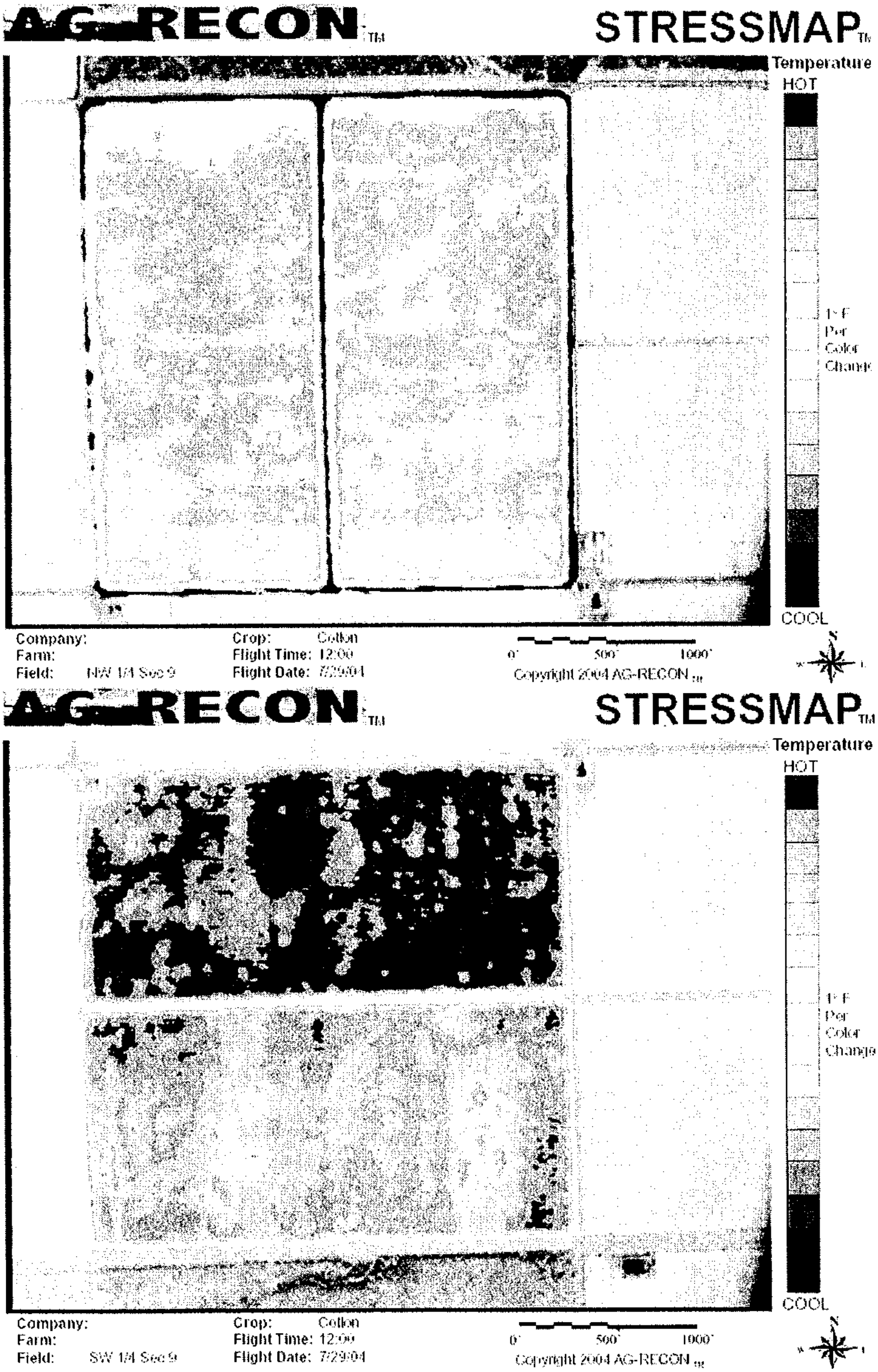


Fig. 8. Color enhanced thermal infrared variation for fields 9-1 and 9-2 on 7/29/04.

