SALINITY PATTERNS On Row Crops under Subsurface Drip Irrigation (SDI) on the Westside of the San Joaquin Valley of California

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EXECUTIVE SUMMARY

This study began with the idea that the wide hose spacing (80 inches) commonly used in subsurface drip irrigation (SDI) fields in the area of study might cause detrimental salinity buildup at the edges of the wetted patterns between the beds, which would require the use of special leaching practices. Its objectives were to:

- Identify if there was detrimental salinity buildup in the upper layers of soil (0-5 feet), caused by the usage of SDI on row crops.
- Identify the extent (spatial distribution and concentrations) of any detrimental salinity buildup.
- Identify successful and/or essential practices used by farmers who use SDI.

For this purpose, multiple soil samples were taken at 4 locations (high pressure, close to an emitter; high pressure, between emitters; low pressure, close to an emitter; between emitters) in six different fields irrigated with SDI. The soil samples were analyzed for salinity content (ECe) and soil salinity profiles were developed. Water usage, water quality, cultural practices, and rainfall were also documented and used to calculate the leaching fraction and expected ECe for each field. Actual results were then compared with each other, with expected results, and with results from 4 control fields irrigated with furrows. The results are summarized below.

- No consistent pattern of salinity on the periphery of the wetted areas (on the edges of the furrows) was found on the six SDI fields studied. Although there were patterns of salinity with respect to depth, and that depended on water quality, the salinity was fairly evenly dispersed across the row crop bed.

- The average salinities midway between emitters were about the same (sometimes higher and sometimes lower) than the salinities measured close to the emitters. This was also true of the pressure locations.

- Soil samples from adjacent furrow irrigated fields did not show obviously different salinities than the SDI fields.

- All of the SDI fields had low average salinities (between 0 - 2 dS/m) that were below the threshold ECe of their crops.

- Good agreement was found between the expected average ECe's, calculated according to standard leaching requirement equations, and measured average ECe's. This may imply that these equations, developed for traditional sprinkler and furrow irrigation, are also suitable for use with buried drip irrigation. However, these calculations could only be made for 3 of the 6 SDI fields.

- All SDI fields showed a gradient of increasing salt concentration above the hose depth due to evaporation from the soil surface and plant water uptake (root activity between the surface and the hose). Salinities remained low below the buried hose depth on most the fields, which is indicative of the application of a high leaching fraction. Since all of the field but one received sprinkler pre-irrigations, the following scenario is likely: Salts build up towards the soil surface during the irrigation season due to the evaporation and plant water uptake (this is the point at which soil samples were taken for this study). Sprinkler pre-irrigation then leaches the salt down to the SDI hose, which then leaches the salt further down over the irrigation season when water is applied to consider the required leaching fraction.

Therefore, it doesn't appear that special leaching practices (other than sprinkler pre-irrigations) are needed on fields irrigated with subsurface drip (SDI).

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INTRODUCTION

The Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo conducted a study to investigate the amount of salt accumulation associated with long-term use of Subsurface Drip Irrigation (SDI) systems on row crops by farmers on the west side of the San Joaquin Valley.

Many San Joaquin Valley farmers are seeking to reduce water lost to deep percolation water (drainage water) to save water, reduce their irrigation costs, and minimize drainage problems. One of the most promising techniques for annual row crops (and crops such as asparagus) is the use of buried drip irrigation systems. It is well recognized that, in general, the average applied irrigation depths under drip irrigation are less than under sprinkler or surface irrigation methods. SDI, which provides water directly to the crop root zone, provides the additional benefits of eliminating spray loss and runoff and decreasing non-beneficial evaporation losses. Farmers are also interested in SDI because of its high potential distribution uniformity (DU), its ease of irrigation scheduling, reduced humidity (and therefore less disease), and fewer weeds. They can also drive and till all over the field at any time.

A number of farmers in the Dos Palos-Mendota area have already operated such systems for several years. Some farmers have noticed excellent yields and other management advantages with the buried drip. Therefore, they are interested in expanding the drip acreage.

However, there were some questions about the long-term effectiveness of these systems, as related to salt buildup and the actual effectiveness of leaching practices. Since only part of the soil is wetted by the drip system, it was thought that prolonged use might cause salt to build up and concentrate on the periphery of the wetted areas, eventually requiring large amounts of water to be applied to leach them out.

In fact, there have been serious failures of drip systems due to salt accumulation around drip emitters, such as the large Paloma Ranch in Arizona (about 12,000 acres), which suffered a massive failure due to salinity buildup in the late 1980's, with cotton on similar drip emitter spacings as found in the area of interest. This indicates serious potential problems in arid areas (such as the San Joaquin Valley) with the sustainability of some types of drip irrigation (particularly SDI). Up until the time of this study, it was largely assumed that there were no problems unless one irrigated with brackish water or was in a high water table area. However, there was no data to support such an assumption. This study investigated several "typical" SDI systems to determine if the present irrigation management and cultural practices used with buried drip on row crops on the west side of the San Joaquin Valley are sufficient to avoid damaging accumulations of salt and achieve sustainable agriculture.

Overview of the Experiment

This project studied subsurface drip irrigation (SDI) in combination with sprinkler pre-irrigation as an irrigation practice and its effect on salinity dynamics and the sustainability of "healthy" non-saline soil with minimum water application. All farms involved in the study are part of Panoche Water District (PWD) and San Luis Water District (SLWD). Farmers in this area typically use a drip line spacing (80 inches) that is much wider than the spacing normally used in other areas of California (12 inches). In addition, PWD mixes subsurface drainage water with its canal water supplies, increasing its irrigation water salinity. All of the farmers, except one, involved in the study utilize sprinkler irrigation at the beginning of each irrigation season.

This study was intended to address the uncertainty of the extent of salt buildup on the periphery of wetted areas and determine what practices can minimize the salt buildup by analyzing soil samples for salinity and documenting water usage, water quality, cultural practices, and rainfall on each field sampled. Its objectives were to:

- Identify if there is detrimental salinity buildup in the upper layers of soil (0-5 feet), caused by the usage of SDI on row crops.
- Identify the extent (spatial distribution and concentrations) of any detrimental salinity buildup.
- Identify successful and/or essential practices used by farmers who use SDI.

To meet these objectives, multiple soil samples were taken at 4 locations (high pressure, close to an emitter; high pressure, between emitters; low pressure, close to an emitter; between emitters) in six different fields irrigated with SDI. The soil samples were analyzed for salinity content (ECe) and soil salinity profiles were developed. Results were compared between the 4 locations within a single field, between fields, to expected results, and to control field results.

The Effects of Salt Accumulation

Salt applied with irrigation water moves with soil water and may accumulate in the periphery of the wetted zone. Accumulations can occur at the soil surface, because of upward water flow induced by capillary action and evaporation from the soil surface, and midway between the laterals.

Salts in the soil water solution can reduce evapotranspiration by making soil water less "available" for plant root extraction. Salts have an affinity for water and hence additional force is required for the crop to extract water from a saline soil. The presence of salts in the soil water solution reduces the total potential energy of the soil water solution (FAO Irrigation and Drainage Paper 56).

Since salt concentration changes as the soil water content changes, soil salinity is normally measured and expressed based on the electrical conductivity of the saturation extract of the soil (ECe). The ECe is defined as the electrical conductivity of the soil water solution after the addition of a sufficient quantity of distilled water to bring the soil water content to saturation. ECe is typically expressed in deciSiemens per meter (dS/m) (FAO Irrigation and Drainage Paper 56). Because this is a single measurement of total salinity, it does not provide information about the various constituents of salt in the sample.

Under optimum management conditions, crop yields remain at potential levels until a specific threshold electrical conductivity of the soil water solution is reached. When salinity increases beyond this threshold, crop yields are presumed to decrease linearly in proportion to the increase in salinity (FAO Irrigation and Drainage Paper 56).

Salinity build-up becomes particularly important when the field is replanted. Since most crops are most sensitive to salt either during germination or immediately after transplantation, upon replanting, the salt that has accumulated in the soil may inhibit crop growth and reduce vigor, especially if the original crop is replaced by a less salt tolerant one.

With permanent SDI on row crops, salt may accumulate on edges of the wetted patterns without affecting the current crop. Therefore, simple observations of present salt damage to the crop may be misleading.

The following table gives the plant response to increasing ECe levels.

Table 1. Plant response to soil salinity levels.

ECe of saturation extract, dS/m	Plant response
0 - 2	Little effect
2 - 4	Some effect on salt-sensitive crops
4 - 8	Considerable effect on salt-sensitive crops

The amount of salinity left in the soil depends in large part upon the salinity of the irrigation water (ECw) and how much water is applied. Enough water should be applied to leach the salts out of the effective root zone. The following figure illustrates the salt concentrations through the soil profile when water is applied with a high leaching fraction and with a low leaching fraction.

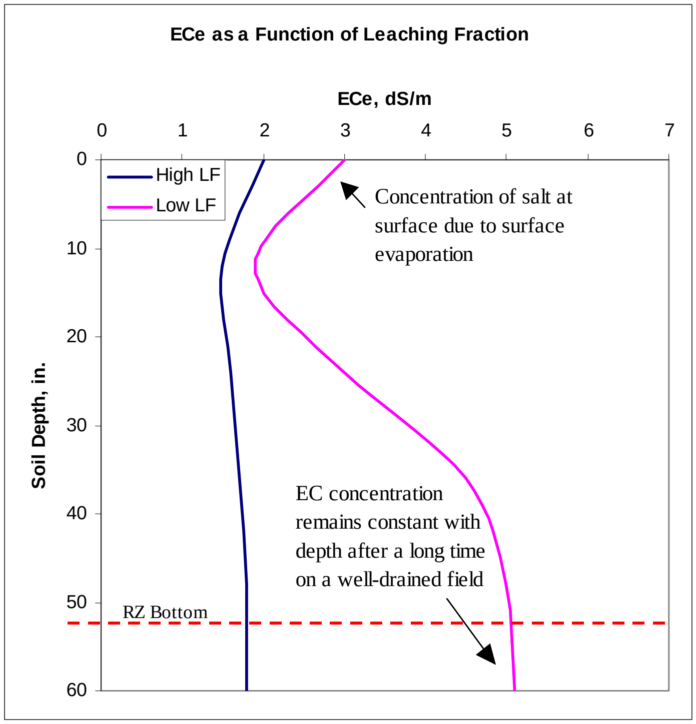


Figure 1. Salinity concentrations at various depths in a root zone with the application of a high and a low leaching fraction (adapted from Burt 2001).

Both curves show a slight increase in salinity towards the soil surface, due to evaporation. However, the low leaching curve shows an accumulation of salinity at the bottom of the root zone as the salts are left behind by plant water uptake and never washed out.

GENERAL SITE LOCATION AND DESCRIPTION

Location

Detailed of soil salinity samples were taken on 6 fields that have SDI (subsurface drip irrigation) on the west side of the San Joaquin Valley, in the Panoche Fan drainage area. This region of the San Joaquin Valley has a semi-arid climate. Soil samples were also taken from 4 nearby control fields, without SDI. All fields were selected in areas without high water tables. They are shown in the figure below.

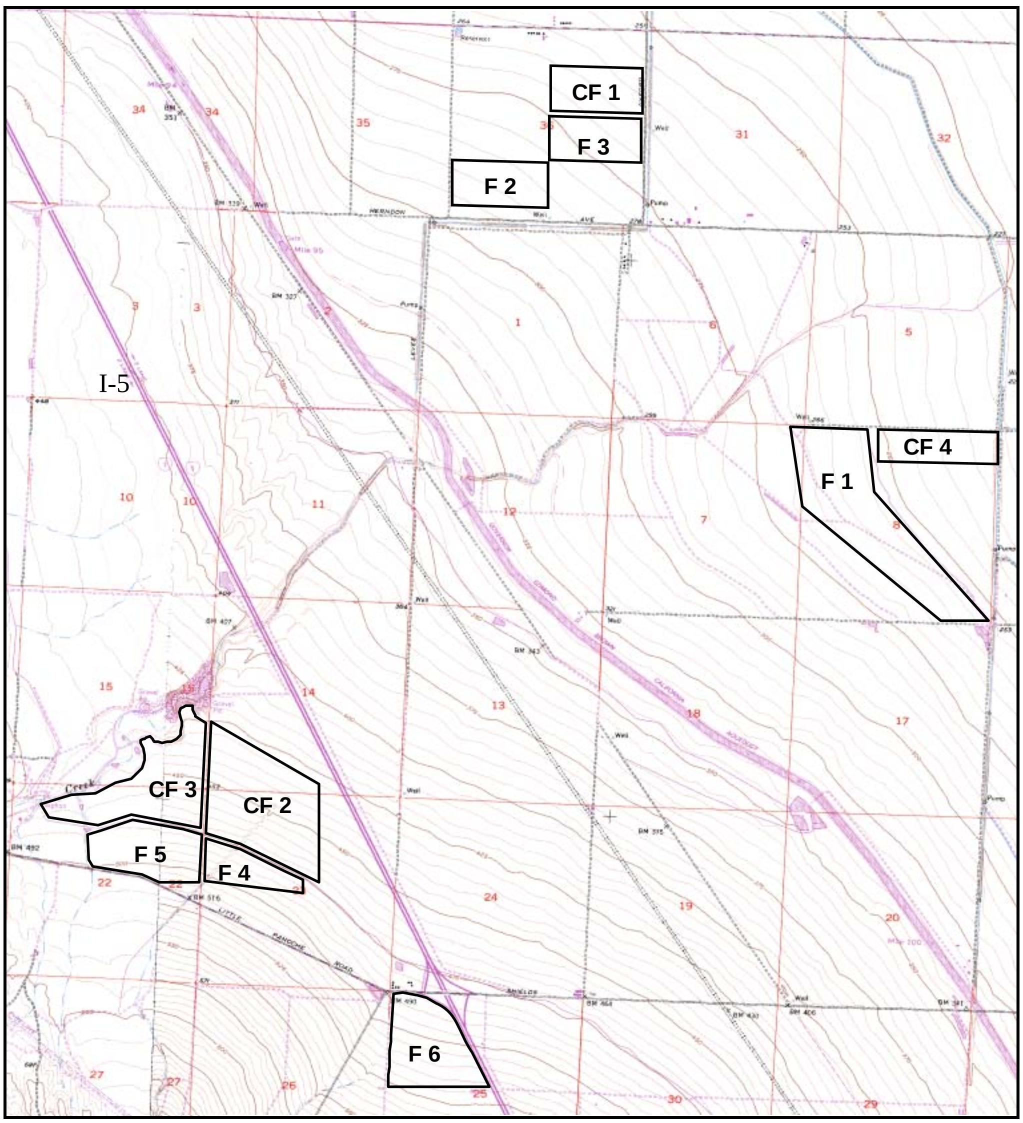


Figure 2. The 6 SDI field and 4 control fields involved in the row crop salinity study.

Water Quality

All fields were supplied with irrigation water from either San Luis Water District (SLWD) or Panoche Water District (PWD). The primary water sources for these districts are the California Aqueduct and the Delta-Mendota Canal.

Panoche WD blends subsurface drainage water (tile water) with its regular canal water supplies to meet San Joaquin River standards. This makes PWD's irrigation water salinities higher than the salinities of SLWD. The average electrical conductivity (ECw) of the irrigation water delivered in the years 1999-2001 by PWD to Hammonds Ranch was 0.81 dS/m, and to Turlock Fruit Co. 0.84 dS/m. SLWD's average ECw for the same period was 0.44 dS/m.

Typical Irrigation Practices

Farmers in PWD and SLWD have adopted row crop drip designs that are different from those found in most other areas of the state. In this area, a typical design for subsurface drip irrigation (SDI) for annual crops uses only one hose every 80". This spacing is considered relatively wide since it only wets approximately 50% of an 80" bed. It was thought that this spacing might result in salt accumulation at the edges of the wetted patterns between the beds.

All of the farmers involved in the study utilize sprinkler irrigation (except on Field 6) at the beginning of each irrigation season.

Participants

Three growers cooperated in the study, all located near Firebaugh, CA. Six fields were planted with field crops under subsurface drip irrigation (SDI) systems of various ages. Four additional fields, not under SDI, were selected as control fields. Specific field information is outlined in the tables below.

Table 2. Field, crop, and irrigation system information for all fields involved in the study.

SDI Fields

Farm	Field	Acres	Soil	Crop	Irr. Season Length	Pre-irrigate?	Water Supply	Tape Type	Typical Tape Length, ft.	Depth Buried, in.	Distance btwn. Tapes, in.	Distance btwn. Emitters, in.	Press. Comp. Emitters?	System Age (years)
Hammonds Ranch	1	160	Clay loam	Asparagus	8-9 mo.	Y	Panoche WD	Typhoon, 16.14 mm 20 mil.	200-600'	20"	60"	18"	Y	8
Turlock Fruit Co.	2	74	Clay loam	Melon	3-4 mo.	Y		Python, 20.63 mm	appr. 1300'	16"	72"	18"	N	5
	3	74	Clay loam	Cotton	6 mo.	Y		Python, 20.63 mm	appr. 1300'	16"	72"	18"	N	5
Joe Del Bosque	4	53	Clay loam	Melon	3-4 mo.	Y	San Luis WD	Python, 20.63 mm 0.23 GPH	450-1280'	12"	80"	18"	Y	5
	5	107	Clay loam	Oat	4 mo.	Y		Python, 20.63 mm 0.23 GPH	appr. 1300'	12"	92"	18"	N	4
	6	120	Clay loam	Asparagus	8-9 mo.	N		Geoflow, 18 mm 0.42 GPH	appr. 800'	24"	35"	24"	Y	3

Control Fields

Farm	Control Field	Crop	Irr. Season Length	Water Supply	Irrigation Method	Typical Furrow Length, ft.	Distance btwn. Furrows, in.
Turlock Fruit Co.	1	Garlic		Panoche WD	Surface	1300'	80"
Joe Del Bosque	2	Cotton	6 mo.	San Luis WD	Furrow or sprinkler	-	40"
	3	Melon	3-4 mo.		Furrow or sprinkler	-	80"
Hammonds Ranch	4	Tomato		Panoche WD	Furrow	-	80"

METHODS AND PROCEDURES

A total of 6 fields under SDI were examined for salinity accumulation. The following data was collected for each field, where possible:

1. Soil samples, taken in an intensive grid and analyzed for salinity content.
2. Information from the farmers about their management practices with drip.
3. Water and weather data, including records of precipitation, ETc, water quality and historical amounts of water applied. This data was then used to calculate the leaching fraction and expected soil salinity for each field.

Soil Sample Collection and Analysis

SDI Fields

Detailed soil samples were taken to document the spatial characteristics of soil salinity under SDI for row crops. Samples were collected in September 2001, after the summer irrigation season and prior to winter rains. Only the perennial row crops (asparagus and cotton) on Fields 1, 3, and 6 were still in the soil; the other fields had already been harvested. No additional soil manipulation or irrigation was performed on the fields prior to sampling.

Within each field, 2 locations were identified for soil sampling based on differences in pressure throughout the field. The intent was to take samples from a location of low pressure and one of high pressure. Since samples were taken when the SDI was not in operation (the irrigation season was over), the high and low pressure locations were estimated based on a graph developed by Burt and Styles 1999, shown below.

