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Cover Crops for Saline Soils

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With 1 figure and 8 tables

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Abstract

A 3-year study was conducted in the Central Valley of California to evaluate 125 prospective winter-growing cover crops for growth and nitrogen productivity in saline soils. Soil saturation paste electrical conductivities (ECes) in the surface 15 cm averaged 7 dS m^{-1} at fall planting and 5.3 dS m^{-1} at spring harvest dates of each experiment. Species evaluated varied substantially in plant height. In general, the tallest plants were the *Brassica* species, which consistently grew to over 1.4 m. Annual grasses (barley, rye, triticale and wheat) averaged about 1.0–1.3 m in each year. Of the legume species screened, heights were greatest for *Hedysarum coronarium*, *Trifolium alexandrium*, *Vicia* spp., and *Medicago polymorpha* and *truncatula*, averaging 59, 47, 39, 38 and 37 cm, respectively, over all experiments. About one third of the species screened produced crop cover in excess of 90 % in each year. Groups of plants with consistently high crop cover percentages included various species/accessions of *Brassica*, *Hedysarum*, annual grasses, cool-season annual medics, *Medicago polymorpha* and *Medicago truncatula*, and two annual clovers, *Trifolium alexandrium* cv 'Multicut' and rose clover, *Trifolium hirtum* cv 'Hykon.' Total above-ground plant dry weights were highest for *Brassica* spp., which produced twice as much biomass as the annual grass species, and roughly four times as much dry matter as any of the legume species. *Hedysarum*, Lana and Namoi woolypod vetch, purple vetch, berseem clover, and several of the annual medic species consistently had the highest biomass among the legumes.

Key words: Cover crops — legumes — salinity — biomass

Introduction

Intensive irrigation practices developed during this century have enabled the San Joaquin Valley (SJV) of California to become one of the most productive agricultural regions in the world (Calif. Stat. Abstr. 1992, Van Schilfgaarde 1990). Continued high levels of crop productivity in this area are seriously jeopardized, however, because good quality irrigation water is increasingly scarce. Additionally, agricultural drainage water is accumulating in many parts of the Valley due to clay layers that impede percolation to deeper ground water zones of applied water that is not evapotranspired (SJV Drainage Program 1990). This drainage water tends to be saline because as plants extract and transpire soil water, much of the salt that is naturally contained in the water concentrates in the root zone, and through leaching accumulates in shallow water tables. While it is generally accepted that long-term agricultural production in this region depends on the construction of adequate drainage outflow systems (Van Schilfgaarde 1990), a variety of short-term management strategies including the alteration of existing cropping systems (Shennan et al. 1994) and use of salt-tolerant crop genotypes (Qualset and Corke 1991) that rely on saline drainage waters for irrigation are being considered to sustain production.

When waters containing high concentrations of Na are used for irrigation (Mitchell et al. 1991), soil structural degradation may occur which can greatly reduce stand establishment and crop yields of many annual row crops in periodically salinized soils (Shainberg and Singer 1990). To address these problems, we have evaluated the effectiveness of including various soil 'amendments' such as green manure crops in cropping systems that rely at least partially on subsurface drainage water sources for irrigation (Mitchell 1995). Several studies have shown benefits of green manure incorporation on various soil physical characteristics (Tisdale and Oades 1982, Macrae and Mehuys 1985, Cassman and Rains 1986) and stand establishment (Groody 1990).

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Keeping the soil surface covered by a crop may also reduce soil losses by both water and wind, and may improve air quality and driving safety in areas such as California's Central Valley, where blowing dust storms are common during the winter when fields are typically bare. While a considerable data bank currently exists on cover crops for a variety of cropping applications, environments, and climates (Miller et al. 1989, Ingels et al. 1994), little information has been formally presented that describes the salinity tolerance of potential winter cover crop species under an irrigated crop rotation where saline drainage water is used and where saline conditions have developed from salt accumulation. In this study, we evaluated the potential of a number of winter-growing species in terms of plant height, biomass and nitrogen productivity under conditions that might exist when saline drainage water is used for summer crop irrigation. Wherever possible, several accessions of a given species were included in our screening to provide information on both inter- and intraspecific growth characteristics. In a broader context, all of the legumes evaluated here are useful in the Mediterranean world as valuable range or pasture plants and in irrigated agriculture as nitrogen-fixing rotation crops (Cocks et al. 1979: Allen and Allen 1981). *Hedysarum* species are used in North Africa, Spain, Italy and Israel as important pasture and silage crops (Gurfel et al. 1982). Subclovers and annual medics have been naturalized in Australia and have been used there to improve more than 40 000 000 hectares in dryland wheat production areas. Introduction of cultivars of *Medicago* spp. or *Trifolium subterraneum* in grain rotations has revolutionized agricultural production in the cereal zone of South Australia since the late 1930s (Webber et al. 1977). The vetches (*Vicia* spp.) are commonly used for hay production and as green manures worldwide due to their high biomass productivities.

