A CROPPING SYSTEMS APPROACH TO IMPROVING WATER USE EFFICIENCY IN SEMI-ARID IRRIGATED PRODUCTION AREAS

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TECHNICAL COMPLETION REPORT

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A cropping systems approach to improving water use efficiency in semi-arid irrigated production areas

ABSTRACT

This recently-completed 3-year field study evaluated the effectiveness of winter cover crop incorporation and surface gypsum applications relative to conventional fallows for maintaining/improving soil physical properties, stand establishment and crop productivity in a cropping system relying on saline drainage water for irrigation. Six amendment/soil cover treatments were imposed on a rotation of tomato-tomato-cotton as summer crops. Drainage water accounted for about 70% of the total water applied over the course of the experiment. Yields of toamtoes irrigated with saline water were maintained relative to non-saline irrigation in year 1, but were decreased by 33% in year 2. Estimated cotton lint yields of plants irrigated with saline drainage water in 1994, following two seasons of drainage water irrigation, were similar to yields of plants irrigated exclusively with non-saline water. Soil surface crust strength, measured by micropenetrometer was lower in gypsum and cover-crop amended plots relative to saline water irrigated fallow plots during the period of cotton seedling emergence in 1994 in the third year of the experiment. Water stable aggregation was increased following cover crop incorporation relative to saline fallows. Following two seasons of saline drainage water reuse, emergence of cotton seedlings was highest in gypsum-amended plots, but considerably lower in cover crop incorporated plots. Mechanisms accounting for poor establishment following cover crop incorporation may include higher incidences of seed and seedling pathogens in plots where cover crop residues had been incorporated into the soil, and stubble-reinforced surface crusts that resulted in interconnected slabs that impeded timely seedling emergence. These findings and increasing soil surface ECe and SAR values during the course of this study point to the need for special management practices for sustained crop production if drainage water is routinely used.

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TITLE: **A cropping systems approach to improving water use efficiency in semi-arid irrigated production areas**

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KEY WORDS: brackish water, conjunctive use, drainage, perched water table, subsurface drainage, water quality, water reuse

PROBLEM AND RESEARCH OBJECTIVES:

Intensive irrigation practices developed this century have dramatically increased agricultural productivity in many areas of the western US, notable in the San Joaquin Valley of California (Hess, 1984; Rubatzky, 1985). These practices, however, have also resulted in increased drainage water production, and chemical contamination of groundwater resources (Halberg, 1987; Lamb, 1986). It is generally acknowledged that long-term agricultural production in irrigated areas is dependent on an adequate drainage outflow system (van Schilfgaarde and Hoffman, 1977), and a variety of management strategies are currently being considered to reduce the volume of drainage ultimately requiring disposal or treatment (UC Committee of Consultants on Drainage Water Reduction, 1988; SJV Drainage Program Management Plan, 1990). Reuse of saline drainage water for irrigation is one option proposed. Cyclic reuse, as proposed by Rhoades (Rhoades, 1984), involves the use or non-saline water in rotation with saline drainage water for the irrigation of selected crops differing in their salinity tolerance. The potential for cyclic reuse of saline drainage water for irrigation has been documented for several lower value crops (Rhoades *et al.*, 1988). Higher value crops such as processing tomato, melons, and cotton have also been produced without sustaining significant yield reductions in short-term studies using saline drainage water (Grattan *et al.*, 1987; Shennan *et al.*, 1988). Similarly, we have shown by a combination of field and greenhouse studies that processing tomato quality is generally improved by exposure to moderate salinity following plant establishment (Mitchell *et al.*, 1991a,b). Longer-term experiments indicate that accumulation of soil B over time is the most likely microelement limitation to cyclic drainage reuse, whereas Se accumulation is unlikely to be a problem since Se is readily removed from the root profile by periodic use of good quality water (Shennan *et al.*, 1991). When non-saline (low EC) water is used to irrigate a field previously salinized by drainage water with SAR's > 15, however, soil slaking may occur which can greatly reduce water infiltration rates and create a strong surface crust, resulting in poor stand establishment and decreased crop yields (Biggar *et al.*, 1988;

Shennan *et al.*, 1988). To prevent these problems, management practices that ameliorate the degradation of soil physical properties should be employed to allow sustainable reuse of drainage water.

The most common method for maintaining soil quality is tillage and incorporations of gypsum into the soil, often at rates from 3 - 5 tons acre-1. Another alternative is the inclusion of a green manure crop. Several studies have shown benefits of green manure incorporation on soil physical characteristics including water infiltration (Cassman and Rains, 1986), aggregation (Macrae and Mehuys, 1985; Patrick *et al.*, 1957; Tisdale and Oades, 1982), water-holding capacity (Macrae and Mehuys, 1985), and porosity (Disparte, 1987). Cover crops may also protect the soil surface from rain or sprinkler drop impact, thereby preventing the formation of soil crusts which often limit infiltration (Disparte, 1987, Stolzy *et al.*, 1960). Organic N input from leguminous cover crops may also reduce the seasonal fertilizer-N requirement (Shennan *et al.*, 1992), reduce soil NO_3^-, and minimize leaching losses from winter rains and spring pre-irrigations (Stivers *et al.*, 1990). Improved seedling emergence of crops that follow incorporated cover crops may be achieved due to reductions in soil crust formation in cover-cropped systems (Miller *et al.*, 1989; Shennan *et al.*, 1989). Roberson *et al.* (1991) recently found significant improvements in macroaggregate slaking resistance in cover cropped versus clear cultivated treatments in a California orchard. Although reference has been made to the potential use of crop residue management in managing salinity (Cassman and Rains, 1986), to date, no research has directly addressed this objective. Many present row-cropping systems in the SJV could benefit from the use of cover crops provided innovative management practices are developed. Our study complements and extends findings from earlier research for non-salinized cover-cropped systems in California to an evaluation of the benefits and constraints of suing winter cover crops in saline drainage water reuse systems.