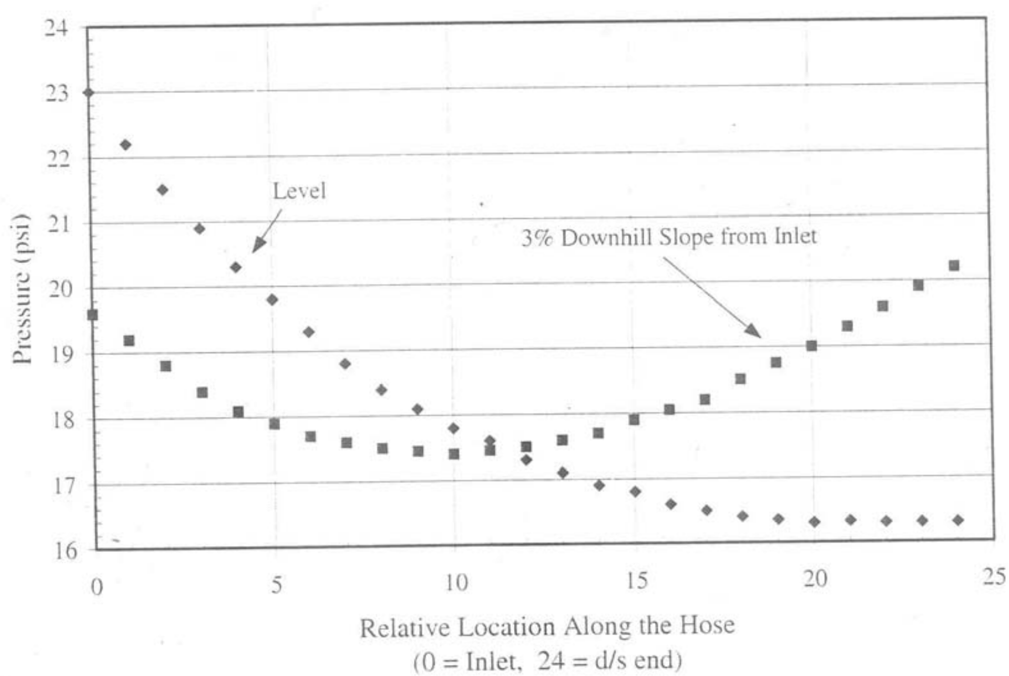


Figure 3. Emitter pressures along a hose on level vs. sloped ground (Burt and Styles, 1999).

At each of the 2 pressure locations, a pit that ran perpendicular to the drip tape was dug with a backhoe. Each pit was 7 feet deep, 80 inches long (enough to cut across a complete bed, from furrow to furrow, assuming an 80" tape/hose spacing), and wide enough for a person to safely stand in. One 80" wall of the pit was directly below an emitter.

This wall was smoothed with shovels and a series of soil samples was taken directly beneath the emitter ("close to the emitter"). The pit wall was then dug back another 6 inches (assuming a typical emitter spacing of 12" on the tape/hose), and another identical set of soil samples was taken from this wall of soil ("midway between emitters"). This means that for each of the 6 fields, salinity profiles were taken at 4 locations:

1. High pressure, close to an emitter (HC)
2. High pressure, midway between emitters (HM)
3. Low pressure, close to an emitter (LC)
4. Low pressure, midway between emitters (LM)

All soil samples were gathered with the aid of a pre-prepared plywood template. A grid of 72 holes (2” diameter) had been cut into an 80” wide x 66” tall plywood sheet. This grid was more concentrated within the top 2 feet of the template, where it contained 4 rows (6” spacing) of 15 holes (5” spacing) each. The lower 3.5 feet of the template contained only 3 rows (12” spacing) of 4 holes (20” spacing) each. This division was based on the hypothesis that the salinity would concentrate with the first 2 feet below the soil surface, where the most active root growth and evaporation occurs.

To take samples, the plywood template was installed in the backhoe trench. The template was centered at the drip tape and a level was used to align the top of the template straight and flush with the surface of the bed. The distance from the top of the template to the soil surface was measured above each column of holes to determine the soil surface profile. The distance to the drip tape was also measured.

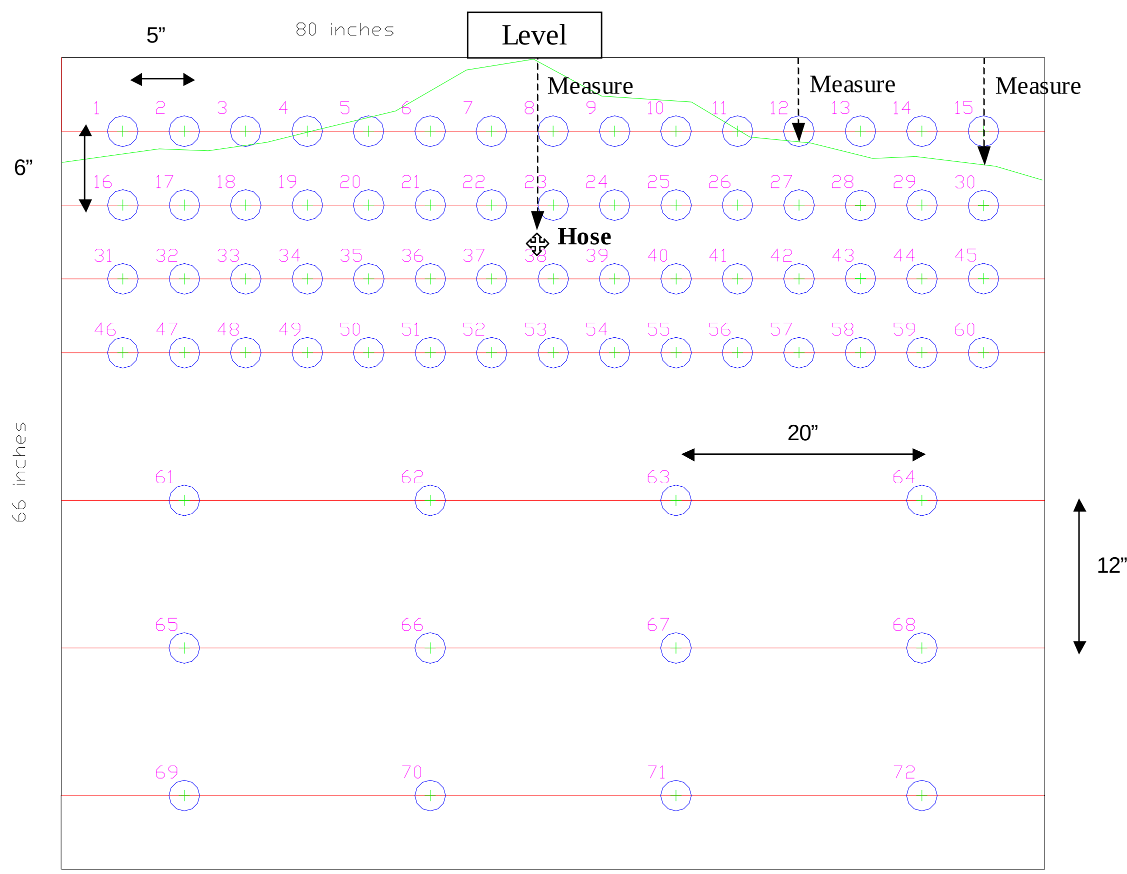


Figure 4. Template used to take the samples. The green line imposed on the template represents the soil surface.

Samples were taken from each hole with enough quantity (~200 grams) for analysis. Each sample was collected in a bag and labeled according to the following:

Field #
Location: High pressure (**H**) or Low pressure (**L**)
Position: Close to the emitter (**C**) or Midway between emitters (**M**)
Sample hole: **1 – 72**

For example, a sample labeled "F2 HC 27" was taken from the second field at the high pressure location, close to the emitter, from hole number 27 in the plywood template. It was possible to take up to 72 samples per position, unless the soil surface dropped below any of the top holes, as seen in the figure above. In the figure above, samples 1-3 and 12-15 would be missing.

Control Fields

Soil samples were also taken from 4 neighboring fields with a similar cropping history but which are not irrigated with drip irrigation. These samples were collected in February 2002 and on a much more limited scale.

Samples were collected at only 2 locations (instead of 4) locations within each field. The template was not used during collection; instead, only 9-14 samples, spaced approximately 1 foot apart, were collected at each location.

Laboratory Testing of the Soil Samples

Each soil sample was tested for salt content in a laboratory set up at the Irrigation Training and Research Center facilities. The electric conductivity of the soil extract from a saturated paste (ECe) was measured according to the testing procedure summarized below:

- The soil was air-dried for 1–1.5 weeks. It was covered at night to prevent re-humidification.
- The soil was ground and, if needed, passed through a 10-mesh sieve.

- Sixty-five grams of soil were weighed out and placed in an eight-ounce cup. Thirty-three ml of distilled water were added to the soil to bring it to saturation. (It had been previously determined that the average soil:water ratio at saturation point was approximately 1:0.5.) The cup was then sealed with a lid.
- The saturated soil samples sat sealed for at least 12 hours.
- A vacuum was used to extract the solution from the soil. A Buchner Funnel, with #1 Whitman filter paper, was used to direct the extract into a small glass jar. At least 2.5 – 3 mL of extract were collected.
- One drop of 0.1% sodium hexaphosphate ($Na(PO_3)_6$) solution was added to the extract. This kept any calcium carbonate in solution.
- The electrical conductivity of the extract solution was measured using a digital readout electrical conductivity meter called an "YSI 3200 Conductivity Instrument".

After all the soil samples had been analyzed, some of the ECe values were weighted to more accurately represent the soil salinity. All contour maps in the report were made with original data. However, all graphs contain weighted values.

Farmer Interview

After sampling had taken place, each farmer was given a questionnaire to fill out which asked for the following information:

- The area of the field in acres.
- How many acre-feet of water were applied each month for the last 5 years (1996 – 2000)?
- What kinds of crops were planted during the last 5 years (1996 – 2000)? When were these crops planted and harvested?
- When was the SDI system was installed? (This information had also been gathered upon initial contact with the farmers.)
- What type of irrigation method was used before installing the SDI?

- Have sprinklers or furrows been used since the SDI was installed? When? How many acre-feet of water were applied with sprinklers/furrows?
- Do you have any water salinity data?
- How often do you irrigate (days) and how many hours in each irrigation set?

Unfortunately, the farmers did not always have all of this information available, especially information regarding applied water and salinity. As a result, this information had to be gathered from other sources, when possible.

Water and Weather Data

Daily weather data regarding grass reference evapotranspiration (ETo) and precipitation was downloaded for station #7 (Firebaugh/Telles) from the California Irrigation Management Information System (CIMIS) website (http://www.cimis.water.ca.gov/) for 1996 to 2001. Monthly soil and crop evapotranspiration (ETc) information was downloaded from the ITRC website (http://www.itrc.org).

Bi-weekly water quality data for Panoche Water District from September 1998 to March 2002 was provided by the PWD office. Daily water quality data for San Luis Water District's Check 13-Onill from August 1999 to November 2001 was downloaded from the California Department of Water Resources (DWR) California Data Exchange Center (CDEC) website (http://cdec.water.ca.gov).

Applied water was estimated based on turnout delivery data provided by the water district offices. PWD provided monthly turnout data for Field 1 from March 1998 to February 2002. SLWD provided event-based turnout data for Fields 4-6 from January 1998 to April 1992. Specific delivery data for Fields 2 and 3 was not available. These two fields receive water from a turnout that services multiple fields, so it was impossible to determine which field received what volume of water.

Calculation of Leaching Fraction and Expected ECe

The theoretical, "expected" soil salinity level for each field was calculated for comparison with the average ECe measured for each field. The expected ECe was calculated taking into account applied water amounts (taken from turnout records), precipitation, evapotranspiration, and deep percolation of applied water. This process is summarized below.

- For each month, the following items were calculated:
  - Beginning soil water (stored water), based on the soil AWHC (Available Water Holding Capacity) and the crop root zone (dependent on the crop).
  - Ending soil water. This was equal to the sum of the beginning soil water, precipitation and applied water minus the effective precipitation and ETc.
  - Deep Percolation, the difference between the ending soil water and the AWHC.
- The monthly values for applied water and deep percolation were then totaled for the years 1999-2201 (also 1998 for Field 5) and used to calculated the field's Leaching Fraction (LF) according to the following equation:

$$\text{LF} = \frac{\text{Depth Deep Percolated}}{\text{Depth Applied}} \qquad \text{(Eq. 1)}$$

- The Leaching Fraction was then used to solve for the expected ECe, as follows:

$$\text{Needed LF} = \left[\frac{\text{ECw}}{5 \times \text{Threshold ECe} - \text{ECw}}\right], \qquad \text{(Eq. 2)}$$

Rearranged:

$$\text{Expected ECe} = \left(\frac{\text{ECw}}{\text{LF}} + \text{ECw}\right) \times 0.2 \qquad \text{(Eq. 3)}$$

where ECw = average irrigation district ECw for the years in question.

RESULTS

Leaching Fraction and Expected ECe

The results of the leaching fraction and expected ECe calculations are summarized below:

Table 3. Leaching fractions and expected ECe's for Fields 1, 4, 5, and 6. The deep percolation and applied water values are totals for 1999-2001 (1998-2001 for Field 5) and take precipitation and ET into account.

Field	2001 Crop	Deep Perc., in.	Applied Irr. Water, in.	ECw, dS/m	LF	Expected ECe, dS/m
1	Asparagus	13.76	129.68	0.81	0.11	1.69
4	Melon	8.28	55.36	0.81	0.15	0.68
5	Oat	9.06	63.14	0.44	0.14	0.93
6	Asparagus	0	77.8	0.81	0	undefined

Note that the expected ECe for Field 6 is undefined because the leaching fraction for that field was zero. Neither leaching fractions nor expected ECe's could be calculated for Fields 2 and 3 because exact data for the applied water was not available.

SDI Fields

This section presents the general results for each of the six SDI fields. Results and figures are presented in the same order for each field:

The first two figures present a more detailed look at each of the 4 sample locations (HC, HM, LC, LM) in a field, with a particular look at the horizontal distribution of salinity at each location. Due to the wide hose spacing (80") commonly used in the area of study, it was thought that salt might accumulate at the edges of the wetted patterns, between the beds. For this reason, depth profiles were developed at a various distances from the buried hose: in line with the hose, 10 inches away from the hose on either side, and 30 inches away on either side.

A following figure presents average salinity as a function of depth for each sample location to examine the vertical distribution of salinity around the hose and to allow comparisons between sample locations at high and low pressures, and close to and midway between emitters.

Then, an overall assessment of the actual leaching fraction and average field ECe is made in comparison with the required leaching fraction, the crop's threshold ECe, and expected ECe.

Comparisons between fields will be made in the Discussion and Comparisons section of this report.

Field 1

Field 1 is part of Hammonds Ranch. Soil samples were gathered in Field 1 on September 6, 2001, after the summer and before the irrigation season had begun.

Field and irrigation system information for Field 1 is summarized in the table below. The same crop, asparagus, has been grown on Field 1 at least since 1999.

Table 4. Field information for Field 1.

Field 1, Hammonds Ranch			
Acres:	160	Tape Type:	Typhoon, 16.14 mm, 20 mil.
Soil:	Clay loam	Tape Length:	200-600 feet
2001 Crop:	Asparagus	Depth Buried:	20 inches
Irr. Season Length:	8-9 mo.	Distance btwn. Tapes:	60 inches
Pre-Irrigate?	Yes	Pressure-Comp. Emitter?:	Yes
Water Supply:	Panoche WD	Distance btwn. Emitters:	18 inches
		System Age:	8 years

To compare the salinity concentration patterns in the soil profile at each of the four sample locations, the measured ECe values were plotted as a two-dimensional contour map in Surfer® 7.

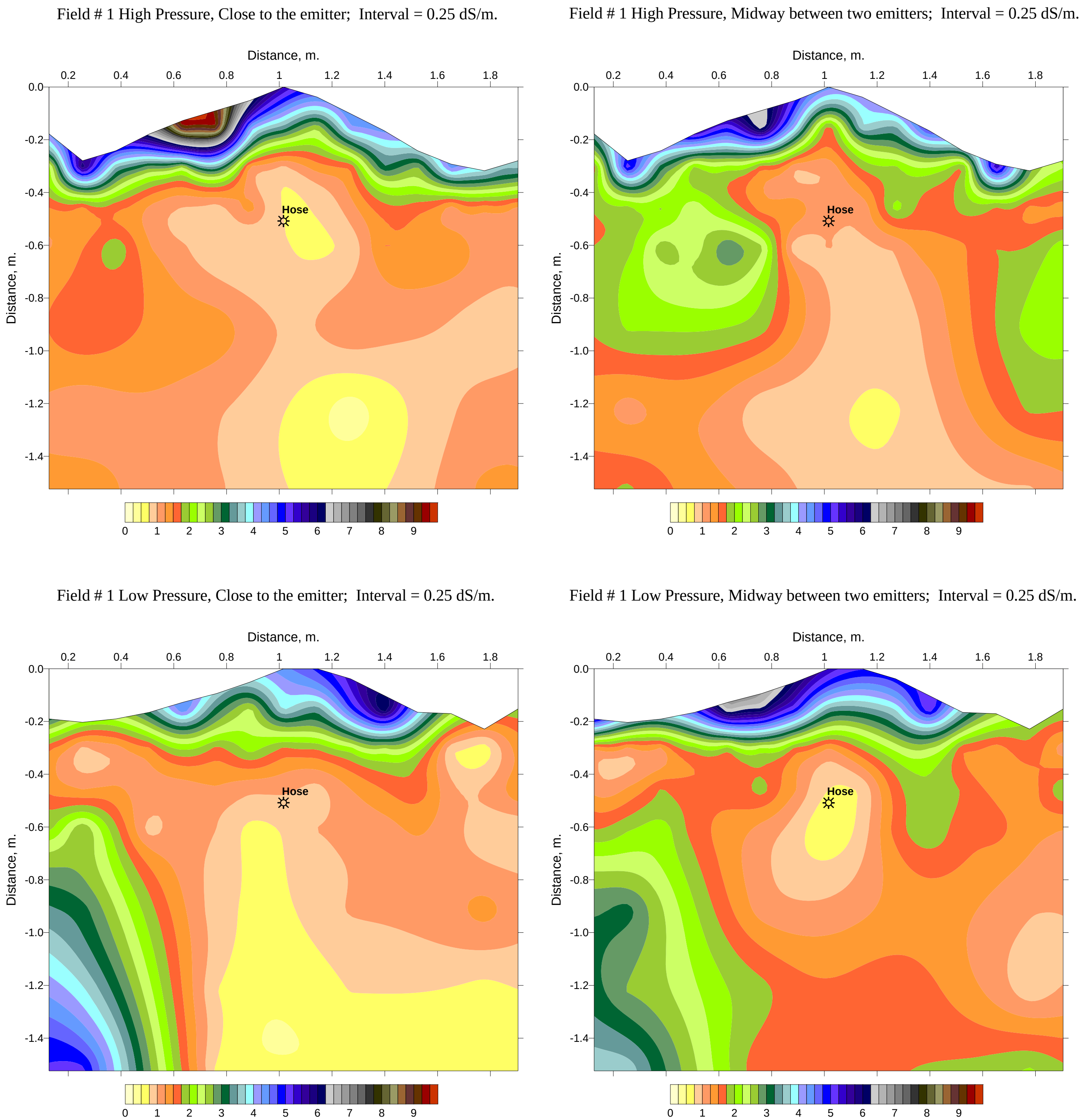


Figure 5. Salt distribution at 4 locations within Field 1.

From this figure, it is apparent that salinity concentrations are generally higher near the soil surface, above the drip tape. The next figure (Figure 6) compares the spatial salinity distribution around the SDI hose at each of the sample locations, graphically.