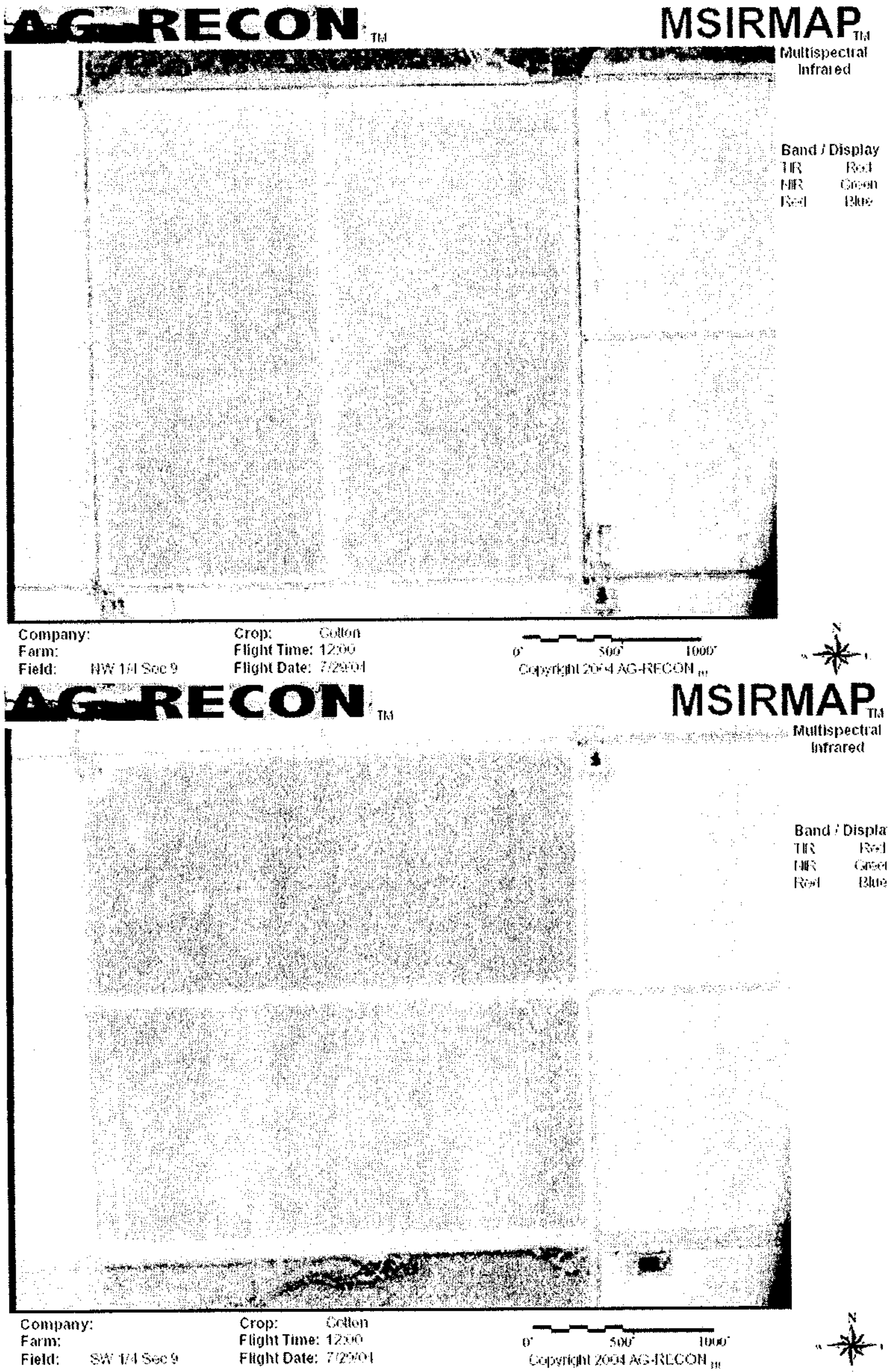
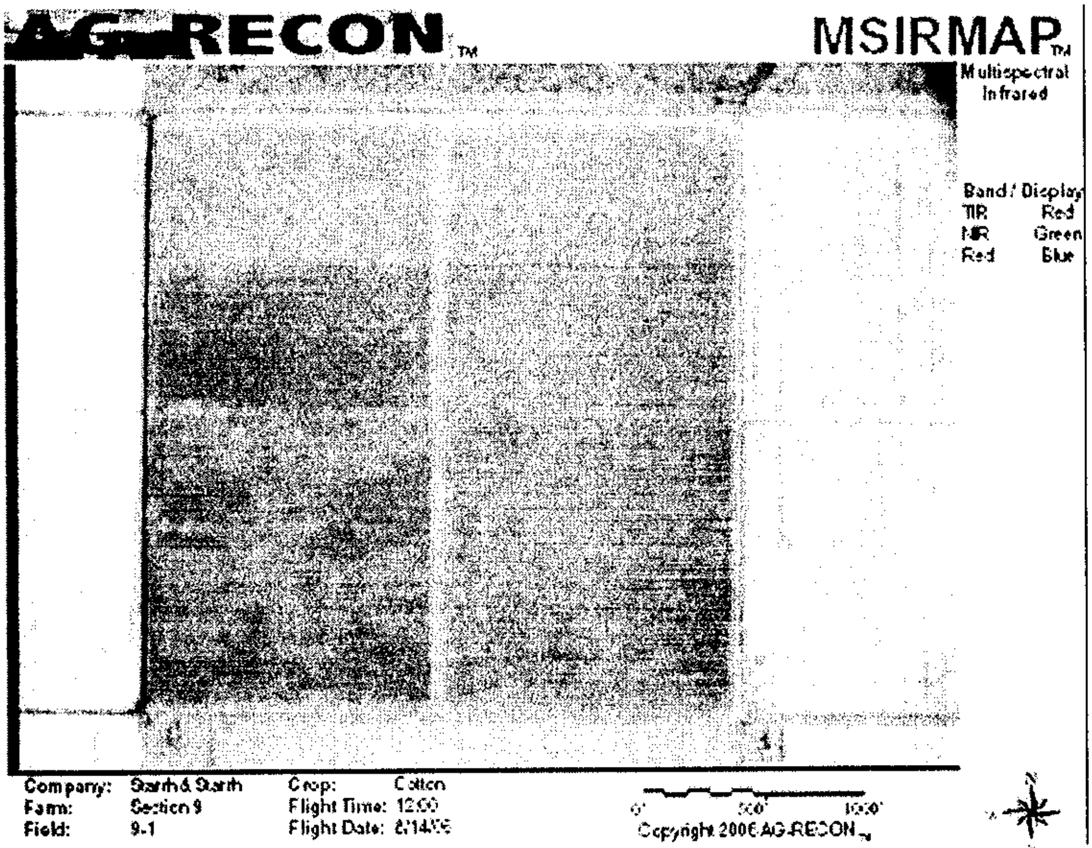