This project has addressed an important research priority of the Water Resources Center by providing comparative information on alternatives of managing and reducing the volume of agricultural drainage water, and for improving water use efficiency through the conjunctive use of saline and surface water on crops grown in the San Joaquin Valley's Westside. Reuse of drainage water for agriculture has been identified by the San Joaquin Valley Drainage Project and the USDI Bureau of Reclamation San Luis Drainage Program Unit, which serves over 3000 square miles, as an important component of regional management strategies for drainage water management and sustained agricultural production in the SJV. Considerable work still needs to be directed however, at reducing the constraints on reuse schemes that arise form poor stand establishment. Due to the increasing demands on the State's scarce water resources, and the drought-induced limited supplies of good quality water, the information generated by this study may thus be timely to growers, irrigation districts, and researchers in areas facing restricted supplies of good quality water, and where saline drainage water poses significant problems to agricultural productivity.

The objective of this project is to compare the relative effectiveness of winter cover crop incorporation and gypsum applications in cropping rotations employing cyclic reuse of saline drainage or shallow groundwater for:

1. improving/maintaining good soil physical properties, as measured by soil crust strength and water stable aggregates
2. improving the emergence and yields of summer crops in the rotation
3. reducing the seasonal fertilizer-N requirement of summer crops, and
4. to determine the extent to which the C:N ratio of selected N-fixing and winter cereal cover crops, alone or in combination, governs the effects of residue management on soil physical properties and N inputs using cyclic saline drainage reuse as a model system, and
5. to determine annual water budgets for the proposed cropping systems

METHODOLOGY:

Experimental Procedures:

A 3-year study has been conducted at the UC Westside Field Station (WSFS), Five Points, California, in which six winter cover crop/fallow treatments are imposed upon a rotation of tomato, tomato and cotton as summer crops. The winter treatments were:

1. barley/summer saline
2. vetch/summer saline
3. barley-legume/summer saline
4. gypsum/fallow/summer saline
5. fallow/summer saline
6. fallow/summer control/fresh

The tomato crops received low EC (0.3 dS m^{-1}) California Aqueduct water for germination and establishment, and saline water from a shallow well (EC = 8.0 dS m^{-1} and SAR = 19 mmoles l^{-1}) from about the 1^{st}-flower growth stage onwards. Cotton was irrigated with saline drainage water after being established with low EC water. Cover crops were sprinkle-irrigated with about 1.5 - 3 inches of Aqueduct water to ensure good establishment prior to the onset of winter rains. A saline screening nursery has also been conducted during each winter to determine good performing legume and non-legumes in terms of biomass and N-productivity under saline Westside SJV conditions.

The experimental design is a randomized complete block, with four replications and each treatment plot measuring 630m, which is large enough to allow normal field operations. During the growing season of the tomato crops, water was applied weekly by furrow irrigation in quantities sufficient to replace evapotranspirative losses, estimated using reference evapotranspiration values provided by a CIMIS weather station located at the WSFS, and crop coefficient values that have been developed at the site by previous investigations (Phene, 1985). The 1994 cotton crop irrigations were scheduled based on ET demand and plant based observations.

Soil samples of the surface 15 cm were collected at 312 sites in a 6.7 X 7 m grid throughout the experimental field every spring and fall during the cropping cycle to determine 1) total soil carbon, 2) total soil nitrogen, 3) ECe, 4) SAR and water stable aggregates.

The irrigation management approach proposed in this project is designed to minimize the introduction of salt into the cropping area. Irrigating with drainage water will not add salt to the system, but rather, will recycle and concentrate existing salt, thereby reducing the water volume ultimately needing disposal into local or regional systems such as evaporation ponds or agroforestry plantations (SJV Drainage Program Final Report, September 1990).

Measurements:

1. To assess the relative effects of cover crops, gypsum application, and winter fallows on soil physical properties (objective 1), the following measurements were made:

    1. **soil crust strength** (micropenetrometer)
    2. **aggregate stability** (water stable aggregate method)

2. Summer crop performance (objective 2) was evaluated by measurement of:

    1. **seedling emergence rates**
    2. **stand counts**
    3. **plant above ground biomass and tissue N content at crop maturity**
    4. **final fruit/lint yield and quality**

3. Soil N-fertility (objective 3) and soil chemical properties that may directly influence soil crusting and seedling emergence are evaluated in relation to changes in soil C/N pools by measurement of:

    1. **C/N ratio of cover crops** (dry combustion carbon determination and Kjeldahl digestion N-determination
    2. **soil organic carbon** (Walkley-Black method)
    3. **total soil nitrogen** (Kjeldahl method)

4. Budgets of water use for the proposed cropping system (objective 5) were determined by measurement of:

    1. precipitation using weather data from the CIMIS station located at the WSFS

    2. total amount of non-saline and saline water applied using in-line flow meters

    3. evapotranspiration (ET) of winter cover crops prior to canopy closure by interpolation of CIMIS weather station values for bare soil and reference ETo based on % canopy cover of the cover crop. After canopy closure, ET of the winter cover crops will be approximated by ETo.

    4. evapotranspiration of summer crops form crop coefficient (ET vs days after planting) curves previously developed for the summer crops at the site

    5. soil water storage by neutron probe at 14-day intervals during the winter at depths of 13, 30, 60, 90, 120, 150 180 and 210 cm

Involvement and Responsibilities of Co-investigators:

Dr. Shennan dedicated about 0.05 of her full-time equivalent to this project, supervised the general implementation of the project, and provided technical supervision of a graduate student research assistant, Jeff Mitchell, who managed the field site, collected field samples, and interpreted data generated by the experiment. Jeff Mitchell managed the project and assisted station personnel on a full-time basis during much of the course of the project, particularly during cover crop establishment and incorporation in the fall and spring, respectively. Dr. Singer was a member of Jeff Mitchell's Ph.D. thesis committee and routinely provided pertinent technical advice. Doug Peters, Staff Research Associate stationed at the Westside Field Station, also assisted with the management of the field experiment. Representatives of the USDA Salinity Lab (Dr. James Rhoades), the USDA Water Management Lab (Dr. Claude Phene), and the UC Cooperative Extension (Terry Prichard, Dr. Robert Miller, Don May and Dan Munk) helped develop this project, made recommendations with respect to the sampling/measurement design, analytical and agronomic aspects of the project, and were routinely consulted as major project decisions were considered.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Winter cover crop growth under Central SJV conditions is quite vigorous, with the barley and barley/vetch mixes averaging about 8000 - 10,000 lbs/acre and the vetch plots yielding 5000 lbs/acre (Figure 1). Changes in soil water storage (0 - 165 cm) under winter fallow and winter cover crops are shown in Figure 2. Net increases in soil water storage during the winter were about 2 inches less under cover cropped conditions than under winter fallow.