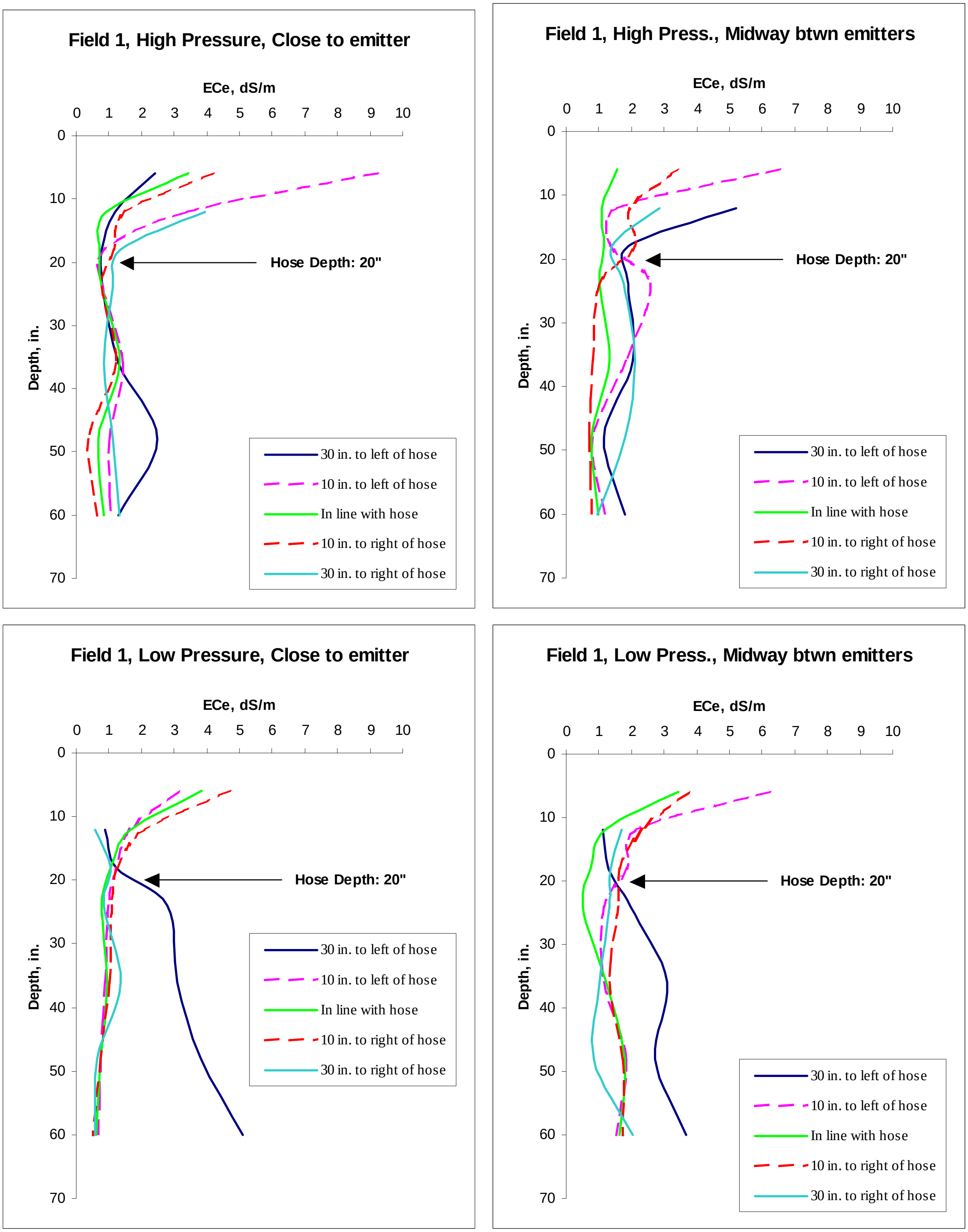


Figure 6. ECe (dS/m) as a function of horizontal position and depth at 4 locations in Field 1. Each graph has 5 curves: One shows the ECe directly in line with the SDI hose. Four represent the ECe some distance away from the hose (30" and 10", horizontally, on either side of the hose).

From Figure 6, several things are clear:

- There is no obvious, consistent pattern of horizontal salinity distribution around the hose. Mirror image curves (10" away on either side and 30" away on either side) are not always similar, either within the same sample location or between sample locations. Salinity also does not appear to be significantly higher at the edges of the beds (30" away).
- However, there does appear to be a pattern of vertical salinity distribution around the hose. On average, the soil salinity is high at the soil surface and low at the bottom of the root zone. Soil salinity is often lowest at the hose depth. In general, salinity increases sharply above the SDI hose and changes only minimally below the hose.

An average ECe graph for each sample location in Field 1 was also created by averaging the values of all samples taken at the same depth (6", 12", 18", 24", 36", 48", 60").

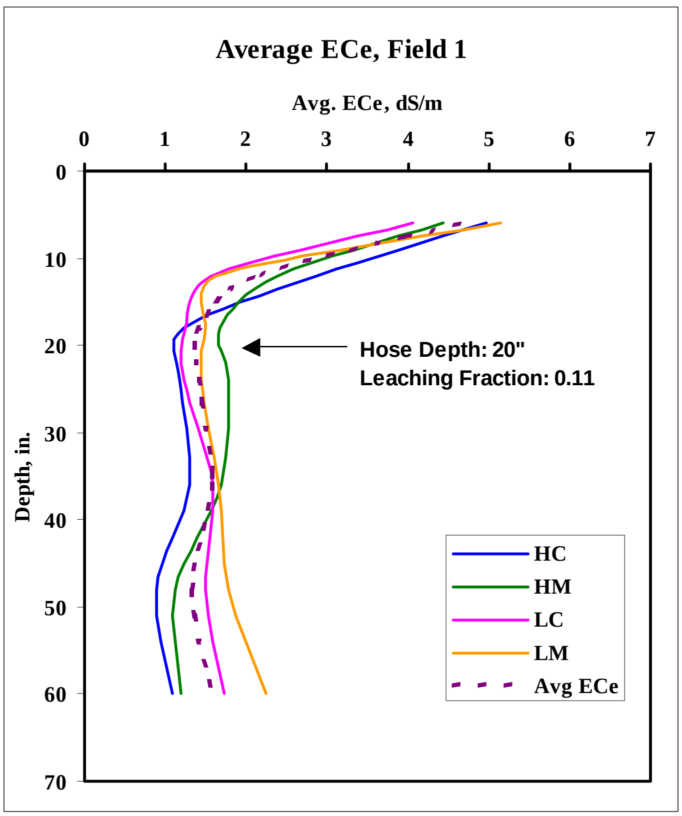


Figure 7. Change of ECe (dS/m) as a function of depth in inches in Field 1.

From Figure 7, it can be seen that there are no major differences in salinity accumulation based on pressure distribution or distance from the emitter. All sample locations present the same pattern – a sharp increase in salinity above the hose depth and only minimal change below it. This pattern may be due to the relatively high leaching fraction that had been applied to this field, especially since asparagus is a perennial crop and remains in the soil for several years, with water applications for 8 to 9 months per year. As can be seen in the table below, the annual application of a high amount of water since 1999 resulted in a high leaching fraction, especially in 2001.

Table 5. Leaching fraction for Field 1, 1999-2001.

Crop	Year	ECw, dS/m	Threshold ECe, dS/m	*Needed LF*	Applied Irr. Water, in.	Deep Perc., in.	*Actual LF*
Asparagus	1999	0.74	4.1	*0.04*	42.83	3.94	*0.09*
Asparagus	2000	0.85	4.1	*0.04*	44.48	2.96	*0.07*
Asparagus	2001	0.84	4.1	*0.04*	42.38	6.85	*0.16*
	Average:	**0.81**	**4.1**	***0.04***	**129.68**	**13.76**	***0.11***

Since more water was applied, more evaporation occurred from the soil surface, resulting in salt accumulation there and above the hose. However, the water applied was also sufficient to move salt below the hose out of the 60-inch test depth.

Asparagus has an average root zone depth of 4 feet (48 inches) and a threshold ECe of 4.1 dS/m. An examination of the average salinities within the effective root zone at the 4 sample locations in Field 1 reveals that the measured salinities are well below the threshold ECe of asparagus.

Table 6. Average salinities (dS/m) within the root zone at the 4 sample locations in Field 1.

Depth	Field 1			
	HC	HM	LC	LM
12	2.86	2.39	1.57	1.62
18	1.23	1.67	1.24	1.49
24	1.17	1.77	1.22	1.44
36	1.31	1.70	1.59	1.65
48	0.90	1.12	1.50	1.79

When the salinities at all sample locations at all depths were averaged, the average field ECe is still well below the threshold ECe, despite the accumulation of salt at the soil surface. This measured average field ECe also showed an acceptable level of agreement with the anticipated ECe calculated for Field 1.

Table 7. Comparison of threshold, expected, and measured ECe values (dS/m) for Field 1.

Field 1, Hammonds Ranch	
2001 Crop:	Asparagus
Threshold ECe:	4.1
Anticipated ECe:	1.69
Measured ECe:	1.76

Field 2

Field 2 belongs to Turlock Fruit Company. Soil samples were gathered at Field 2 on September 12, 2001, after the summer and before the irrigation season had begun.

Field and irrigation system information for Field 2 is summarized in the table below.

Table 8. Field information for Field 2.

Field 2, Turlock Fruit Co.			
Acres:	74	Tape Type:	Python, 20.63 mm
Soil:	Clay loam	Tape Length:	approx. 1300 feet
2001 Crop:	Melon	Depth Buried:	16 inches
Irr. Season Length:	3-4 mo.	Distance btwn. Tapes:	72 inches
Pre-Irrigate?	Yes	Pressure-Comp. Emitter?:	No
Water Supply:	Panoche WD	Distance btwn. Emitters:	18 inches
		System Age:	5 years

The first of the following figures presents the salinity concentration contour maps plotted in Surfer® 7. The next figure presents a detailed graphical analysis of the spatial salinity distribution at the 4 sample locations.

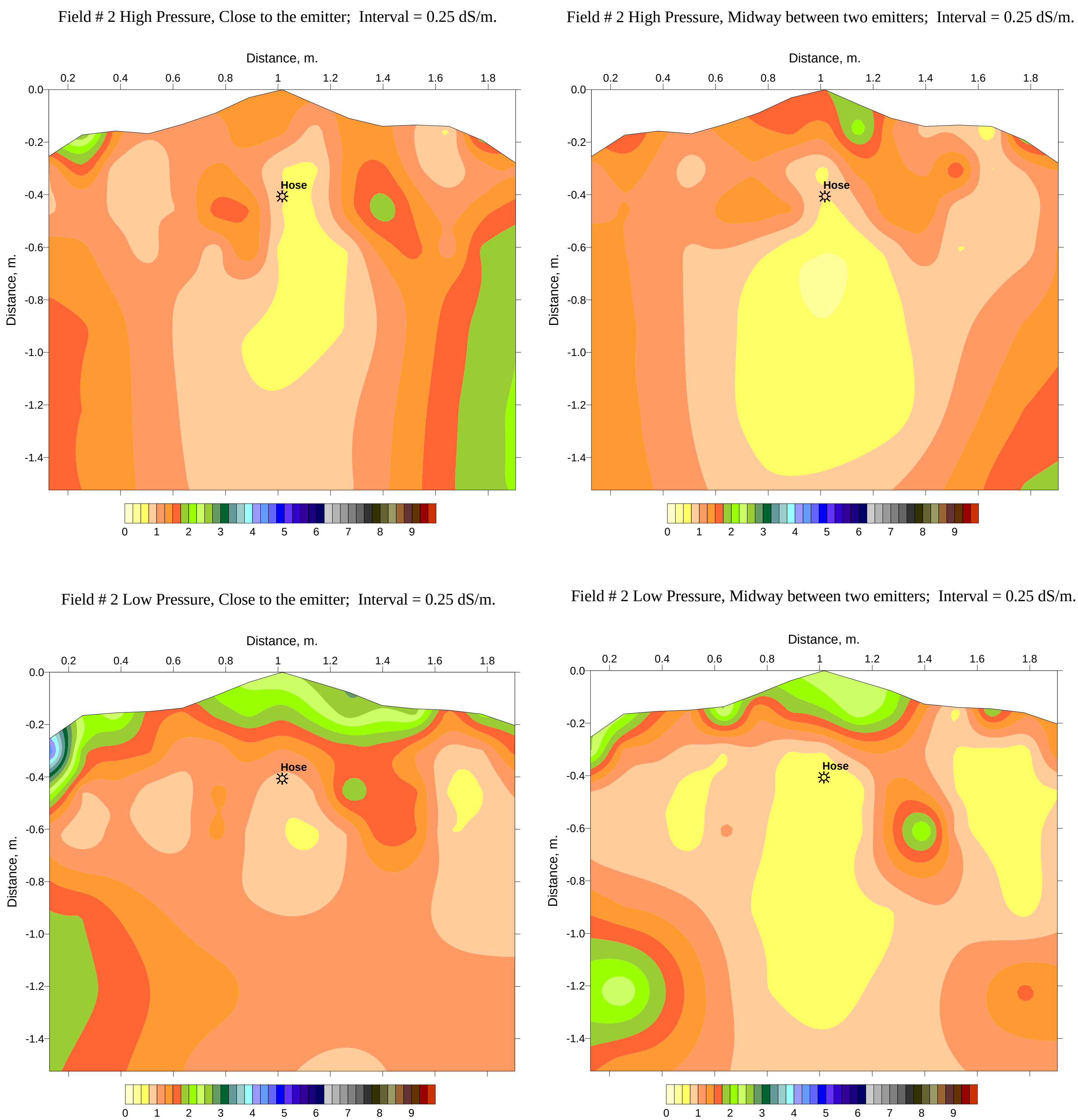


Figure 8. Salt distribution at 4 locations within Field 2.

There is no uniform pattern of salinity distribution apparent from the above figure, other than, perhaps, an area of lower salinity around and below the hose buried at 16 inches.

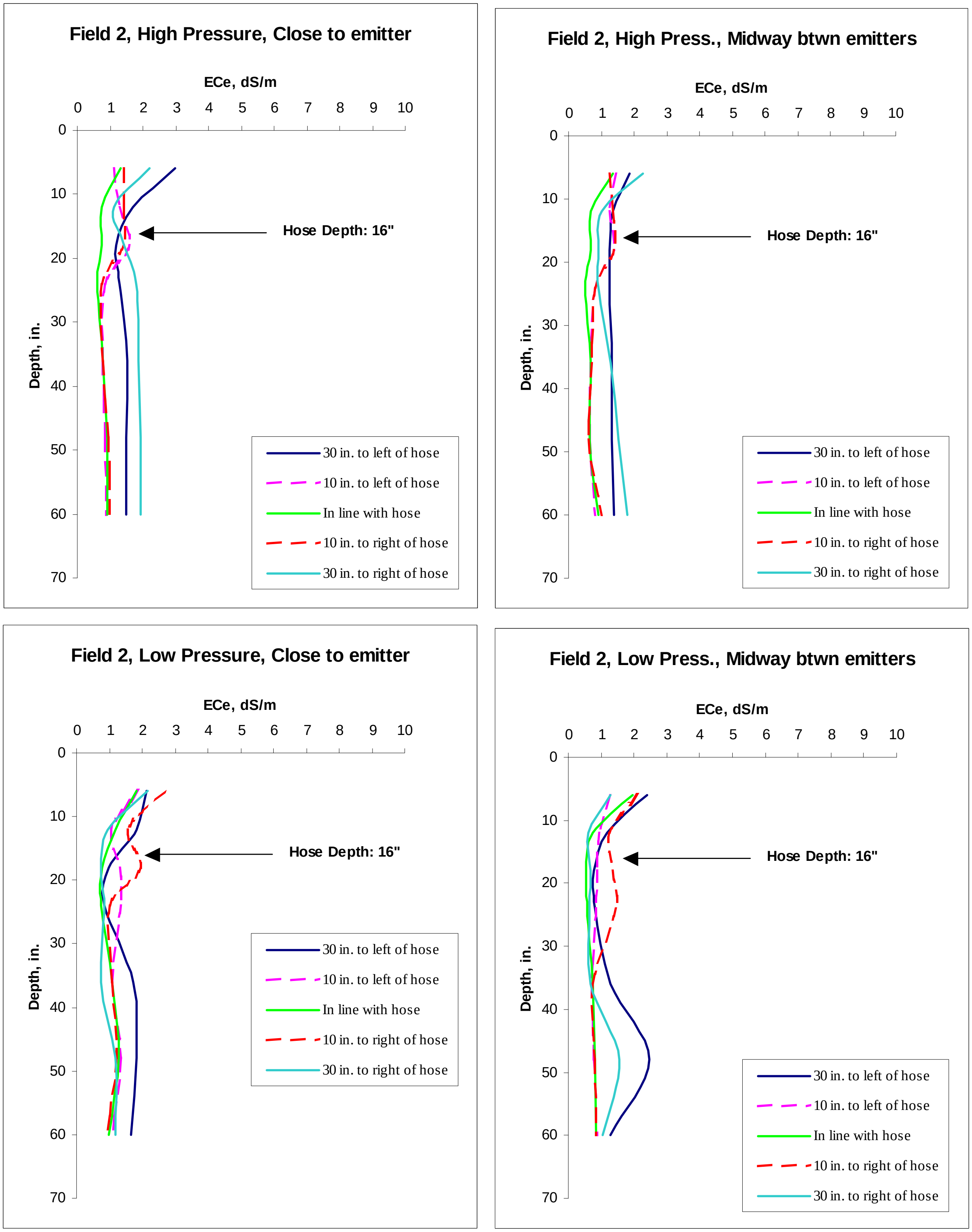


Figure 9. ECe (dS/m) as a function of horizontal position and depth at 4 locations in Field 2. Each graph has 5 curves: One shows the ECe directly in line with the SDI hose. Four represent the ECe some distance away from the hose (30" and 10", horizontally, on either side of the hose).

Figure 9 does not show a strong, uniform pattern of horizontal salt distribution in Field 2. The salinity curves 30” away from the hose tend to increase slightly below the hose depth, while curves 10” away from the hose decrease in salinity below the hose depth. In general, salinity is less at all depths in line with the hose. There does appear to be a vertical trend of increasing salinity towards the soil surface at all sample locations. This trend is more apparent in the next figure, which presents the ECe distribution as a function of depth for each sample location in Field 2.

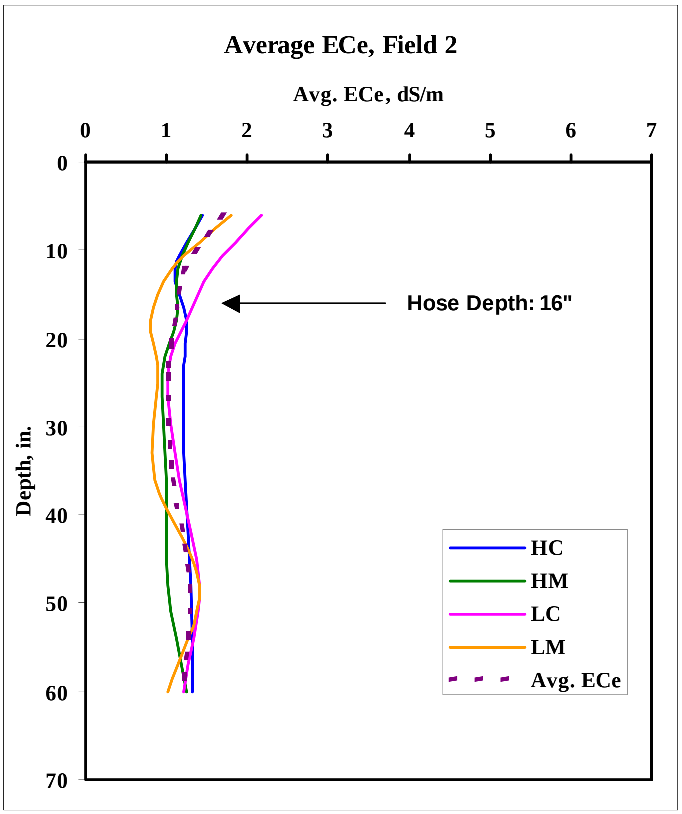


Figure 10. Change of ECe (dS/m) as a function of depth in inches in Field 2.

Figure 10 shows that although the 4 sample locations (HC, HM, LC, and LM) do not share a uniform pattern of salinity distribution with depth, the average trend is the same as in Field 1, though not as pronounced. In general, the salt concentration beneath the hose is relatively low, but at the soil surface it is slightly higher. This would indicate that the field has a relatively high leaching fraction, which causes water evaporation at the surface and leaching of salt below the hose. In addition, the irrigation season for melon is quite short, 3 to 4 months, which is not quite long enough for salt to build up.

Unfortunately, it is not possible to validate the high leaching fraction at this field since applied water data was unavailable. However, salinity values within the melon's effective root zone (30" depth), as well as the average field ECe for all sample locations at all depths, are below the 2.2 dS/m threshold ECe for melon.

Table 9. Average salinities (dS/m) within the root zone at the 4 sample locations in Field 2.