Fig. 9. Color enhanced multispectral NDVI analysis for fields 9-1 and 9-3 on 7/29/04.



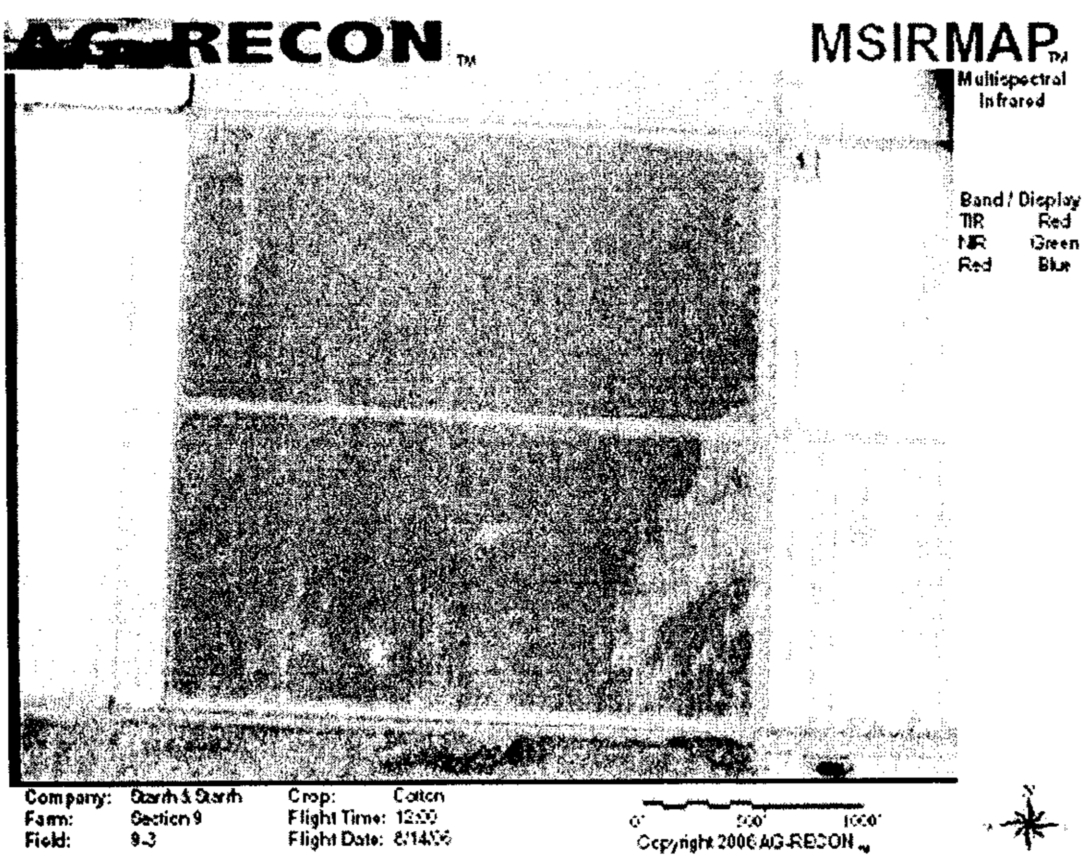


Fig. 10. Color enhanced multispectral NDVI analysis for fields 9-1 and 9-3 on 8/14/06.