The saline drainage water used to irrigate the summer crops has an EC of about 7 dS/m and is quite high in B (Table1). It is likely that the soil salinities that developed during the course of summer irrigations (Figure 5), which reach about 7 dS/m, may have had an adverse effect on plant growth and productivity. Two patterns of yields are seen in the two tomato seasons. In 1992, yields were reduced in plots following cover crop incorporation, perhaps suggesting significant N-immobilization in the cover cropped plots. In 1993, the effects of the saline water irrigations and perhaps of high soil solution boron levels were observed, as yields were reduced by a third in all plots that were irrigated with saline water. Leaf blade boron levels throughout much of the season were in fact higher in plants irrigated with saline water than in plants irrigated with non-saline water. Because boron is often recognized as the element that is most likely to cause toxicity problems when present in small amounts, because the differences between deficiencies and toxicities is small, boron levels in this saline irrigation water may well be a major constraint to the reuse strategy. In both years, fruit soluble solids, an important indicator of fruit quality, were enhanced by use of saline water (Table 3).

Preliminary results show that soil crust strength determined by a micropenetrometer of the top 1 cm was reduced by both the gypsum and cover crop treatments in 1992 (data not shown).

Table 4 shows results of soil water stable aggregate determinations for spring 1992, before saline irrigations were started, and for spring 1994, after two seasons of saline irrigation.

Incorporation of cover crops into the soil seems to maintain aggregate stability to some extent relative to gypsum-amended and unamended fallows.

Figure 6 shows the number of cotton plants that emerged in each treatment per 104 m of plot. While emergence was slightly earlier in the fresh fallow plots, the final stand was actually highest in plots to which gypsum had been applied. The number of cotton plants that emerged in each of the three cover crop incorporated plots was distinctly, and somewhat surprisingly lower. Two mechanisms may account for this observation. First, soil organisms that feed on seeds and seedlings likely exacted a heavy toll in plots where cover crop residue had been incorporated into the soil. Secondly, when soil surface crusts form in cover cropped plots, organic residues (barley stubble and vetch stems) reinforce horizontally and vertically dispersed soil crusts as "rebar" in reinforced concrete, in effect resulting in interconnected surface slabs that impede timely seedling emergence. This stubble-reinforced "adobe" presents a formidable and heavy barrier to seedlings. The longer seedlings are under such slabs, the more prone they are to pathogens, the weaker they become, and if they emerge at all, they often do not survive long.

We also conducted several screening nursery trials to assess the potential of various winter annuals in terms of biomass and N-productivity under the moderate soil salinities we develop during the course of our irrigation/crop rotation system. Many plants, particularly various *Brassica*, vetch, berseem and *Hedysarum* species, have produced substantial biomass (Table 4).

The following conclusions can be made from the hypotheses that have been tested in this project:

1. Cyclic reuse of saline subsurface drainage water for irrigation may conserve good quality water and provide a means of sustaining crop productivity over short terms.
2. Soil surface salt and boron accumulation however, may be major constraints to this cropping strategy and will limit productivity if appropriate irrigation/leaching and crop management practices are not followed.

3. Special management practices for stand establishment are required in saline drainage water reuse systems including shallow seed placement, keeping the soil surface moist, and using mechanical crust-breaking implements when appropriate.
4. Winter cover crop incorporation does not improve stand establishment of subsequent crops in cyclic saline drainage water reuse systems. In our system, cover crop incorporation resulted in interconnected surface crusts that actually seemed to impede timely seedling emergence.
5. Cover crop incorporation did however, result in slight improvements in soil water stable aggregation following saline water irrigations relative to bare fallows.
6. Surface applications of gypsum may be useful in cotton stand establishment in cyclic saline drainage water reuse systems, though soil aggregate stability may not be improved by the use of gypsum.
7. Net increased in soil water storage (0 - 165cm) during the winter due to rainfall were about 2 inches less than under cover cropped conditions than under winter fallows.

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TRAINING ACCOMPLISHMENTS:

	Training Level			
	Undergraduate	**MS**	**PhD**	**Post-PhD**
Plant Biology			1	
Soil/Water	3*			

* Two undergraduate student assistants were hired during the course of this project to process samples, compile computer data and perform a variety of lab tasks on project samples. In addition, one high school Westinghouse Young Scholars Program student held an internship with Jeff Mitchell and worked on this project.

GRADUATE INFORMATION:

Mitchell, J.P.	Ph.D. F1994	Plant Biology	UC Cooperative Extension Specialist Dep't. of Vegetable Crops UC Davis/Kearney Ag Center

PUBLICATIONS AND PROFESSIONAL PRESENTATIONS:

1. Mitchell, J.P. M.J. Singer, T. Prichard, D. Peters, D. May, R.O. Miller, C. Shennan, J.D. Rhoades C.J. Phene. 1995. Effects of organic and inorganic amendments on soil physical properties and stand establishment in cyclically salinized soils. Fourth National Symposium on Stand Establishment of Horticultural Crops. April 23-26, 1995. Monterey, CA. Accepted.
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In addition, manuscripts are currently being prepared as part of Jeff Mitchell's dissertation for submission to the following journals:

1. Mitchell, J.P., W.L. Graves, C. Thomsen and C. Shennan. 1994. Cover crops for saline soils. J. Agron. & Crop Science. In preparation.

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LIST OF TABLES AND FIGURES

Table 1. Irrigation water quality

IRRIGATION WATER QUALITY

	EC (dS/m)	SAR	B (ppm)	NO_3^--N (ppm)
Non-saline	0.5	2	0.2	0.8
Saline	6.8	9	6	33

Table 2. Quantities of irrigation water applied in 1992 and 1993

QUANTITY OF IRRIGATION WATER APPLIED

	Non-saline	Saline	Total	Saline as % of Total
1992	8.6 inches	16.5 inches	25.1 inches	66
1993	4.6 inches	20.6 inches	25.2 inches	81

Table 3. Tomato fruit quality. Means of four replicates ± standard errors.