Depth	Field 2			
	HC	HM	LC	LM
12	1.10	1.14	1.57	1.06
18	1.25	1.11	1.25	0.81
24	1.20	0.94	1.02	0.90
36	1.24	0.99	1.16	0.86
48	1.31	1.02	1.40	1.41

Table 10. Comparison of threshold and measured ECe values (dS/m) for Field 2.

Field 2, Turlock Fruit Co.	
2001 Crop:	Melon
Threshold ECe:	2.2
Measured ECe:	1.25

Field 3

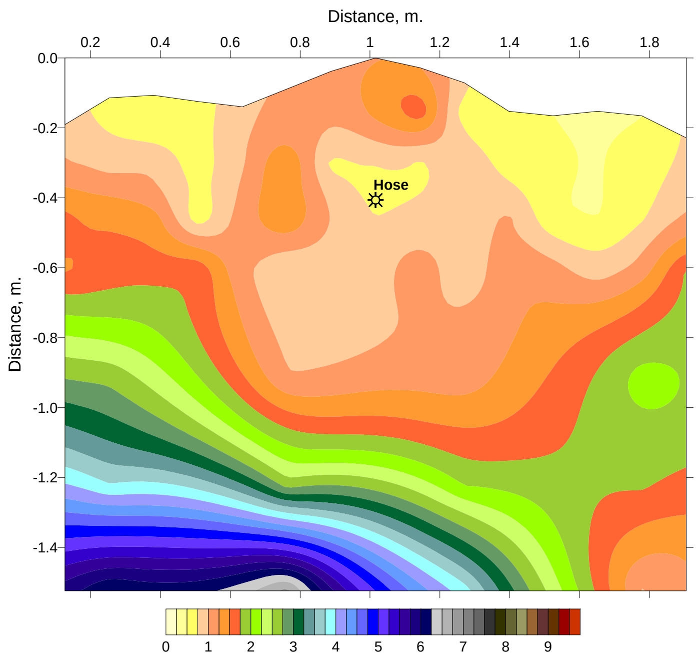
Soil samples were collected on September 13, 2001 at Field 3, which is also part of the Turlock Fruit Company. Field and irrigation system information for Field 3 is summarized below.

Table 11. Field information for Field 3.

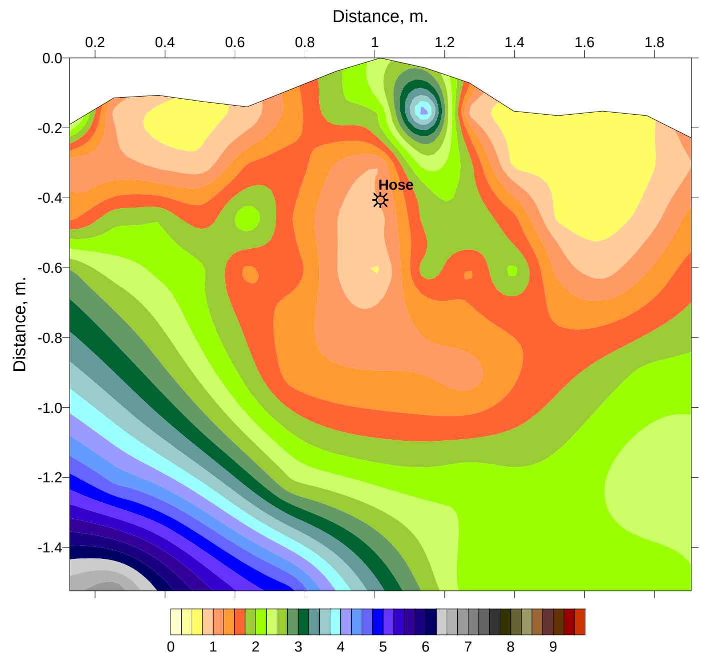
Field 3, Turlock Fruit Co.			
Acres:	74	Tape Type:	Python, 20.63 mm
Soil:	Clay loam	Tape Length:	approx. 1300 feet
2001 Crop:	Cotton	Depth Buried:	16 inches
Irr. Season Length:	6 mo.	Distance btwn. Tapes:	72 inches
Pre-Irrigate?	Yes	Pressure-Comp. Emitter?:	No
Water Supply:	Panoche WD	Distance btwn. Emitters:	18 inches
		System Age:	5 years

The salinity concentration contour maps for Field 3 are shown in the following figure. It is apparent that the salinity patterns at the high and low pressure locations are radically different. The high pressure locations (top) exhibit higher overall salinity, increasing with depth. The low pressure locations (bottom) exhibit low overall salinity, decreasing with depth.

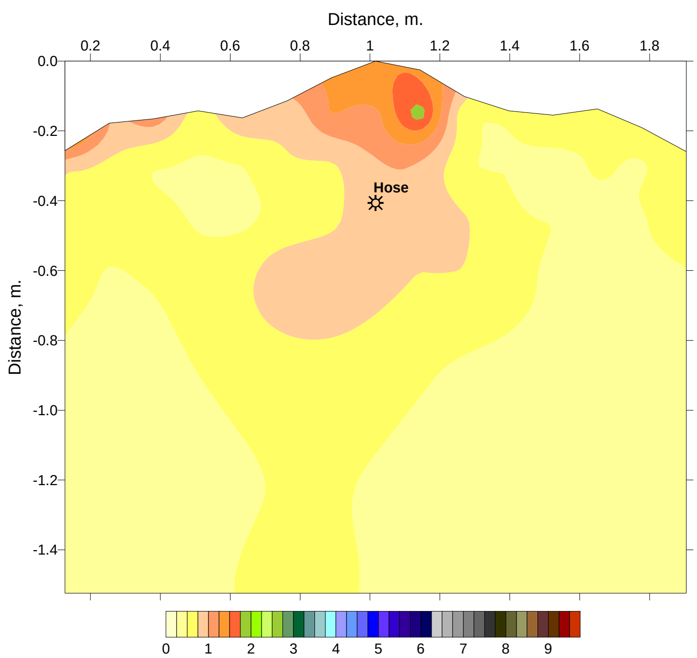
Field # 3 High Pressure, Close to the emitter; Interval = 0.25 dS/m.



Field # 3 High Pressure, Midway between two emitters; Interval = 0.25 dS/m.



Field # 3 Low Pressure, Close to the emitter; Interval = 0.25 dS/m.



Field # 3 Low Pressure, Midway between two emitters; Interval = 0.25 dS/m.

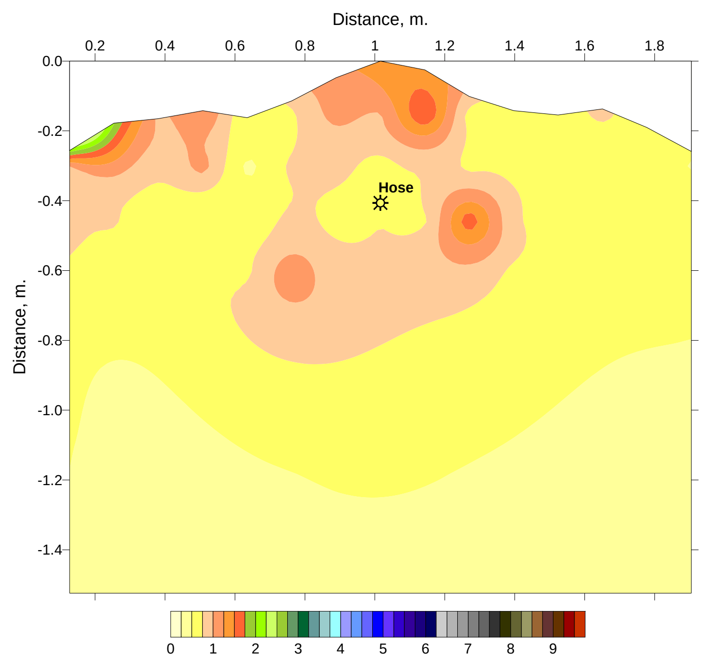


Figure 11. Salt distribution at 4 locations within Field 3.

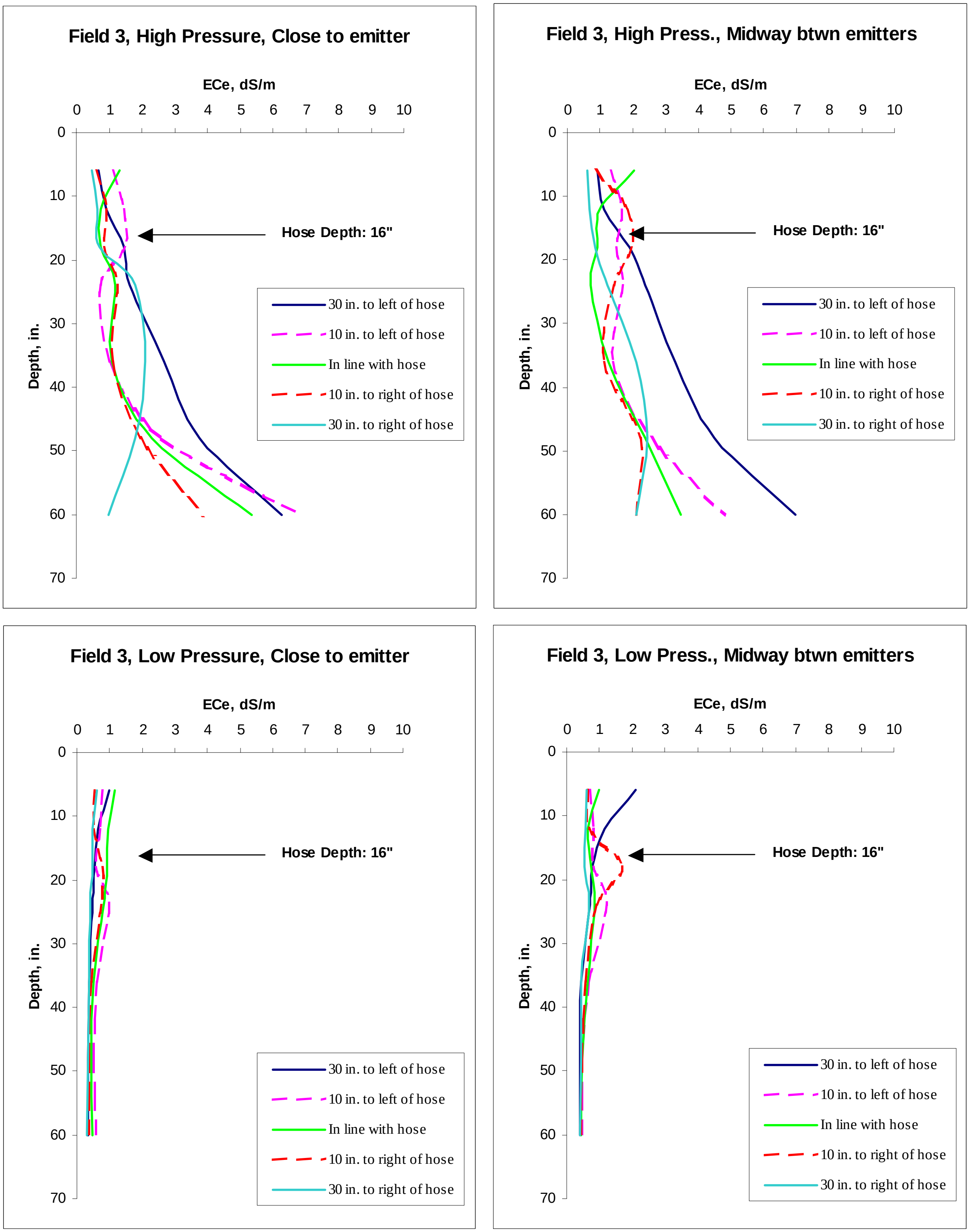


Figure 12. ECe (dS/m) as a function of horizontal position and depth at 4 locations in Field 3. Each graph has 5 curves: One shows the ECe directly in line with the SDI hose. Four represent the ECe some distance away from the hose (30" and 10", horizontally, on either side of the hose).

Figure 12 confirms the patterns seen in Figure 11. Although there are no pronounced patterns of salt distribution around the hose horizontally, there are obvious patterns of vertical salinity distribution at each of the pressure locations. This can be seen in the average ECe over depth for each of the 4 sample locations (Figure 13).

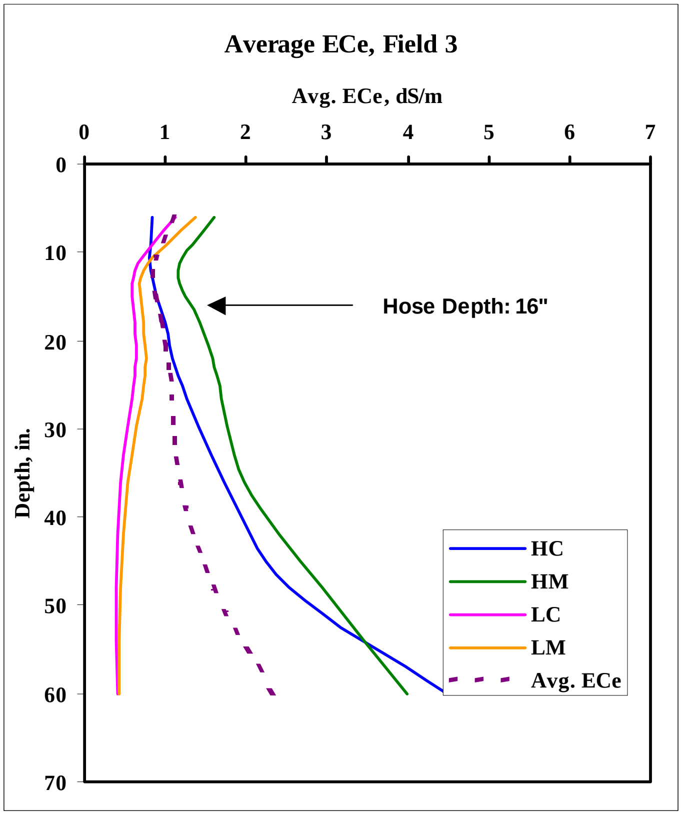


Figure 13. Change of ECe (dS/m) as a function of depth in inches in Field 3.

It is clear that the ECe patterns at the high pressure locations (HC and HM) are almost opposite to those found at the low pressure locations (LC and LM). The salt distribution profiles obtained under low hose pressure (LC and LM) follow the same general pattern already observed in Fields 1 and 2, with slight salt accumulation above the hose depth towards the soil surface and low salinity values below the hose depth. This pattern suggests the application of a high leaching fraction.

The profiles obtained under high pressure (HC and HM), however, are not only high overall, but also show a gradual increase in salt accumulation with depth, with the highest salinities at the bottom of the test depth. This pattern suggests the application of a low leaching fraction.

Unfortunately, without applied water data for this field, it was not possible to calculate the actual leaching fraction applied to this field and determine whether it was high or low. It is possible that the pattern seen at the low pressure locations is more representative of actual field conditions, while the pattern observed at the high pressure locations is a localized condition due to something such as a plugged emitter.

Even so, the observed salinity values at all locations were well below the ECe for cotton (7.7 dS/m) within the root zone. The average measured ECe for the whole field was also well within an acceptable range for this crop.

Table 12. Average salinities (dS/m) within the root zone at the 4 sample locations in Field 3.

Depth	Field 3			
	HC	HM	LM	LC
12	0.81	1.15	0.74	0.62
18	0.99	1.43	0.73	0.62
24	1.15	1.64	0.75	0.63
36	1.74	1.99	0.54	0.45
48	2.54	2.93	0.45	0.40

Table 13. Comparison of threshold, expected, and measured ECe values (dS/m) for Field 3.

Field 3, Turlock Fruit Co.	
2001 Crop:	Cotton
Threshold ECe:	7.7
Measured ECe:	1.44

Field 4

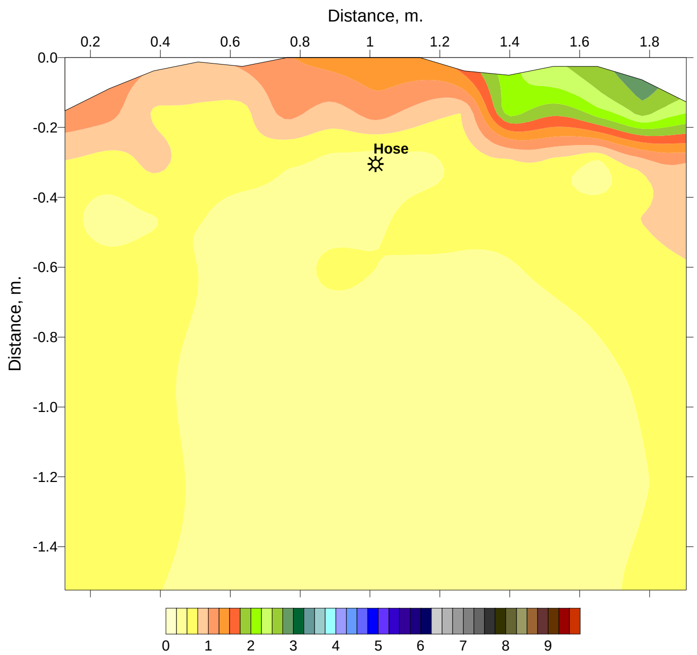
Field 4 belongs to Joe Del Bosque Farms. Soil samples were collected in this field on September 18, 2001. Field and irrigation system information are summarized below.

Table 14. Field information for Field 4.

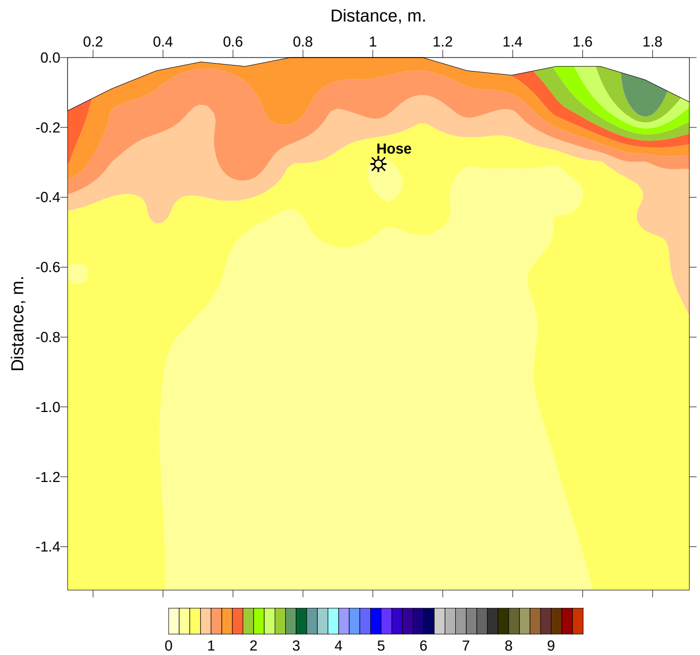
Field 4, Joe Del Bosque			
Acres:	53	Tape Type:	Python, 20.63 mm, 0.23 GPH
Soil:	Clay loam	Tape Length:	450-1280 feet
2001 Crop:	Melon	Depth Buried:	12 inches
Irr. Season Length:	3-4 mo.	Distance btwn. Tapes:	80 inches
Pre-Irrigate?	Yes	Pressure-Comp. Emitter?:	Yes
Water Supply:	San Luis WD	Distance btwn. Emitters:	18 inches
		System Age:	5 years

The salinity concentration contour maps for Field 4 are presented in the following figure. The high pressure locations (top) in Field 4 present a clear pattern of salinity distribution, with a slight increase in salinity above the hose depth towards the soil surface, and almost uniform salinity directly below the hose. The low pressure locations (below) have a less distinct pattern of distribution, but also have low salinities below the hose.

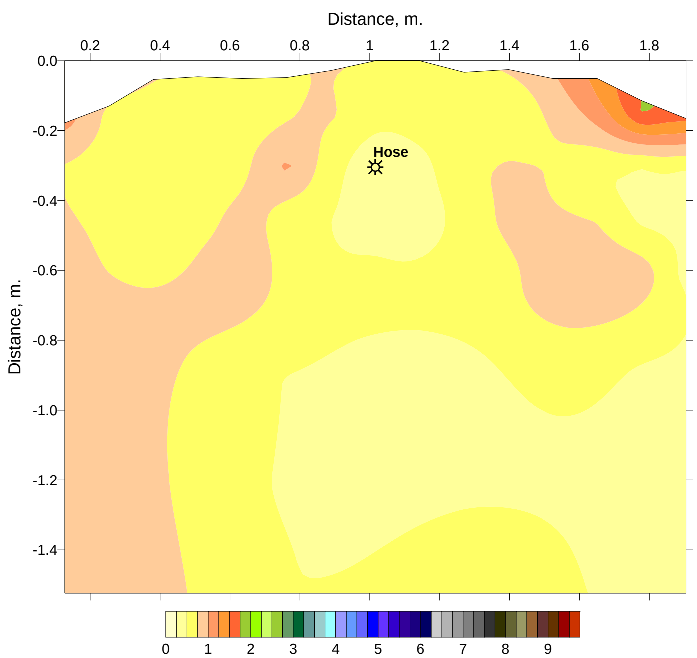
Field # 4 High Pressure, Close to the emitter; Interval = 0.25 dS/m.



Field # 4 High Pressure, Midway between two emitters; Interval = 0.25 dS/m.



Field # 4 Low Pressure, Close to the emitter; Interval = 0.25 dS/m.



Field # 4 Low Pressure, Midway between two emitters; Interval = 0.25 dS/m.

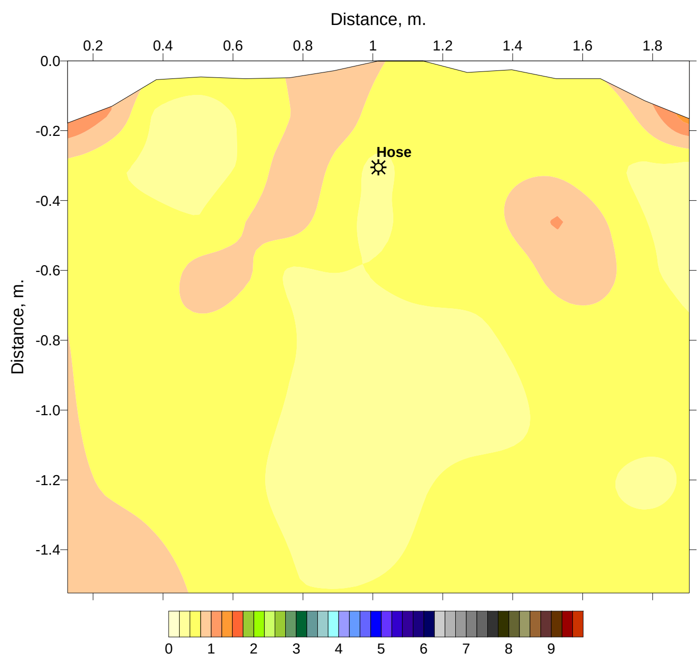


Figure 14. Salt distribution at 4 locations within Field 4.

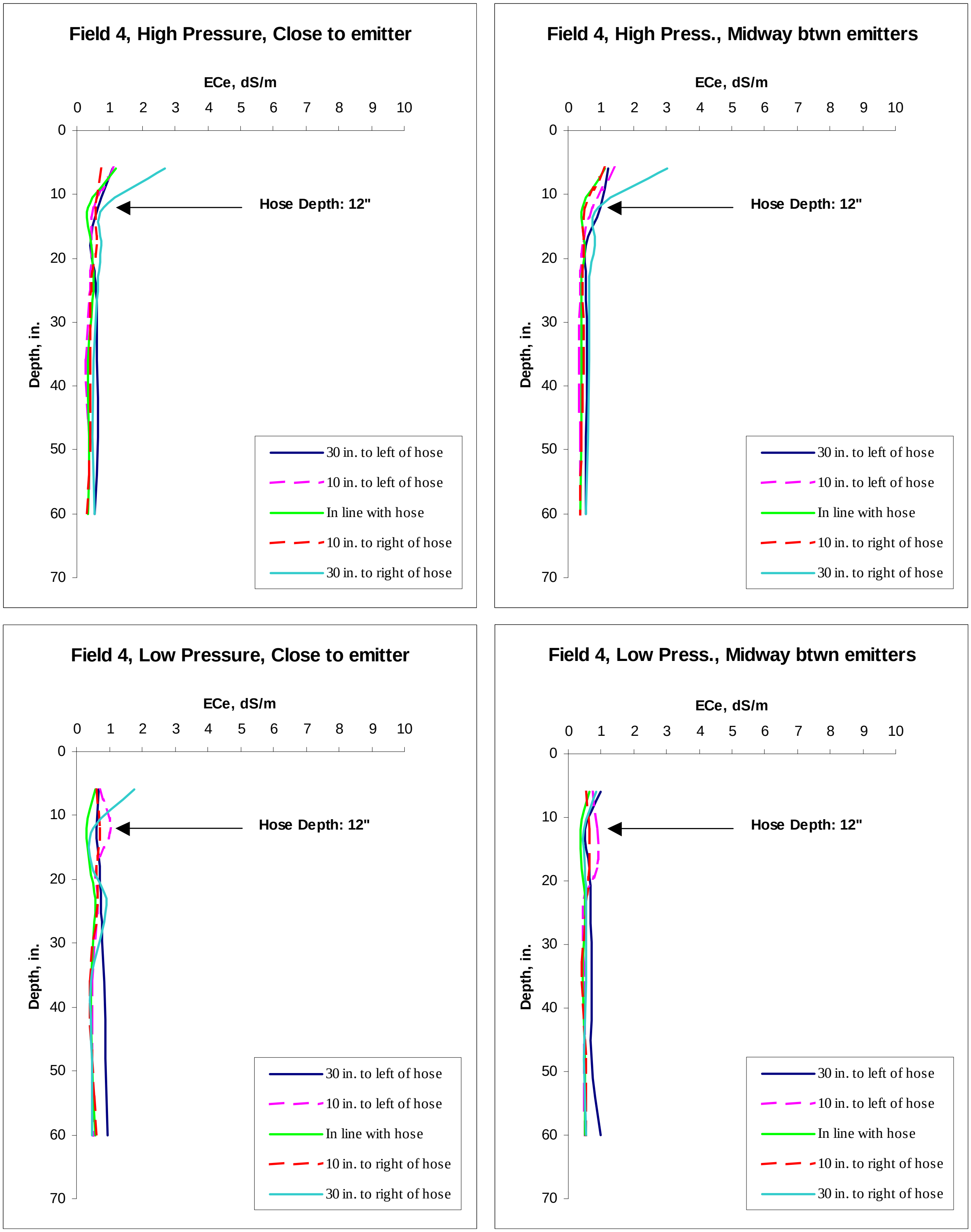


Figure 15. ECe (dS/m) as a function of horizontal position and depth at 4 locations in Field 4. Each graph has 5 curves: One shows the ECe directly in line with the SDI hose. Four represent the ECe some distance away from the hose (30" and 10", horizontally, on either side of the hose).

Although Field 4 has one of the widest tape spacings (80 inches) of the six fields, salt build up away from the hose, between the beds is not apparent. Figure 15 shows that, other than a slightly higher soil surface salinity accumulation 30 inches to the right of the hose, the horizontal profiles are almost identical, regardless of their distance away from the hose. All present a small increase in salinity above the hose and uniform salinity below the hose. This vertical pattern is present at all 4 sample locations (Figure 16).

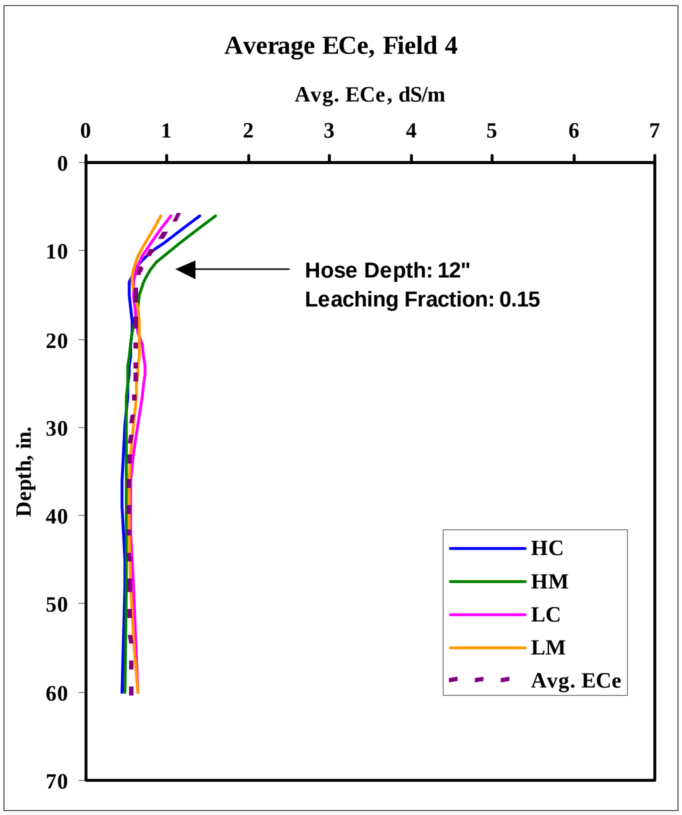


Figure 16. Change of ECe (dS/m) as a function of depth in inches in Field 4.

Field 4's vertical salinity distribution follows the same general pattern seen so far in Fields 1, 2, and the low pressure locations in Field 3, though the salinity levels in Field 4 are overall much lower and especially uniform below the hose depth.

Field 4 exhibits the lowest salinities of the six fields, and also has, not surprisingly, the highest leaching fraction (table below).

Table 15. Leaching fraction for Field 4, 1999-2001.

Crop	Year	ECw, dS/m	Threshold ECe, dS/m	*Needed LF*	Applied Irr. Water, in.	Deep Perc., in.	*Actual LF*
Cotton	1999	0.43	7.7	*0.01*	27.17	0	*0.00*
Melon	2000	0.39	2.2	*0.04*	10.19	0.55	*0.05*
Melon	2001	0.51	2.2	*0.05*	18.00	7.73	*0.43*
	Average:	**0.44**	**2.2**	***0.04***	**55.36**	**8.28**	***0.15***

Although the leaching fractions applied in 1999 and 2000 were either less or only slightly more than needed, the exceedingly high leaching fraction applied in 2001 (0.43) probably washed any prior salinity accumulation below the hose out of the 60-inch test depth.

Other contributing factors to Field 4's low salinities could include a) the short irrigation season for melon (3-4 mo.), which is not long enough for salt to accumulate, b) good system design, which allows irrigation water to be distributed uniformly across the field, and c) the fact that the field is located next to a San Luis WD canal, from which it might receive canal seepage water.

As can be seen from the table below, average salinities within the root zone of Field 4 are well below melon's ECe threshold of 2.2 dS/m.

Table 16. Average salinities (dS/m) within the root zone at the 4 sample locations in Field 4.

Depth	Field 4			
	HC	HM	LC	LM
12	0.61	0.80	0.62	0.58
18	0.57	0.60	0.62	0.66
24	0.54	0.51	0.72	0.64
36	0.45	0.50	0.55	0.54
48	0.48	0.49	0.58	0.55

It should also be noted in Table 17, below, that the measured average field ECe shows good agreement with the calculated, anticipated ECe.

Table 17. Comparison of threshold, expected, and measured ECe values (dS/m) for Field 4.

Field 4, Joe Del Bosque	
2001 Crop:	Melon
Threshold ECe:	2.2
Anticipated ECe:	0.68
Measured ECe:	0.63

Field 5

Soil samples were gathered in Field 5, part of Joe Del Bosque Farms, on September 19, 2001. General field and irrigation system information for this field is presented below.

Table 18. Field information for Field 5.

Field 5, Joe Del Bosque			
Acres:	107	Tape Type:	Python, 20.63 mm, 0.23 GPH
Soil:	Clay loam	Tape Length:	approx. 1300 feet
2001 Crop:	Oat	Depth Buried:	12 inches
Irr. Season Length:	4 mo.	Distance btwn. Tapes:	92 inches
Pre-Irrigate?	Yes	Pressure-Comp. Emitter?:	No
Water Supply:	San Luis WD	Distance btwn. Emitters:	18 inches
		System Age:	4 years

Since Field 5 has the widest tape spacing (92 inches) at the shallowest buried depth (12 inches) of all the fields, it would be expected that this field would show signs of salt build up on the soil surface (due to more evaporation) and in between the beds, away from the hose. However, both Figures 17 and 18 show that this was not the case. In fact, similar to Field 4, this field shows low overall salinities and fairly uniform distribution of salinity both horizontally and vertically below the hose depth.

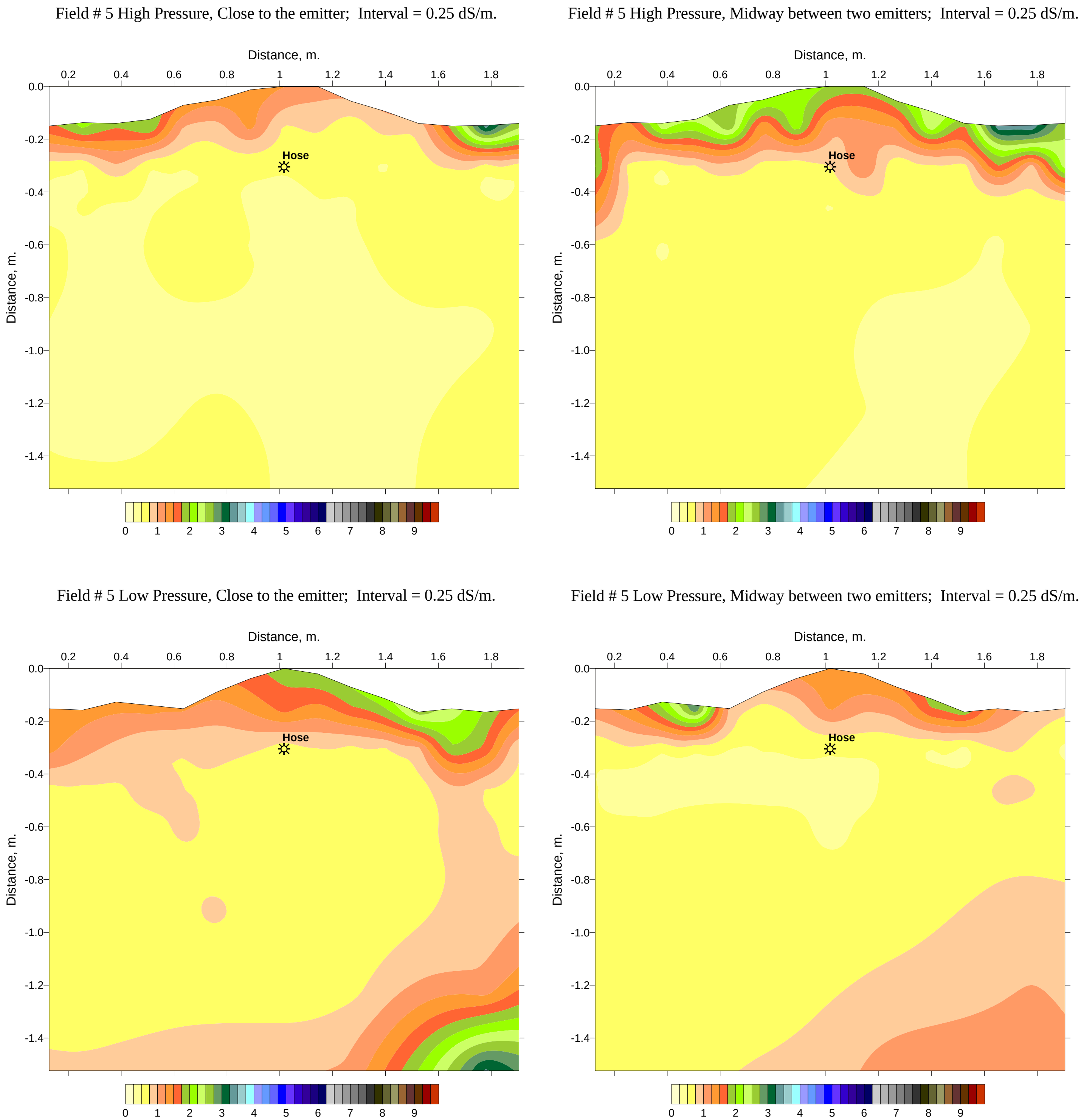


Figure 17. Salt distribution at 4 locations within Field 5.

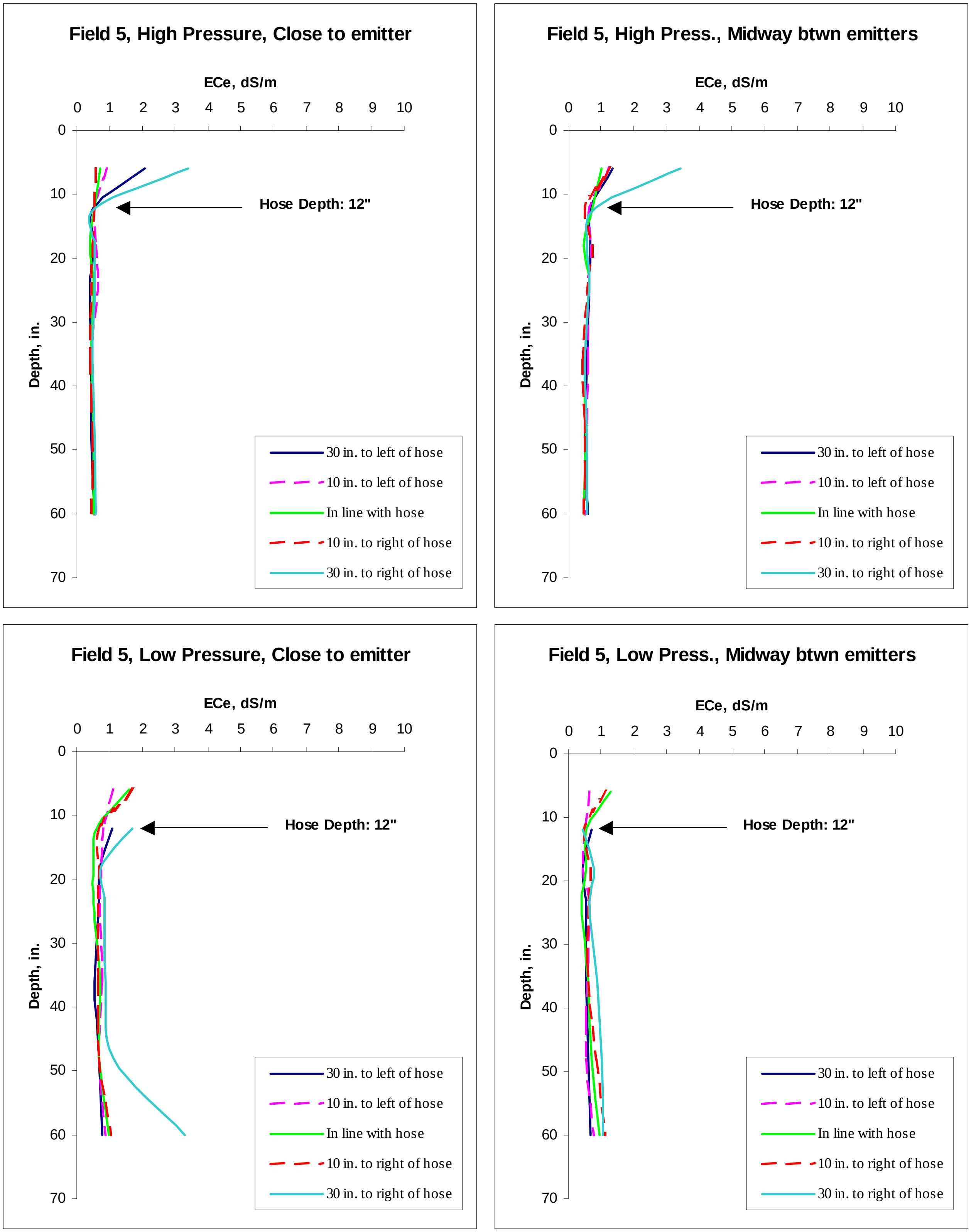


Figure 18. ECe (dS/m) as a function of horizontal position and depth at 4 locations in Field 5. Each graph has 5 curves: One shows the ECe directly in line with the SDI hose. Four represent the ECe some distance away from the hose (30" and 10", horizontally, on either side of the hose).