TOMATO FRUIT QUALITY

1992	BRIX	pH	BOSTWICK
freshwater following fallow	5.0 ± 0.1	4.37 ± 0.03	17.7 ± 0.32
saline water following gypsum	5.1 ± 0.1	4.38 ± 0.01	17.4 ± 0.12
saline water following fallow	5.4 ± 0.1	4.39 ± 0.04	16.5 ± 0.35
saline water following barley	5.4 ± 0.0	4.41 ± 0.03	15.5 ± 0.28
saline water following barley+vetch	5.4 ± 0.1	4.38 ± 0.03	16.8 ± 0.31
saline water following vetch	5.2 ± 0.3	4.39 ± 0.02	16.6 ± 0.16

1993	BRIX	pH	BOSTWICK
freshwater following fallow	5.1 ± 0.1	4.36 ± 0.02	16.6 ± 0.26
saline water following gypsum	5.9 ± 0.2	4.37 ± 0.01	15.3 ± 0.52
saline water following fallow	5.7 ± 0.1	4.35 ± 0.03	15.6 ± 0.28
saline water following barley	5.6 ± 0.1	4.40 ± 0.03	16.0 ± 0.60
saline water following barley+vetch	5.6 ± 0.1	4.38 ± 0.02	15.9 ± 0.20
saline water following vetch	5.6 ± 0.1	4.36 ± 0.01	16.3 ± 0.23

Table 4. Water stable aggregates (%) 1992 and 1994

Treatment	1992	1994
Fresh fallow	35.5	33.5
Saline/gypsum fallow	35.9	18.7
Saline fallow	34.0	17.5
Saline/barley	39.4	28.8
Saline/barley-vetch	38.9	22.9
Saline/vetch	36.5	25.0

Contrasts	*p-values*	
cover crop vs saline	0.0195	0.0001
fresh vs saline	ns	0.0001

Table 5. Plant height, plant weight and % cover for selected legume and non-legume species grown under saline soil conditions (about 8 dS m^{-1} in surface 15 cm) in 1991 - 92, 1992 - 93 and 1993 - 94, and under non-saline conditions in 1993 - 94. Data for saline trials are means of either one, two or three years of data that are based on three replicates per each year.

SCIENTIFIC NAME	ACCESSION	GRAVES COLLECTION NUMBER	LIFE CYCLE DURATION	SALINE NUMBER OF YEARS	SALINE PLANT HEIGHT CM	FRESH PLANT HEIGHT CM	SALINE PLANT WEIGHT KG/HA	FRESH PLANT WEIGHT KG/HA	SALINE % COVER	FRESH % COVER
1 Atriplex canescens	Marana 476816		perennial	1	30	15	727		43	51
2 Agropyron elongatum			perennial	2	49		5551		69	
3 Atriplix nummulana	Oldman Salt Bush		perennial	1	13	14			5	50
4 Brassica carinata	Ethiopian mustard		annual	3	166	192	16975	15353	100	100
5 Brassica juncea	Indian mustard 77-1352		annual	3	147	170	21440	21464	100	100
6 Brassica juncea	Indian mustard 77-12854		annual	3	132	170	22180		100	100
7 Brassica nigra	Black mustard		annual	1	142		7813		100	
8 Festuca arundinacea			perennial	2	49		3886		97	
9 Eriogonum umbellatum	Sierra			1	13	5			35	15
10 Hordeum brachyantherum	Meadow barley		perennial	1	46				100	
13 Hedysarum carnosum	T-465		perennial	1	61		3859		42	
11 Hedysarum coronarium	T-115		perennial	3	48	59	2942	3469	87	100
12 Hedysarum coronarium	Sulla	HC-6	perennial	2	50		3124		97	
14 Hedysarum coronarium		HC-249	perennial			78		7814		100
15 Hedysarum coronarium		HC-252	perennial			73		10116		100
16 Hedysarum coronarium		T-456	perennial			73		9312		100
17 Hedysarum coronarium		T-8113	perennial			64		7433		100
18 Hedysarum coronarium		HC-862	perennial			64		6293		100
19 Hedysarum carnousm		HC-857	perennial			59		4371		85
20 Hedysarum coronarium		T-115	perennial			59		3469		100
21 Hedysarum coronarium		T-8114	perennial			54		5138		98
22 Hordeum vulgare	Barley		annual	3	98	78	10241	6280	98	100
23 Lupinus nanus	Gilpin	LUNA		1	13				33	
24 Medicago arborea	MR504540	MRU-3		1	13		1489		52	
25 Medicago ciliaris	MC4989736	MECI-2		2	37		2768		97	
26 Mediciago ciliaris	MC498753	MECI-3		3	31	41	2003	4588	96	100
27 Medicago ciliaris	MC368928	MECI-1		3	24	40	2126	4036	89	100
28 Medicago ciliaris		MECI-852		1	36		1178		100	
29 Medicago ciliaris		MECI-841		1	23				67	
30 Medicago ciliaris		MECI-372		1	23				92	
31 Medicago ciliaris		MECI-825		1	18				67	
32 Mediciago discoformis	MD487333	MEDI-1		2	19				76	
33 Medicago doliata	MD495293	MEDO-1		1	15		2554		73	
34 Medicago doliata	MD5704	MEDO-2		1	13				65	
35 Medicago doliata	495293	MEDO-49		1	48		3629		100	
36 Medicago discoformis	487333	MEDI		1	23				83	
37 Medicago doliata	5704	MEDO-5		1	23		1298		100	
39 Melilotus indica	MI9059045		biennial	1	8				30	
40 Medicago littoralis	cv Harbinger	MML-1		3	36	48	4390	6650	90	100
41 Medicago laciniata	ML498888	MLA-17		2	28				89	
42 Medicago laciniata	ML498874	MLA-16		2	22				78	
43 Medicago laciniata	ML495293	MLA-14		2	22				77	
44 Medicago laciniata	ML498871	MLA-15		1	15		1432		68	
45 Medicago laciniata	ML498851	MLA-13		2	18		2641		90	
46 Medicago laciniata	ML5668	MLA-19		2	21				82	
47 Medicago laciniata	498889	ML-18		1	28				100	
48 Medicago laciniata	498852	ML-14		1	28				100	
51 Medicago minima	MM498986	MMI-14		2	18				84	
52 Medicago minima	GR-548	MMI-4		1	13		1462		57	
53 Medicago minima	MM499005	MMI-15		2	18	29	2137	3646	85	98
54 Medicago minima	GR-129	MMI-6		1	13		1219		40	
56 Medicago minima	GR-585	MMI-9		1	13		1438		70	
57 Medicago minima	MM499020	MMI-16		2	14				67	
58 Medicago minima	GR-451R	MMI-2		2	21		2450		68	
60 Medicago minima		MMI-1		1	8				55	
61 Medicago minima	GR-126	MMI-8		1	5				32	
50 Medicago murex	cv Zodiac	MMU-1		3	21	43	3174	4543	71	100
55 Medicago murex	Sapo	MRU-2		1	13				33	
59 Medicago murex	Papaponto	MRU-3		1	13	30		3379	18	58
62 Medicago polymorpha	SCO 9001	MP-5	annual	3	42	59	5684	4929	98	100
63 Medicago polymorpha	MP4932931378530	MP-12	annual	2	29	46	3240	8300	93	100