Other than the pocket of salinity accumulation at the bottom of the LC sample location, 30 inches to the right of the hose at the, the various horizontal profiles seem very similar. This can also be seen in Figure 19, which presents the average profiles for each of the four sample locations.

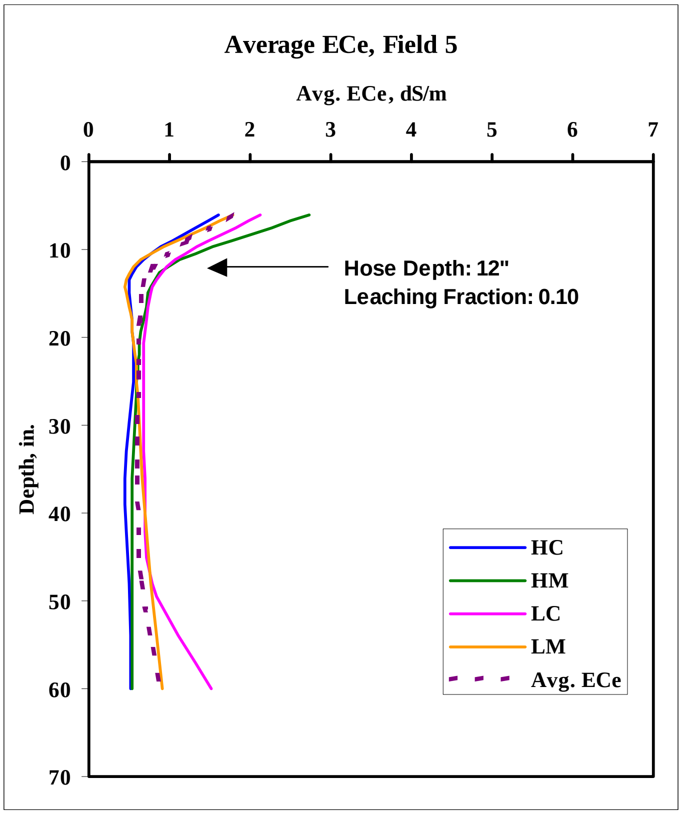


Figure 19. Change of ECe (dS/m) as a function of depth in inches in Field 5.

The profiles from Field 5 match the vertical salinity distribution seen Field 1, Field 2, the low pressure locations of Field 3, and Field 4. In Field 5, there is a marked increase in salinity above the hose depth to the soil surface. Salinities below the hose remain low, especially at the high pressure locations. This is indicative of the application of a high leaching fraction. As can be seen in the table below, Field 5 does have a high total leaching fraction (0.10) for 1998-2001, with an especially large leaching fraction (0.37) applied in 1999.

Table 19. Leaching fraction for Field 5, 1998-2001.

Crop	Year	ECw, dS/m	Threshold ECe, dS/m	*Needed LF*	Applied Irr. Water, in.	Deep Perc., in.	*Actual LF*
Cotton	1998	-	7.7	-	23.27	0	*0.00*
Melon	1999	0.43	2.2	*0.04*	18.67	6.91	*0.37*
Cotton	2000	0.39	7.7	*0.01*	32.58	2.15	*0.07*
Oat	2001	0.51	3.0	*0.04*	11.89	0	*0.00*
	Average:	**0.44**	**3.0**	***0.03***	**63.14**	**9.06**	***0.14***

It is possible that the large leaching fraction applied in 1999 was sufficient to wash accumulated salinity out of the test zone, and that, with only 10 months of irrigation in 2000 and 2001 (6 months for cotton and 4 months for oat), salinity has not had time to build up significantly since then. The slightly higher ECe values at the bottom right of the low pressure locations could be the beginnings of new salinity accumulation, and/or indicative of a slight pressure variation along the hose, perhaps due to the fact that the emitters are not pressure compensating.

However, ECe values within the root zone at all sample locations are within the tolerance level of oat, which is moderately tolerant of salinity.

Table 20. Average salinities (dS/m) within the root zone at the 4 sample locations in Field 5.

Depth	Field 5			
	HC	HM	LC	LM
12	0.60	0.99	0.97	0.56
18	0.54	0.68	0.71	0.54
24	0.54	0.60	0.67	0.60
36	0.45	0.53	0.71	0.66
48	0.50	0.54	0.79	0.76

Note also the acceptable level of agreement between the anticipated and measured ECe for the field as a whole.

Table 21. Comparison of threshold, expected, and measured ECe values (dS/m) for Field 5.

Field 5, Joe Del Bosque	
2001 Crop:	Oat
Threshold ECe:	moderate
Anticipated ECe:	0.9
Measured ECe:	0.82

Field 6

Field 6 is also part of Joe Del Bosque Farms. Soil samples were collected there on September 20, 2001. Field and irrigation system information is summarized in the table below.

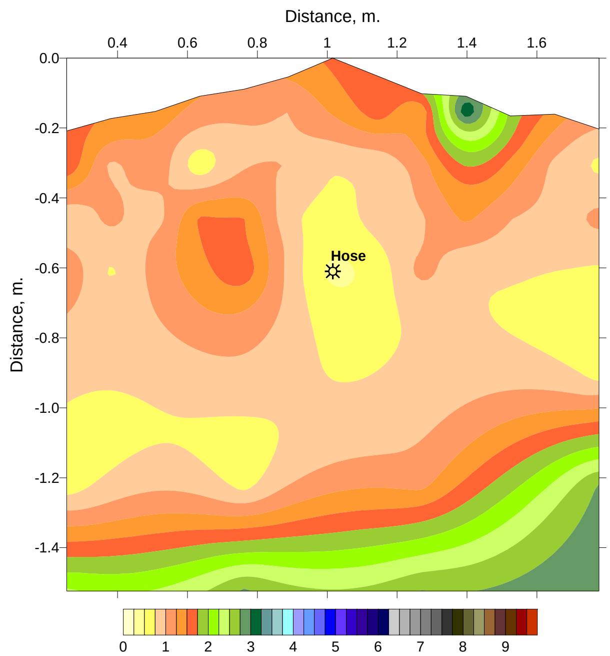
Table 22. Field information for Field 6.

Field 6, Joe Del Bosque			
Acres:	120	Tape Type:	Geoflow, 18 mm, 0.42 GPH
Soil:	Clay loam	Tape Length:	approx. 800 feet
2001 Crop:	Asparagus	Depth Buried:	24 inches
Irr. Season Length:	8-9 mo.	Distance btwn. Tapes:	35 inches
Pre-Irrigate?	No	Pressure-Comp. Emitter?:	Yes
Water Supply:	San Luis WD	Distance btwn. Emitters:	24 inches
		System Age:	3 years

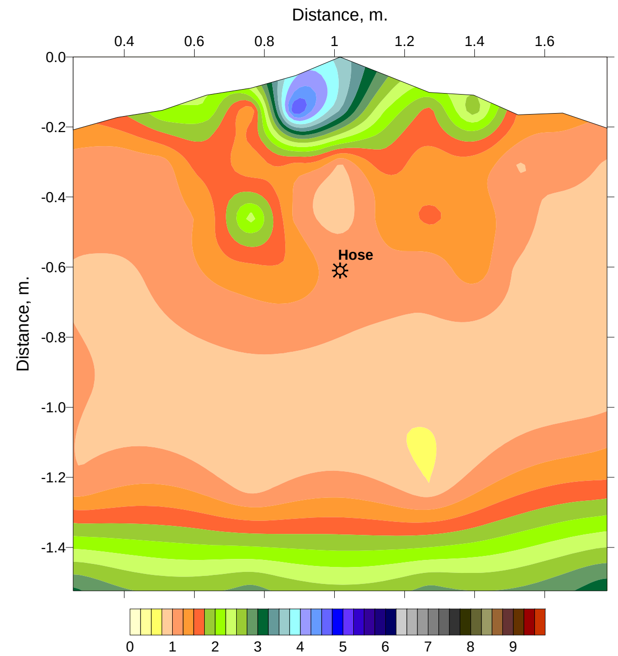
Field 6 was also the only field that was not pre-irrigated. This field also had the deepest burial depth (24 inches), the narrowest tape spacing (35 inches) and the widest emitter spacing (24 inches) of all the fields. Due to the narrow tape spacing, the sample area width was reduced by 5 inches on both sides, making the total width 70 inches instead of 80 inches.

Salinity profiles for Field 6 are shown in Figure 20. From this figure, it is clear that the high pressure locations (top) exhibit salinity accumulation at the top and bottom of the test zone. The low pressure locations (bottom) do not show such strong accumulation at the bottom. This is also apparent in Figures 21 and 22.

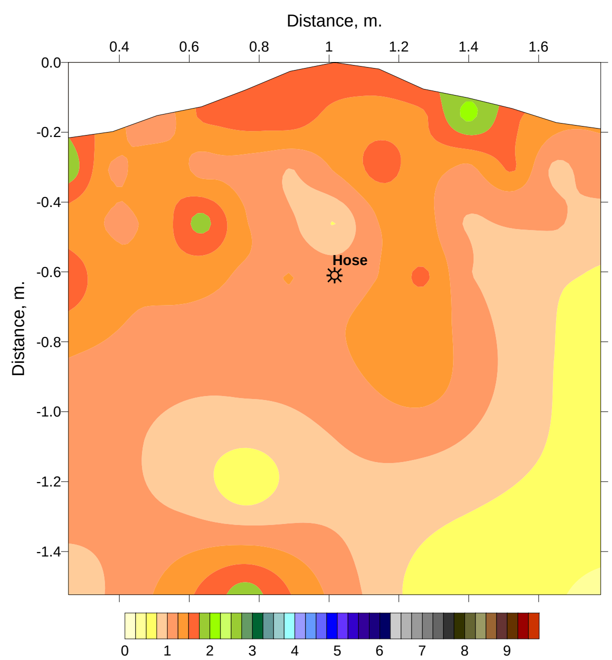
Field # 6 High Pressure, Close to the emitter; Interval = 0.25 dS/m.



Field # 6 High Pressure, Midway between two emitters; Interval = 0.25 dS/m.



Field # 6 Low Pressure, Close to the emitter; Interval = 0.25 dS/m.



Field # 6 Low Pressure, Midway between two emitters; Interval = 0.25 dS/m.

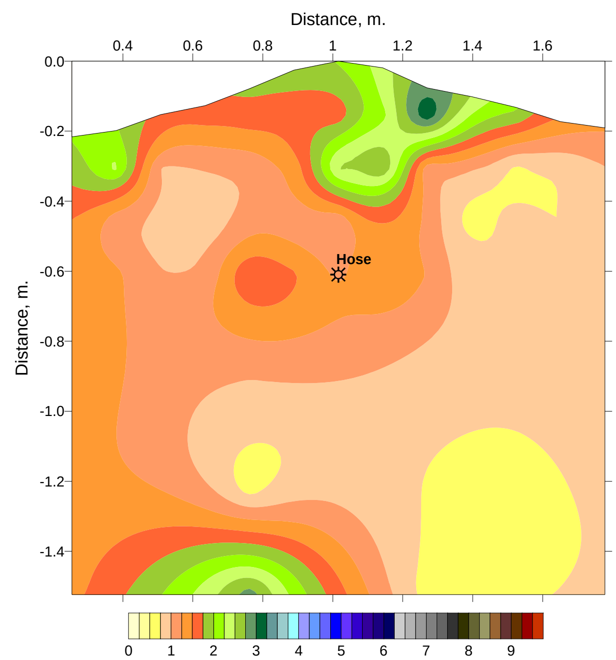


Figure 20. Salt distribution at 4 locations within Field 6.

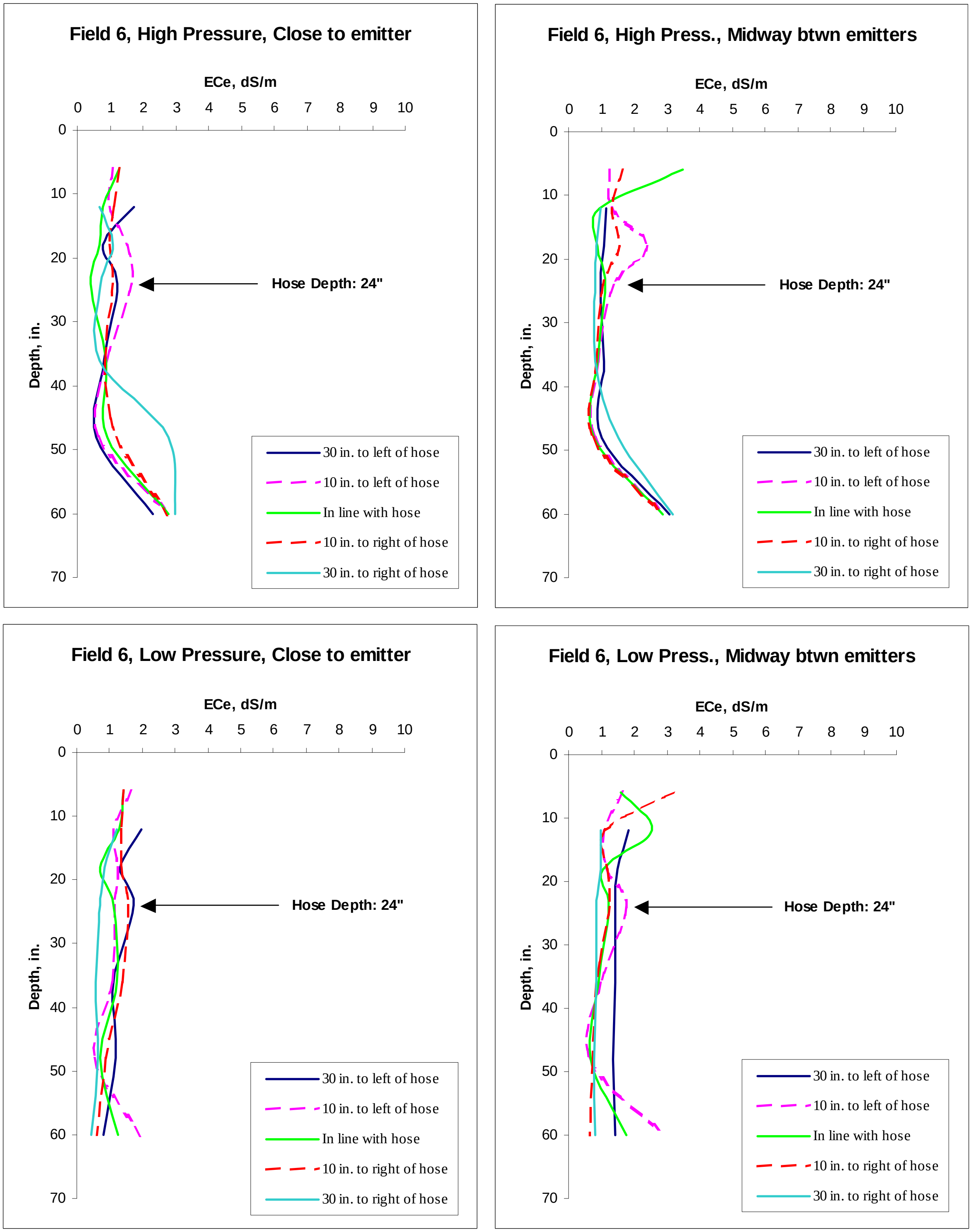


Figure 21. ECe (dS/m) as a function of horizontal position and depth at 4 locations in Field 6. Each graph has 5 curves: One shows the ECe directly in line with the SDI hose. Four represent the ECe some distance away from the hose (30" and 10", horizontally, on either side of the hose).

Figure 21 shows that the salinity distribution throughout the soil profiles is definitely not uniform. However, the general trends for each sample location, shown in Figure 22, agree with the observations noted from Figure 20.

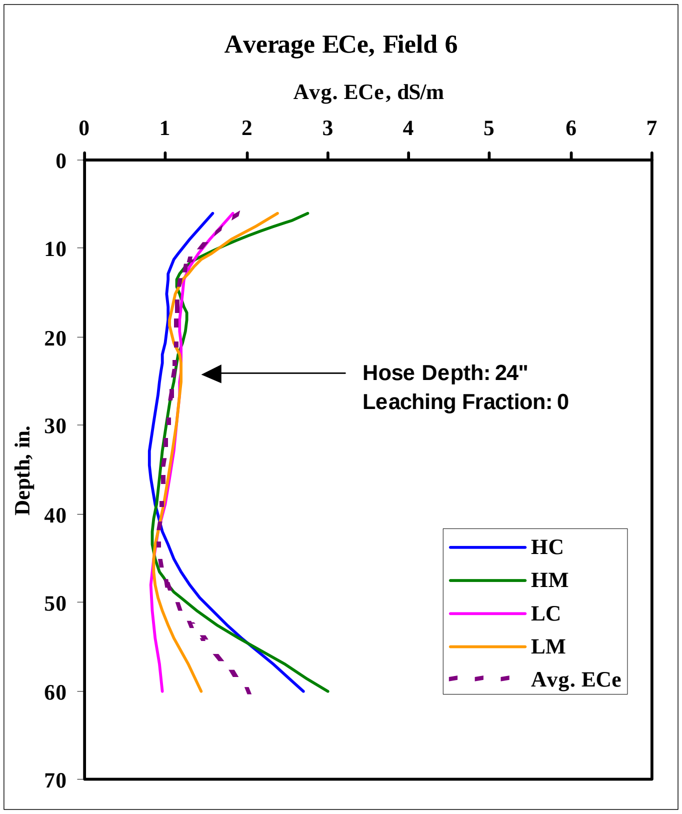


Figure 22. Change of ECe (dS/m) as a function of depth in inches in Field 6.

It is clear that all sample locations show an increase in salinity content towards the soil surface. However, there seems to be notable difference between the high pressure and the low pressure locations. The low pressure curves (LC and LM) are similar to the trend seen in the other fields, with slight salinity accumulations at the surface and low salinities below the hose depth. Although the LM curve shows a slight salinity accumulation at the bottom, it is still less than the surface accumulation.

The high pressure locations (HC and HM), however, exhibit a strong increase in salinity concentrations at lower depths, similar to what was seen at the high pressure locations in

Field 3. In both cases, accumulation at the bottom of the test zone is greater than accumulation at the soil surface.

The contrast between the low and high pressure sites is not as marked as in Field 3. This makes it difficult to determine the pattern seen that the high pressure sites is due to a localized condition such as a plugged emitter (as is most likely in Field 3), or if it results from the general application of a low leaching fraction.

As noted earlier, this was the only field without pre-irrigation. It was also the only field on which water was applied without considering a leaching fraction. As is evident in the following table, the needed annual leaching fraction was not met and no deep percolation at all occurred from 1999-2001.

Table 23. Leaching fraction for Field 6, 1999-2001.

Crop	Year	ECw, dS/m	Threshold ECe, dS/m	*Needed LF*	Applied Irr. Water, in.	Deep Perc., in.	*Actual LF*
Asparagus	1999	0.43	4.1	*0.02*	23.5	0	*0.00*
Asparagus	2000	0.39	4.1	*0.02*	28.8	0	*0.00*
Asparagus	2001	0.51	4.1	*0.03*	25.5	0	*0.00*
	Average:	**0.44**	**4.1**	***0.02***	**77.80**	**0.00**	***0.00***

Even so, ECe levels within the root zone were below the 4.1 dS/m threshold ECe for asparagus.

Table 24. Average salinities (dS/m) within the effective root zone at the 4 sample locations in Field 6.