64 Medicago polymorpha	MP292428	MP-11	annual	3	38	50	3074	8283	100	100
65 Medicago polymorpha	MP292418	MP-10	annual	2	22	59	1817	4929	97	100
66 Medicago polymorpha	MP197539	MP-8	annual	3	33	48	4017	7193	82	100
67 Medicago polymorpha	MP9041018	MP-3	annual	2	22	53	2804	7400	63	100
68 Medicago polymorpha	Santiago	MP-2	annual	2	33	50	2714	4604	99	100
69 Medicago polymorpha	cv Serena	MP-1	annual	2	32	45	3926	5507	100	100
70 Medicago polymorpha	MP283656	MP-9	annual	3	31	45	2871	7331	96	100
71 Medicago polymorpha	MP493293	MP-13	annual	3	30	48		8300	92	100
72 Medicago polymorpha	Circle Valley	MP-14	annual	3	30	50	2048	8283	83	99
73 Medicago polymorpha	TAH		annual	1	46	44	4695		100	100
74 Medicago polymorpha	cv Serena	MP-1	annual	1	41				100	
78 Medicago rigidula	MR441949			1	10		1489		52	
79 Medicago rigidula	MR441996	MERI-6		1	8				7	
94 Medicago rigidula	MR441950			1	10				42	
76 Medicago rugosa	Paragosa	MERU-11		1	23				52	
77 Medicago rugosa	GR-67	MRU-5		1	18				55	
81 Medicago scutellata	Sava	MS-3		2	36		2377		100	
82 Medicago scutellata	Snail 9041678	MS-2		2	44				100	
83 Medicago scutellata	cv Kelson	MS-1		2	44	55	4099	7008	91	100
86 Medicago tornata	cv Rivoli	MTO-1		3	38	44	4219	7172	99	99
84 Medicago truncatula	Parabinger	MTR-1	annual	2	38		2662		100	
87 Medicago truncatula	Jemalong	MTR-4	annual	3	32	44	6318	7198	85	100
88 Medicago truncatula	Paraggio	MTR-2	annual	3	30	44	2391	5775	82	100
89 Medicago truncatula	Sephi	MTR-3	annual	3	28	46	2975	6240	85	100
90 Medicago truncatula	cv Borong	MTR-8	annual	1	43		4588		100	100
95 Pisum sativum	Field pea		annual	1	28				17	
96 Secale cereale	Merced rye		annual	3	135	170	10505	12063	99	100
97 Triticum aestivum	Wheat		annual	3	85	102	8308	10756	96	100
98 Trifolium alexandrium	Berseem clover		annual	3	45	52	3794	3369	96	100
99 Trifolium balansae	cv Paradana	TB-1		2	33	48	1333	9378	91	100
38 Trifolium hirtum	No Ca Rose	TH-4	annual	1	23				67	
100 Trifolium hirtum	Hykon	TH-1	annual	3	27	35	2102	3984	89	90
101 Trifolium hirtum	Kondinin	TH-2	annual	1	23		2386		58	
102 Trifolium hirtum	TX RH-18	TH-6	annual	2	27	30		3613	69	95
103 Trifolium hirtum	Wilton	TH-5	annual	2	26	28	3885	2829	69	98
104 Trifolium incarnata	Flame	TI	annual	2	29				74	
105 Trifolium resupinatum	cv Maran			1	43				83	
106 Trifolium resupinatum	Kyambro			1	33				100	
108 Trifolium subterranean	Koala	TSB-3	annual	2	26		842		77	100
109 Trifolium subterranean	T-43F	TSB-11	annual	2	21				78	100
110 Trifolium subterranean	Rosedale	TSB-2	annual	2	19				61	
111 Trifolium subterranean	Trikkala	TSY-2	annual	2	18				75	
112 Trifolium subterranean	T-400	TSB-10	annual	2	18				58	
113 Trifolium subterranean	T-41060	TSB-13	annual	2	15				52	
114 Trifolium subterranean	Lansa	TSY-2	annual	1	8				43	
116 Trifolium subtermaean	cv Nuba		annual	1	36				100	
117 Trifolium subterranean	cv Koala	TSB-3	annual	1	33		842		91	
118 Trifolium subterranean	cv Clare	TS-1	annual	1	28				92	
119 Trifolium subterranean	T-45A	TSB-12	annual	2	18				69	
120 Trifolium vesiculosa	Arrowleaf	TV-1		2	49		2269		92	
121 Triticosecale	Triticale		annual	3	117	142	10233	12228	97	100
122 Vicia benghalensis	Purple vetch	V-3	annual	3	50	62	3131	8495	79	98
123 Vicia blanchfleur		V-1	annual	1	23	61	532	3669	27	94
124 Vicia dasycarpa	Lana vetch	V-4	annual	3	59	60	5734	6629	98	100
125 Vicia faba	Horsebean		annual	1	46		1057		40	
126 Vicia namoi	Namoi vetch	V-2	annual	3	61	58	4284	7652	98	100
128 Vicia sativa	2541			1	41	50		4604	100	100
			LSD		15	15	3632	3179		