Depth	Field 6			
	HC	HM	LC	LM
12	1.07	1.24	1.31	1.35
18	1.03	1.17	1.17	1.04
24	0.93	1.11	1.19	1.18
36	0.82	0.92	1.05	1.04
48	1.29	1.04	0.82	0.88

Since the leaching fraction applied to this field was 0, it was not possible to calculate an expected ECe for this field. However, the average measured field ECe was also below asparagus' threshold.

Table 25. Comparison of threshold, expected, and measured ECe values (dS/m) for Field 6.

Field 6, Joe Del Bosque	
2001 Crop:	Asparagus
Threshold ECe:	4.1
Anticipated ECe:	undefined
Measured ECe:	1.34

Control Fields

Since initial analysis of data from the six SDI fields revealed that salinity accumulation did not appear to be a problem in the SDI fields, only limited soil sampling was done in the control fields. Only two locations were sampled in each control fields, with 9 to 12 soil samples taken for each location (as opposed to up to 72 samples per location on the SDI fields). These samples were not taken according to the sample grid used on the SDI fields, but were taken differently in every control field. Columns of samples were spaced 15 to 20 inches apart, horizontally. Within each column, samples were vertically spaced at 12 inches. For comparison's sake, the all figures within this section are shown at the same scale as the earlier SDI figures. Sample locations and salinities are also indicated on the figures.

Soil samples in the control fields were gathered in February and March 2002, 5-6 months after samples were gathered in the SDI fields.

Control Field 1

Soil samples were gathered at Control Field 1, which belongs to the Turlock Fruit Co, on February 13, 2002. Field information is summarized in the table below. ECe contour graphs are shown in the following figure.

Table 26. Field information for Control Field 1.

Control Field 1, Turlock Fruit Co.	
Crop:	Garlic
Irrigation Method:	Surface
Water Supply:	Panoche WD
Typical Furrow Length:	1300 feet
Distance btwn. Furrows:	80 inches

Control Field 1, Site 1; Interval = 0.25 dS/m. Control Field 1, Site 2; Interval = 0.25 dS/m.

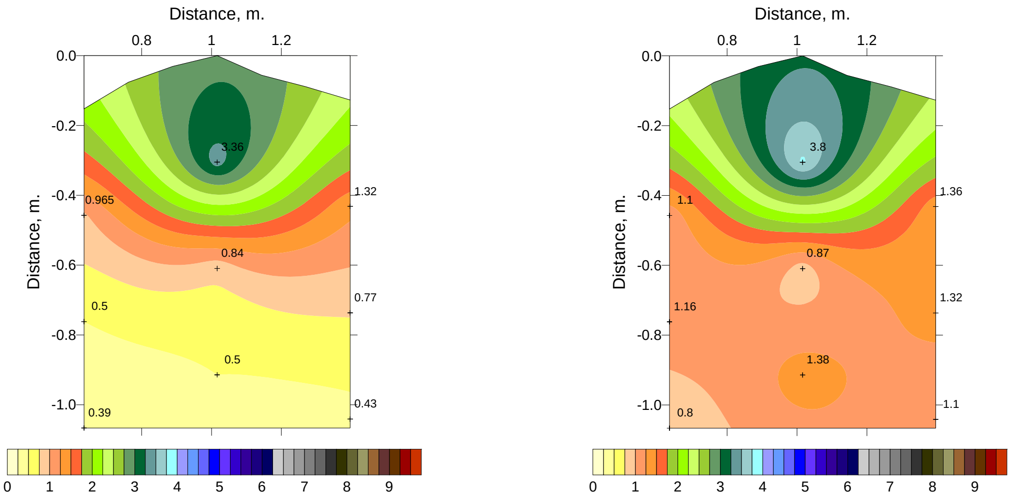


Figure 23. Salt distribution at 2 locations within Control Field 1.

From Figure 23, it is clear that, similar to most of the SDI field locations, salinity values near the soil surface are much higher than salinity values further down. With furrow irrigation, as with SDI irrigation, water reaches the top of the beds from below, by capillary action. Water (and salts) moves downward from the furrow bottoms, then out between the furrows and up into the top of the beds between the furrows. Evaporation and plant uptake then remove the water from the bed, leaving the salts behind at the top of the beds.

Control Field 2

Control Field 2 belongs to Joe Del Bosque Farms. Soil samples were also collected February 13, 2002. Field information is summarized below. Contour graphs are shown thereafter.

Table 27. Field information for Control Field 2.

Control Field 2, Joe Del Bosque	
Crop:	Cotton
Irr. Season Length:	6 mo.
Irrigation Method:	Furrow or Sprinkler (depend. on crop)
Water Supply:	San Luis WD
Distance btwn. Furrows:	80 inches

Control Field 2, Site 1; Interval = 0.25 dS/m. Control Field 2, Site 2; Interval = 0.25 dS/m.

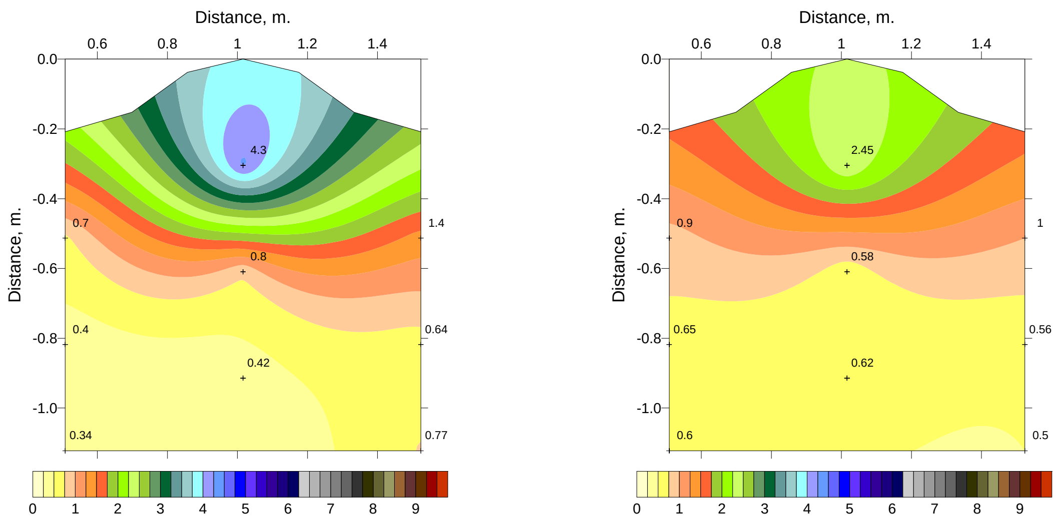


Figure 24. Salt distribution at 2 locations within Control Field 2.

This control field shows a similar pattern of salt accumulation to that seen in Control Field 1 and the SDI fields. Salt has also accumulated at the tops of the beds due to evaporation and plant water uptake.

Control Field 3

Soil samples were collected at Control Field 3, another Joe Del Bosque Farms field, on February 13, 2002 as well. Field information and contour graphs follow.

Table 28. Field information for Control Field 3.

Control Field 3, Joe Del Bosque	
Crop:	Melon
Irr. Season Length:	3-4 mo.
Irrigation Method:	Furrow or Sprinkler (depend. on crop)
Water Supply:	San Luis WD
Distance btwn. Furrows:	80 inches

Control Field 3, Site 1; Interval = 0.25 dS/m. Control Field 3, Site 2; Interval = 0.25 dS/m.

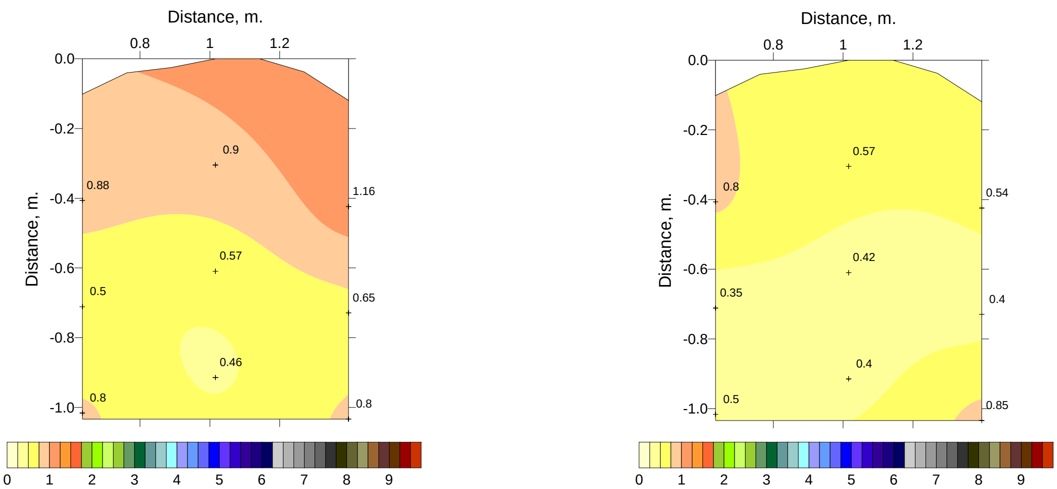


Figure 25. Salt distribution at 2 locations within Control Field 3.

This field shows minimal salt accumulation, even at the soil surface. However, values still tend to decrease with depth.

<u>Control Field 4</u>

Control Field 4 belongs to Hammonds Ranch. Soil samples were gathered here on March 29, 2002. Field information and contour graphs are given below.

Table 29. Field information for Control Field 4.

Control Field 4, Hammonds Ranch	
Crop:	Tomato
Irrigation Method:	Furrow
Water Supply:	Panoche WD
Distance btwn. Furrows:	80 inches

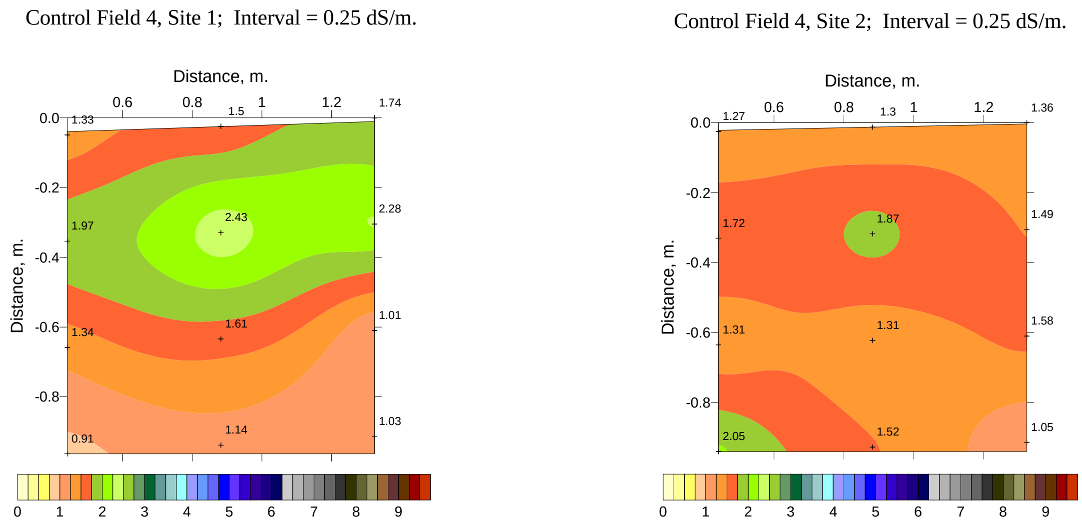


Figure 26. Salt distribution at 2 locations within Control Field 4.

Although this field does not show the increase in salinity at the soil surface, values at Site 1 (left) and on the right in Site 2 (right) still tend to decrease with depth.

DISCUSSION AND COMPARISON

This section consists of several parts. First, a discussion of the results from all 6 SDI fields will be made. This discussion will look at patterns of horizontal and vertical salinity distribution and will make comparisons between pressure locations within and between the six fields. Average ECe and leaching fraction information will also be compared between the six fields.

Then, fields on which the same crop was grown will be compared (asparagus – Fields 1 and 6; melon – Fields 2 and 4). Finally, a short comparison with the control fields will be made between the SDI and the control fields.

SDI Fields

Due to the wide hose spacing (80”) commonly used in the area of study, it was thought that salt might accumulate at the edges of the wetted patterns, between the beds and emitters. For this reason depth profiles were developed for locations at a various distances from the hose: in line with the hose, 10 inches away from the hose on either side, and 30 inches away on either side. However, as the figure below shows, although salinity was found to increase some 30 inches away from the hose, especially to the left of the hose, the increase with horizontal distance from the hose was not great.

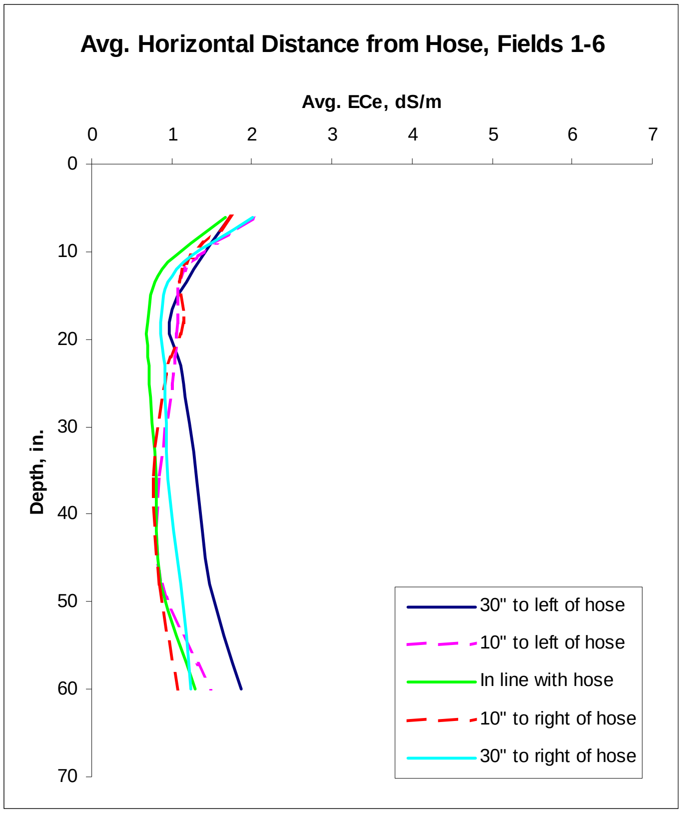


Figure 27. Salinity at various horizontal locations from the SDI hose, for all six SDI fields.

It was also thought that increased salinity buildup might be seen between emitters, along the hose. However, as the next figure illustrates, this was not at all the case. There is hardly any difference between the average salinities at sample locations close to the emitters and sample locations midway between emitters (approximately 6 inches away from an emitter). Horizontal distance from the emitter was not found to lead to an increase in salinity in the fields studied.

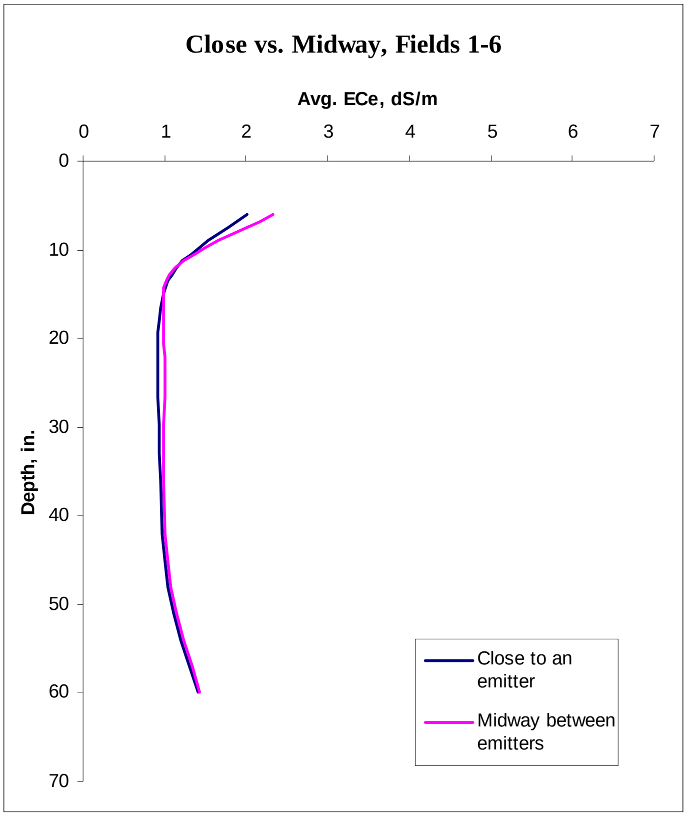


Figure 28. Salinity per depth for sample locations close to an emitter and midway between emitters for all six SDI fields.

The next figure also illustrates that locations between emitters did not consistently have higher ECe values than their counterparts close to an emitter, as was expected.

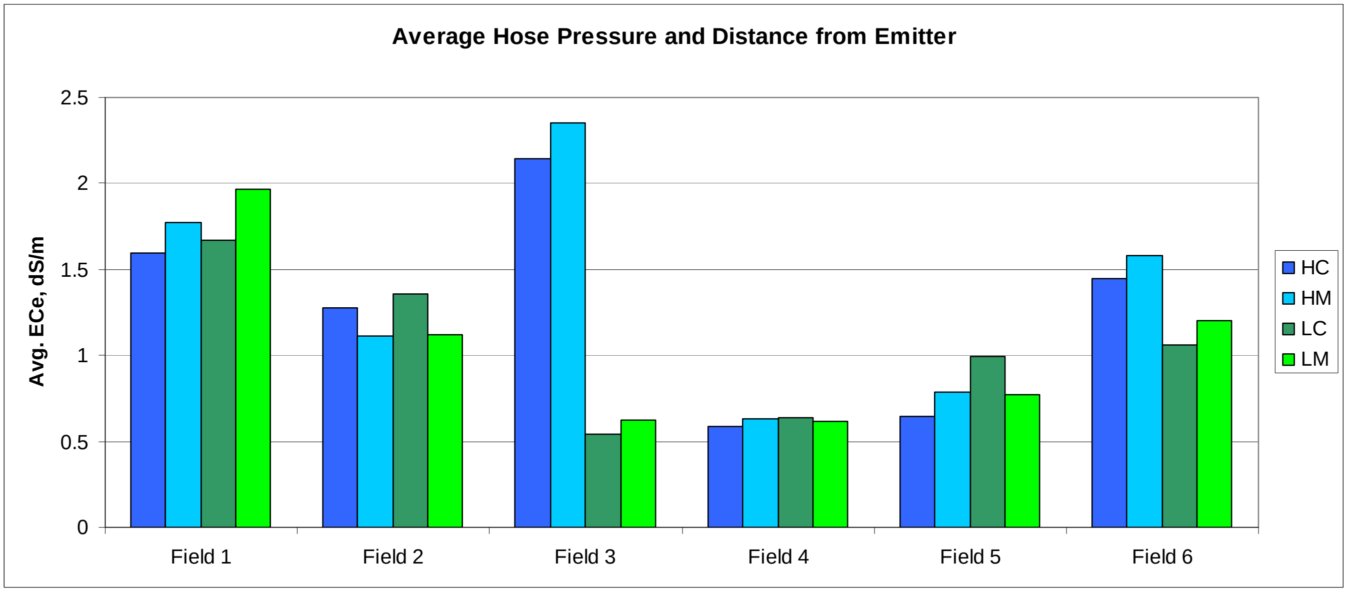


Figure 29. The average ECe, regardless of depth, found at each of the sample locations within the 6 SDI fields.

Figure 29 also shows that low pressure ECe values were also not consistently higher than high pressure values, as was considered possible. It was thought that, due to pressure variation along the hose, high pressure locations might receive more water and therefore have lower ECe's than low pressure locations. However, in most of the fields, the average ECe variation between the sample locations was less than 0.5 dS/m. Values were most uniform in Field 4. Highest variations were found in Fields 3 and 6, which both had higher ECe values (exceptionally high in Field 3) at their high pressure sites. These high average values are a result of the salinity build up at the bottom of the test zone found at the high pressure sites in these 2 fields (Figure 30).