Figure 1. Winter cover crop growth

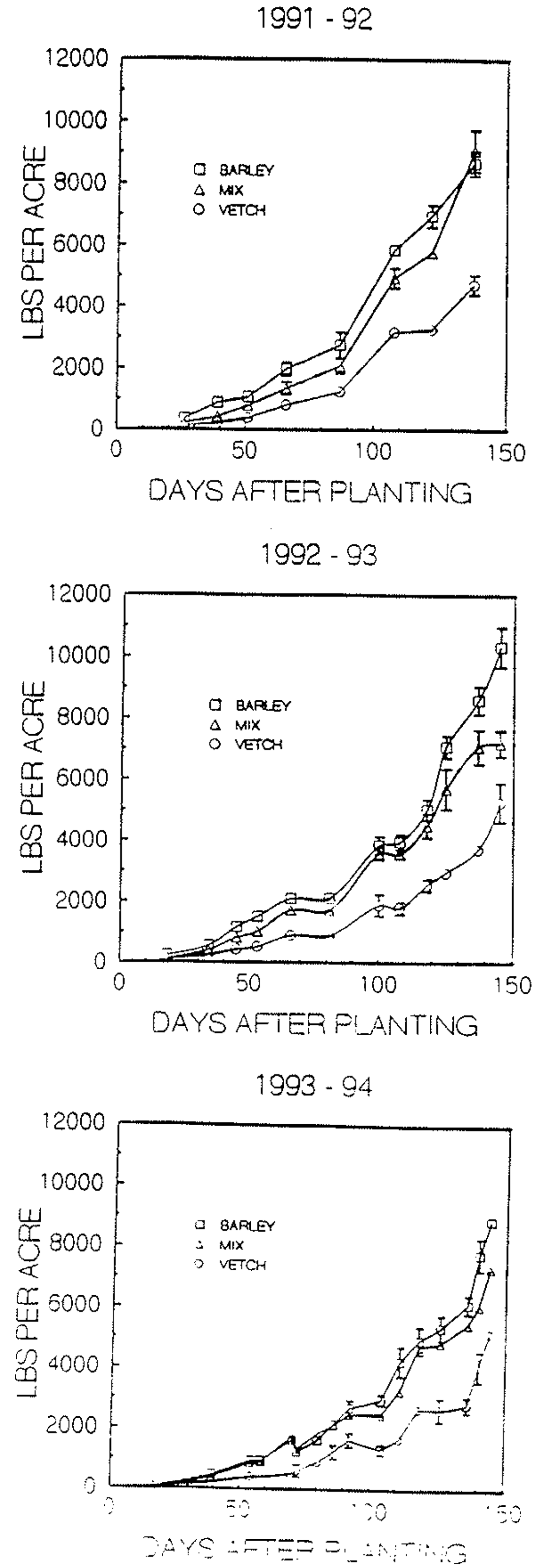
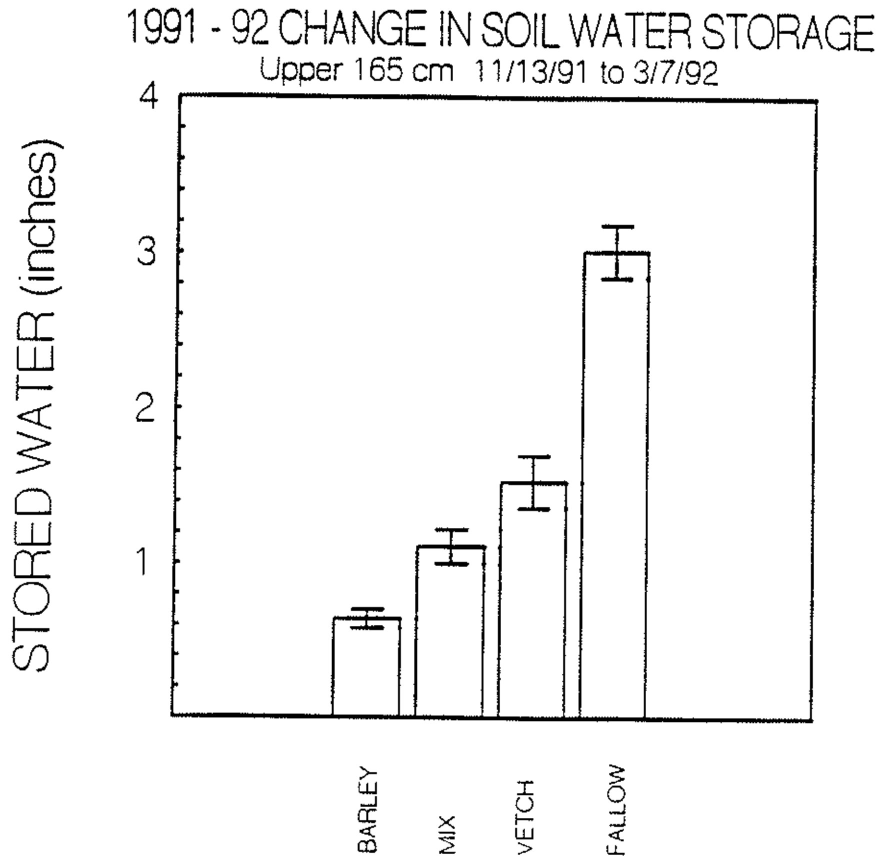


Figure 2. Change in soil water storage during winter cover crop growth period



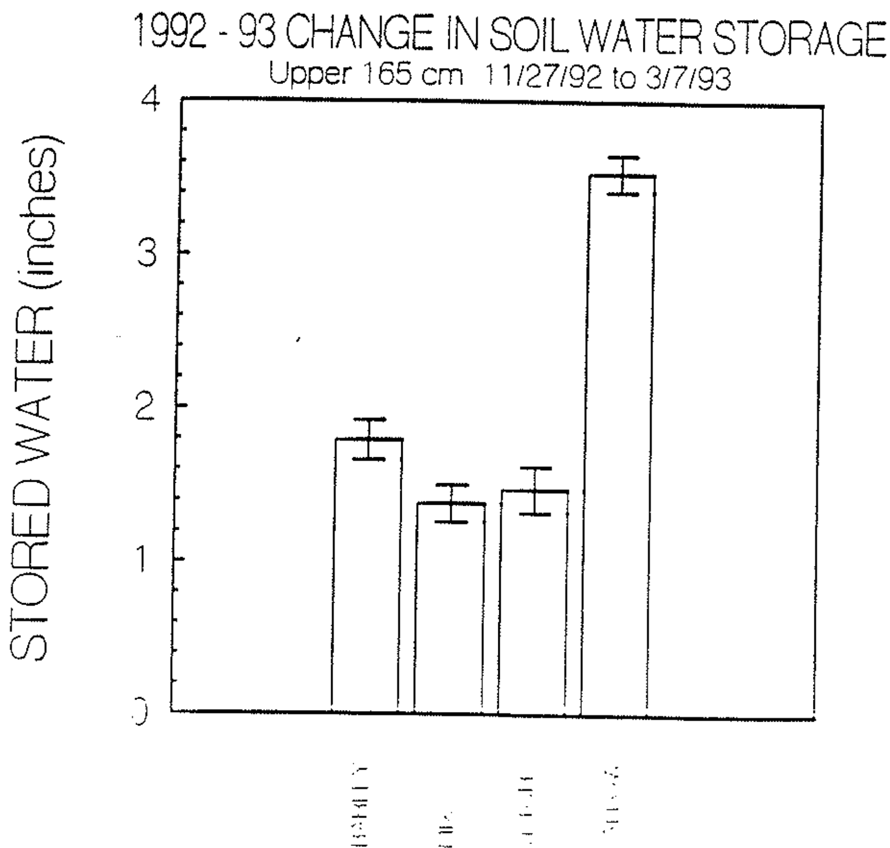


Figure 3. Tomato yields (tons/acre) 1992 and 1993

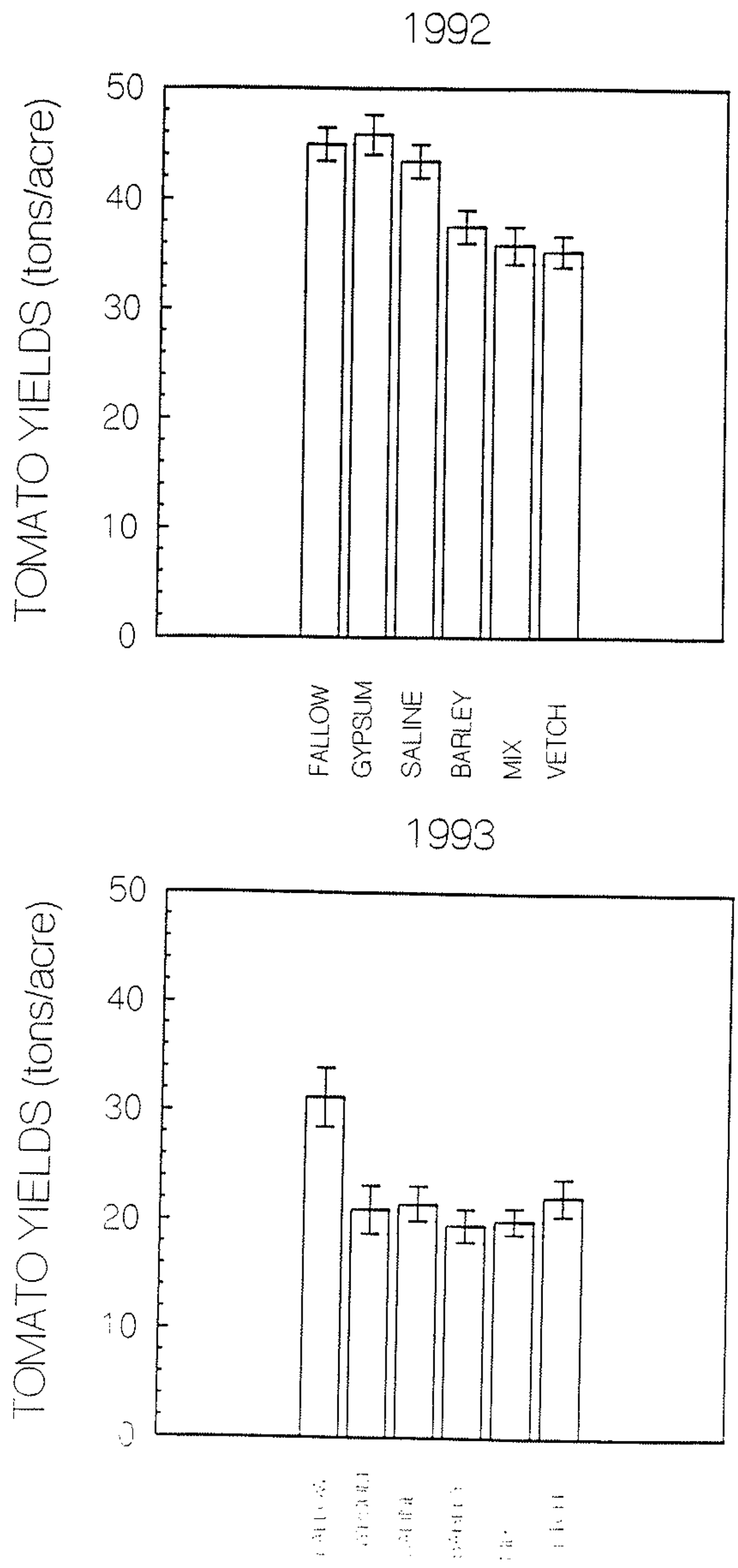


Figure 4. Boron accumulation in tomato leaf blades 1993

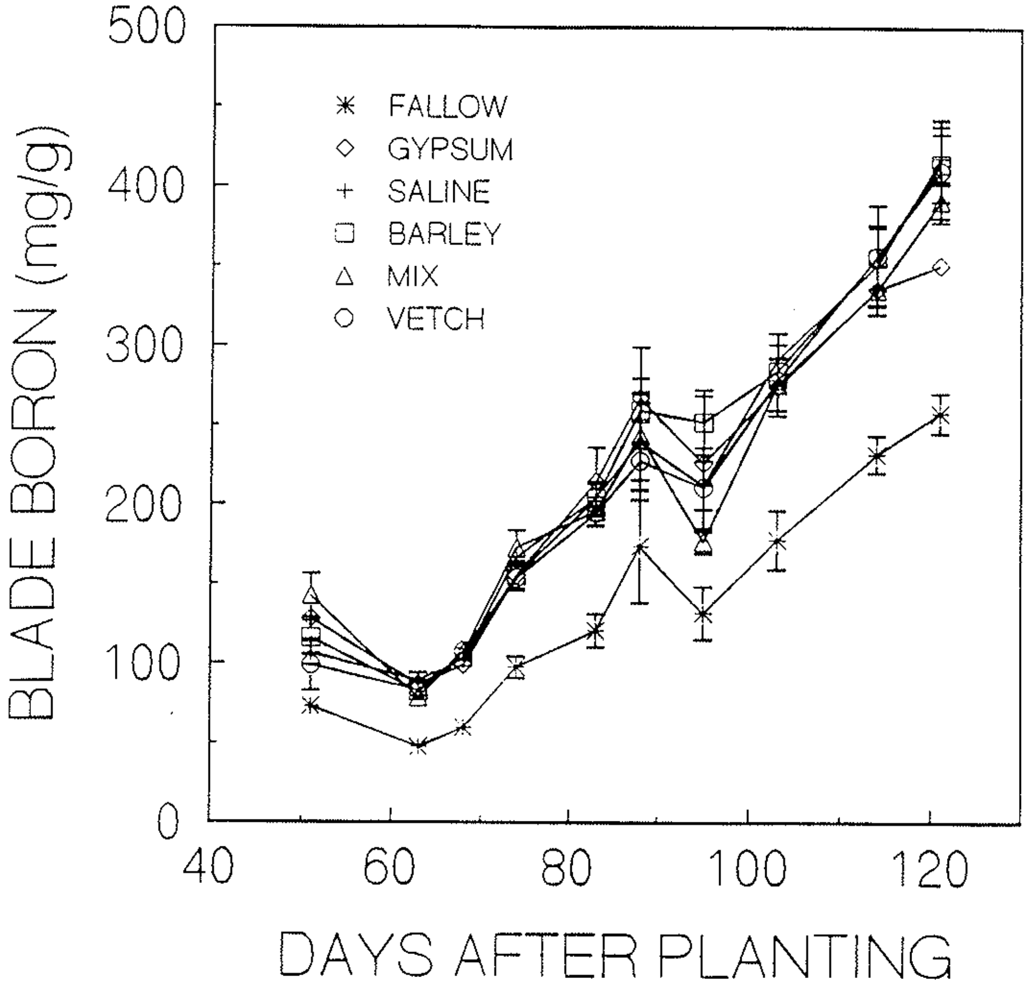