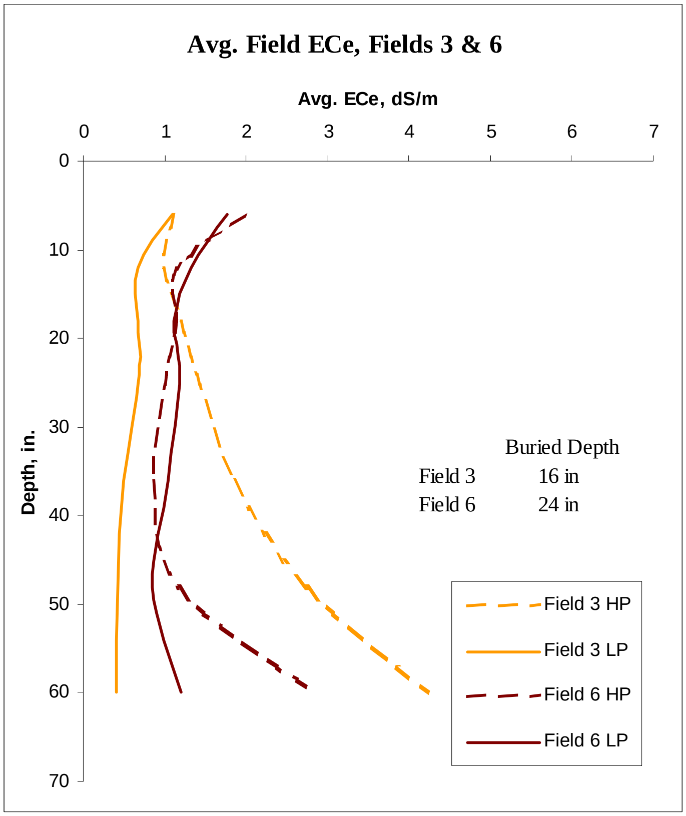


Figure 30. The difference between the high and low pressure sites in Fields 3 and 6.

The high pressure locations in Fields 3 and 6 were the only sites found in all the fields to show a pattern of salinity build up at the bottom of the test zone. As the above figure shows, even the low pressure sites within these fields did not show the same pattern. This could imply that the salinity build up seen at these locations are localized conditions due to plugged emitters or something similar. This is especially clear in Field 3, where the contrast between the high and low pressure locations is extremely high. For this reason, the next figure presents two high pressure curves: one which includes the high pressure locations in Fields 3 and 6, and one which does not.

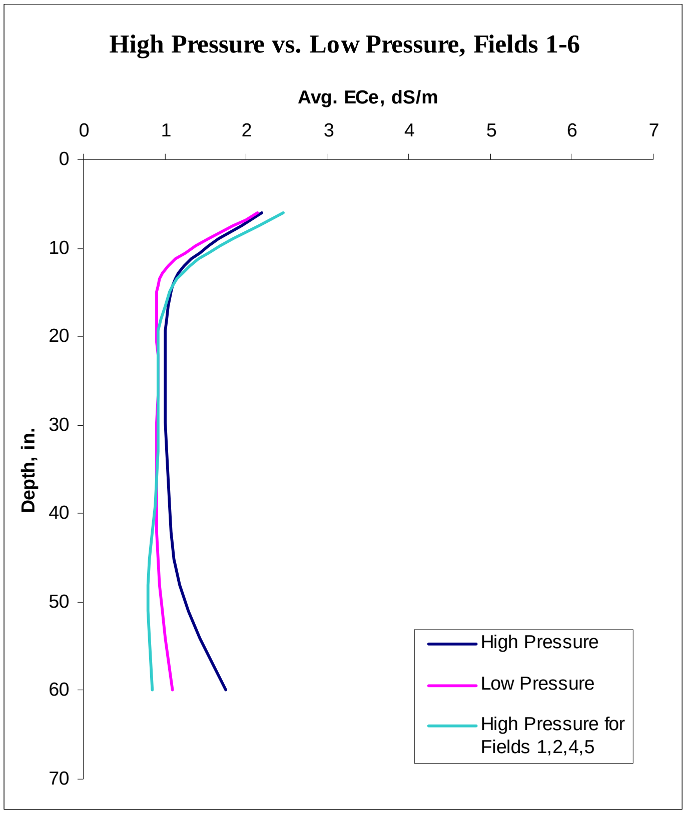


Figure 31. Average salinity at high pressure and low pressure sites in all six fields. The yellow curve does not include the high pressure sites from Fields 3 and 6.

Figure 31 shows that there is not a significant difference between the average salinities found at high and low pressure sites in the six fields tested. The blue curve illustrates that the average salinity at high pressure for all six fields is slightly higher than the average salinity at low pressure. This is a bit surprising it was expected that high pressure locations would receive more water and therefore have lower salinity levels. The yellow curve, which excludes the questionable high pressure data from Fields 3 and 6, is a better representation of the conditions at most of the fields. This curve has slightly higher salinity concentrations towards the soil surface and slightly lower concentrations at the bottom of the test zone than the low pressure curve (pink). The higher concentrations at the top, resulting from more evaporation, and the lower concentrations at the bottom, resulting from more water movement out of the test zone, are indicative that the high pressure locations receive a bit more water than the low pressure locations.

Average ECe's per depth for all six fields are presented in the figure below. The right-hand graph presents average ECe's from all fields; the left-hand graph presents information for Fields 3 and 6 by pressure location.

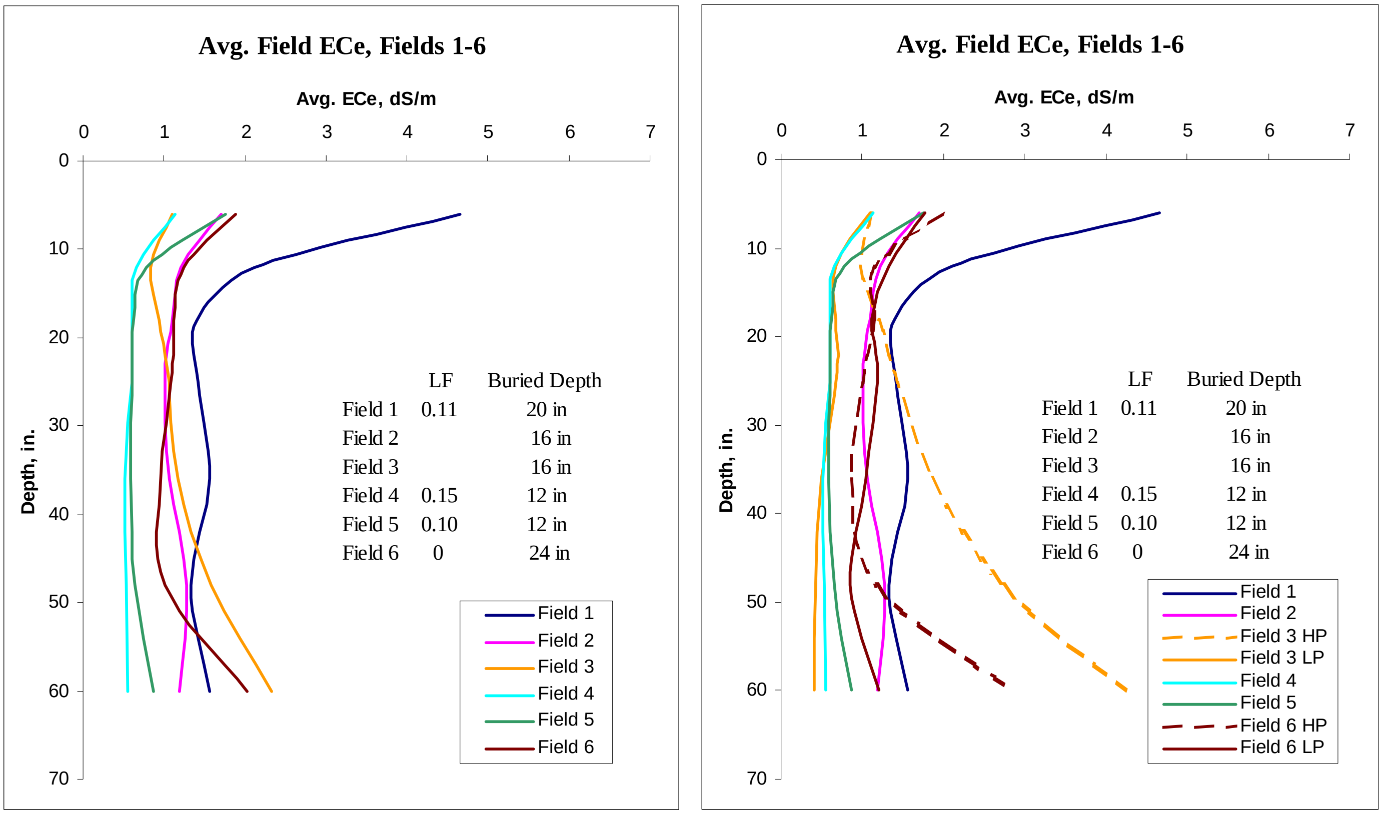


Figure 32. The average ECe levels as a function of depth for all six fields. The left graph presents the average values for Fields 3 and 6. The right figure breaks up data from these two fields into high and low pressure averages.

As can be seen above on the left, the average salinities of all of the fields except Fields 3 and 6 follow the same pattern – an increase in salinity concentrations above the hose depth and low salinities below the hose. When broken up into high and low pressure locations, the low pressure locations from Fields 3 and 6 (solid lines) also match this pattern (above right).

The large increase in salinity towards the surface in Field 1 can probably be attributed to high amount of applied water this field received (see table below), which meant that much more water evaporated or was taken up by plants at or near the soil surface, increasing the amount of salt left behind in the soil.

Table 30. Applied irrigation water, leaching fraction and average ECe information for each field.

Field	2001 Crop	Avg. ECw, dS/m	Needed LF	Applied Irr. Water, in.	Deep Perc., in.	Actual LF	ECe Threshold, dS/m	Expected ECe, dS/m	Measured Avg. ECe, dS/m
1	Asparagus	0.81	0.04	129.68	13.76	0.11	4.1	1.69	1.76
2	Melon	0.84	0.08	-	-	-	2.2	-	1.25
3	Cotton	0.84	0.02	-	-	-	7.7	-	1.44
4	Melon	0.44	0.04	55.36	8.28	0.15	2.2	0.68	0.63
5	Oat	0.44	0.03	63.14	9.06	0.14	moderate	0.93	0.82
6	Asparagus	0.44	0.02	77.80	0	0	4.1	undefined	1.34

All fields for which expected ECe's were calculated showed good agreement between expected and measured results. It should also be noted that higher ECe levels were found in those fields irrigated with water from Panoche WD.

Comparison of Field 1 and 6 (Asparagus)

A basic comparison of Fields 1 and 6, on which asparagus is grown, is as follows:

Table 31. Comparison of asparagus fields, Fields 1 and 6.

Field	Crop	Threshold ECe, dS/m	Year	ECw, dS/m	Needed LF	Applied Irr. Water, in.	Deep Perc., in.	Actual LF	Expected ECe, dS/m	Measured Avg. ECe, dS/m
1	Asparagus	4.1	1999	0.74	0.04	42.83	3.94	0.09		
			2000	0.85	0.04	44.48	2.96	0.07		
			2001	0.84	0.04	42.38	6.85	0.16		
			Average:	**0.81**	**0.04**	**129.68**	**13.76**	**0.11**	**1.69**	**1.76**
6	Asparagus	4.1	1999	0.43	0.02	23.5	0	0		
			2000	0.39	0.02	28.8	0	0		
			2001	0.51	0.03	25.5	0	0		
			Average:	**0.44**	**0.02**	**77.80**	**0**	**0**	**undefined**	**1.34**

It is rather surprising that the field with the higher leaching fraction should have a higher average ECe. However, this could be accounted for by two things:

- The large increase in salt content towards the soil surface. This is a result of increased evaporation due to the much larger amount of applied water and the shallower hose depth. (See figure below.)
- The high ECw level of the applied water.

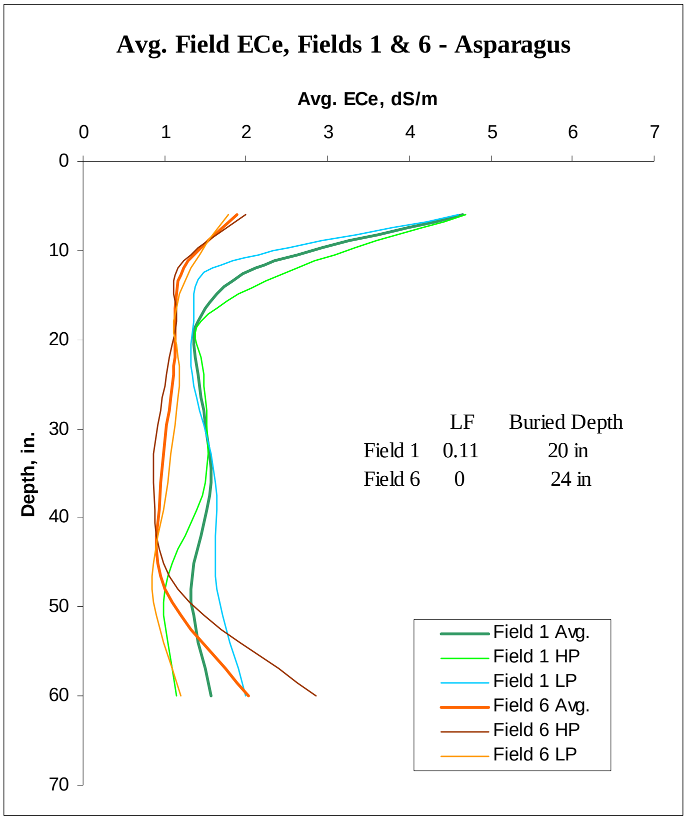


Figure 33. Comparison of ECe levels in Fields 1 and 6, asparagus.

Both fields show variation in salinity distribution between their high and low pressure sites. The lower values towards the soil surface and higher values towards the bottom indicate that the low pressure curve for Field 1 (blue) may receive slightly less water than the high pressure location. The Field 6 locations present similar curves until a depth of about 40 inches, when salinity levels begin increasing at the high pressure location. Again, it is uncertain whether this is due to a localized condition such as a plugged emitter, or to the small amount of applied water.

Comparison of Field 2 and 4 (Melon)

As can be seen below, the average ECe found in Field 2 was almost twice that found in Field 4.

Table 32. Comparison of melon fields, Fields 2 and 4.

Field	Crop	Threshold ECe, dS/m	Year	ECw, dS/m	Needed LF	Applied Irr. Water, in.	Deep Perc., in.	Actual LF	Expected ECe, dS/m	Measured Avg. ECe, dS/m
2	Melon	2.2	Average:	0.84	0.08	-	-	-	-	1.25
4	Cotton	7.7	1999	0.43	0.01	27.17	0	0.00		
	Melon	2.2	2000	0.39	0.04	10.19	0.55	0.05		
	Melon	2.2	2001	0.51	0.05	18.00	7.73	0.43		
		2.2	**Average:**	**0.44**	**0.04**	**55.36**	**8.28**	**0.15**	**0.68**	**0.63**

However, as the following figure illustrates, the salinity distribution over depth in both fields is almost identical.

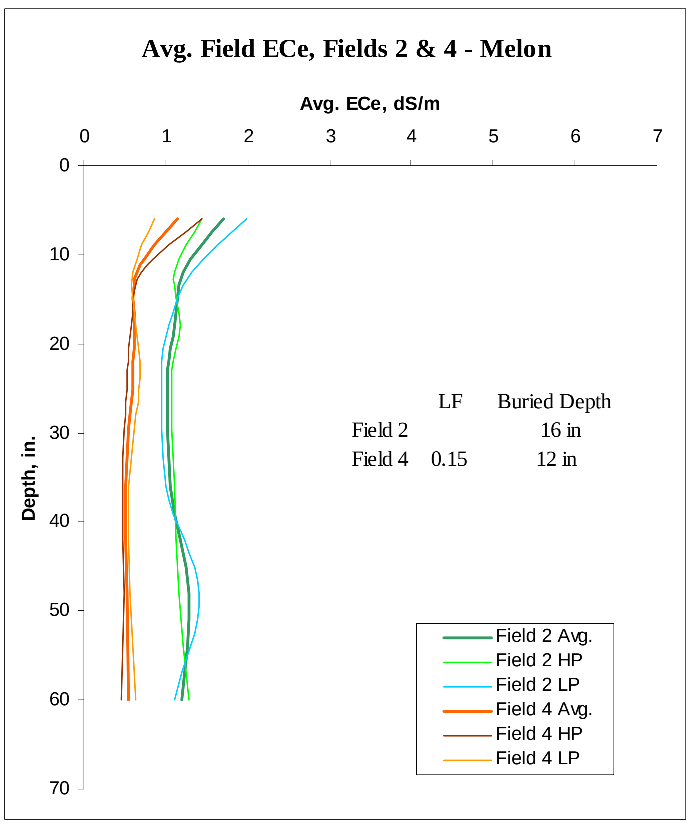


Figure 34. Comparison of ECe levels in Fields 2 and 4, melon.

Both fields show very little variation between their high and low pressure sites. The higher salinities levels in Field 2 can most likely be attributed to the higher ECw of the irrigation water.

Comparison to control fields

As can be seen below, the average field ECe levels found in the SDI fields were not significantly different from the levels found in their respective control fields.

Table 33. Comparison of average ECe (dS/m) between control and SDI fields.

Farm	Water Supply	Control Field	Crop	Furrow Spacing, in.	Avg. ECe, dS/m	SDI Field	Crop	Tape Spacing, in.	Avg. ECe, dS/m
Turlock Fruit Co.	Panoche WD	1	Garlic	80"	1.01	2	Melon	72"	1.25
						3	Cotton	72"	1.44
Joe Del Bosque	San Luis WD	2	Cotton	40"	1.09	6	Asparagus	35"	1.34
		3	Melon	80"	0.75	4	Melon	80"	0.63
						5	Oat	92"	0.82
Hammonds Ranch	Panoche WD	4	Tomato	80"	1.53	1	Asparagus	60"	1.76

CONCLUSIONS

This study began with the idea that the wide hose spacing (80 inches) commonly used in the area of study might cause detrimental salinity buildup at the edges of the wetted patterns between the beds, which would require the use of special leaching practices. It was also thought that salt accumulation might occur between emitters and that ECe levels might be higher at low pressure locations than high pressure locations. However, this was not found to be the case on the six SDI fields studied.

- No consistent pattern of salinity on the periphery of the wetted areas (on the edges of the furrows) was found on the six SDI fields studied. Although there were patterns of salinity with respect to depth, and that depended on water quality, the salinity was fairly evenly dispersed across the row crop bed.

- The average salinities midway between emitters were about the same (sometimes higher and sometimes lower) than the salinities measured close to the emitters. This was also true of the pressure locations.

- Soil samples from adjacent furrow irrigated fields did not show obviously different salinities than the SDI fields.

- All of the SDI fields had low average salinities (between 0 - 2 dS/m) that were below the threshold ECe of their crops.

- Good agreement was found between the expected average ECe's, calculated according to standard leaching requirement equations, and measured average ECe's. This may imply that these equations, developed for traditional sprinkler and furrow irrigation, are also suitable for use with buried drip irrigation. However, these calculations could only be made for 3 of the 6 SDI fields.

- All SDI fields showed a gradient of increasing salt concentration above the hose depth due to evaporation from the soil surface and plant water uptake (root activity between the surface and the hose). Salinities remained low below the buried hose depth on most the fields, which is indicative of the application of a high leaching fraction. Since all of the field but one received sprinkler pre-irrigations, the following scenario is likely: Salts build up towards the soil surface during the irrigation season due to the evaporation and plant water uptake (this is the point at which soil samples were taken for this study). Sprinkler pre-irrigation then leaches the salt down to the SDI hose, which then leaches the salt further down over the irrigation season when water is applied to consider the required leaching fraction.

Therefore, it does not appear that special leaching practices (other than sprinkler pre-irrigations) are needed on fields irrigated with subsurface drip (SDI) in conditions without a high water table.