Figure 5. Soil ECe (0 - 15 cm) Fall 1991 through Fall 1993

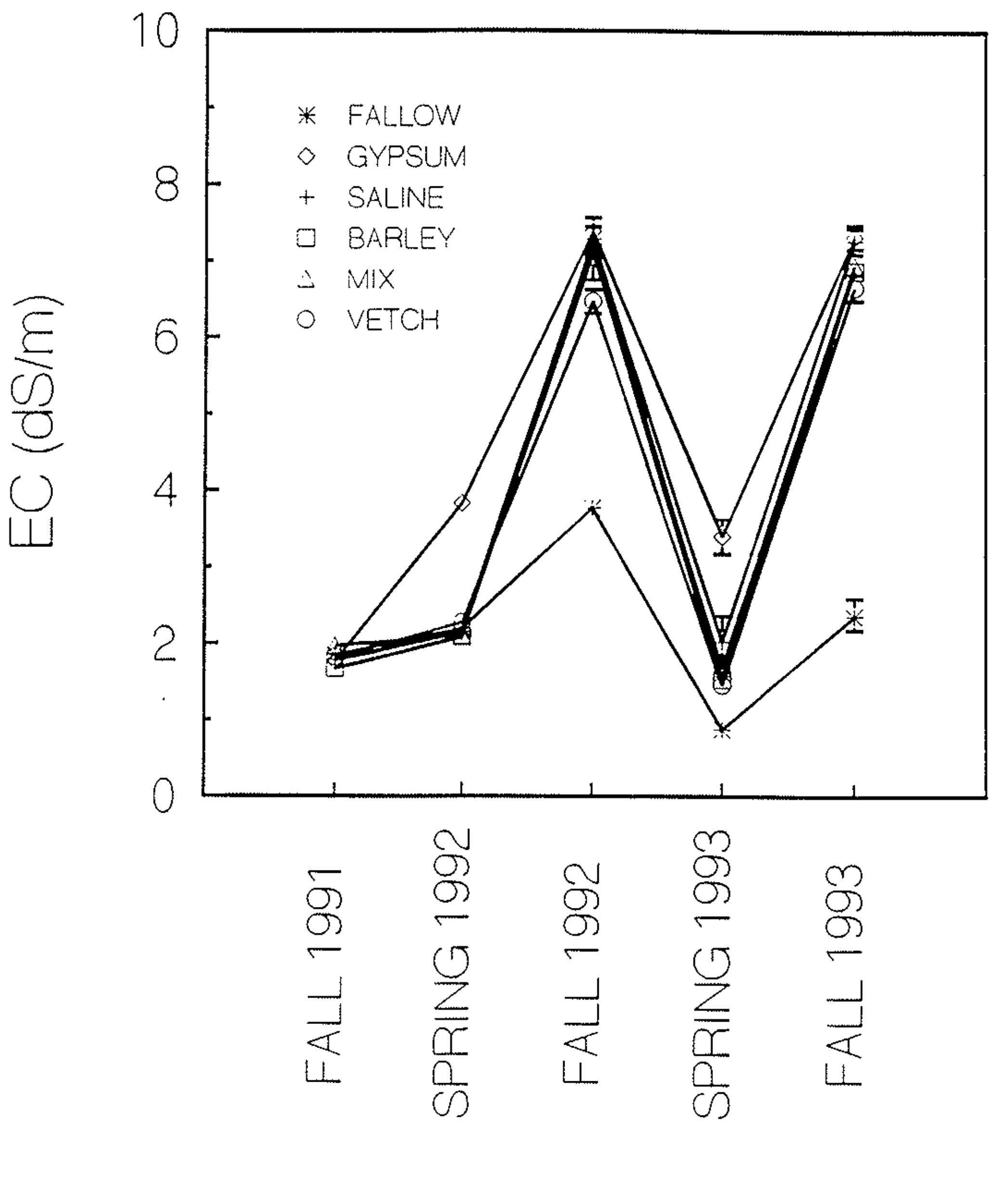


Figure 6. Cotton seedling emergence 1994. Each value if a mean of 4 replicates for the total number of seedlings emerged along 104 meters of bed. Standard errors of the means are shown when they exceed the height of the symbol.