Materials and Methods

Plant materials

The species screened in these experiments were obtained from local commercial seed suppliers, the USDA Soil Conservation Service Lockeford Plant Materials Center and the legume seed collection of Walt Graves that is maintained by the Genetic Resources Conservation Program at the University of California, Davis.

Experimental procedures

Experiments were conducted on a Panoche clay loam (fine–loamy, mixed Calcareous, thermic Typic torrienthent) at the University of California West Side Research and Extension Center (WSREC) in Five Points, California in 1992, 1993 and 1994. To generate soil surface salinity levels comparable to those that might commonly develop in drainage water reuse irrigation systems in the SJV, the 0.2-ha field used for each of the saline screening experiments in this study was initially salinized by sprinkler application of about 25 cm of water (7.0 dS m^{-1}) from a perched water table (= 10 m under the soil surface) before planting in October 1991. Soil electrical conductivity (ECe) was determined in the surface 15 cm of every individual plot in the fall of 1991, to evaluate the uniformity of the initial salinization, and at 0–15, 15–30, 30–60 and 60–90 cm increments in the fall and spring of each year for all subsequent experiments. A randomized complete block design with three replications was used for both the saline and the nonsaline experiments. The nonsaline experiment was carried out in a field that had never been irrigated with saline water. The nonsaline experiment was only conducted in 1 year due to space limitations at the experimental site and because our primary objective was to determine productivity under the moderate soil salinities that conceivably could be generated in a drainage water reuse system. Prior to planting each year, 20 kg of phosphorous (as P_2O_5) was broadcast with a hand spreader. All of the legumes were inoculated with their appropriate *Rhizobia* the evening before planting. Seeds were planted at a rate of 50 kg ha^{-1} and lightly raked over in 1.5-m^2 plots replicated three times. This uniform planting rate was determined to be adequate for adapted species based on prior experience. Plots were weeded by hand as needed, to minimize interspecific competition. Weather data were secured from a California Irrigation Management Information System (CIMIS) weather station located 100 m from the experimental fields. Measurements of plant height and visual estimates of percentage canopy cover were made 1–2 days prior to harvest in each year. Above-ground plant matter was hand harvested for determination of dry matter production and nitrogen content.

Experiments were also conducted in 1993 and 1994 to compare the productivity of promising species at three different soil salinities (henceforth referred to as saline gradient experiments). To establish the soil salinities, different ratios of nonsaline and saline drainage water were ponded in plots to create low, medium and high soil salt levels. Each salinity level was replicated three times. The total amounts of water applied to each plot were equivalent. In October 1992, berseem clover, lana vetch, triticale and sweet vetch were planted in 9 m × 6 m plots, and in 1993, triticale, lana, sweet and purple vetches were planted in 2 m × 2.6 m plots. Seeding rates for each species and year are given in Table 1.

Statistical computations of effects due to cover crop were assessed using the PROC GLM procedure of SAS Version 6.1 software. Response variables considered were plant height, above-ground plant biomass and percentage cover. Significance was determined using an F test as described by McIntosh (1983), and means were separated

Table 1: Seed planting rates for saline gradient experiments

1993	(kg · ha^{-1})
Trifolium alexandrium	34
Vicia villosa subsp. *varia*	65
Triticosecale	110
Hedysarum coronarium T-115	40
1994	
Vicia villosa subsp. *varia*	65
Triticosecale	110
Hedysarum coronarium T-115	56
Vicia benghalensis	65

at the 0.05 probability level using Fisher's protected least significant difference (L.S.D.).

Results

Winter growing season conditions

Planting and harvest dates and the total number of growing days for the 1992, 1993 and 1994 experiments are given in table 2. Daily maximum and minimum air temperatures during each winter growing season are shown in the figure, with 30-year averages included for comparison. While winter air temperatures were relatively normal for the Central SJV during the course of these experiments, the average rainfall amounts that were recorded varied considerably from year to year (Table 3). Rainfall was somewhat typical for this region of the Valley in 1993–94, below average in 1992–93, and the third highest amount ever recorded in 1992–93. The amounts and quality of supplemental irrigation water applied for germination and establishment are shown in table 3. Saline drainage water was used for these initial irrigations in 1992, however, in both 1993 and 1994, nonsaline water was applied to augment leaching by winter rainfall of surface salts. Soil surface salinities (0–15 cm) were 'moderate' at the beginning of each fall and were at a level that would

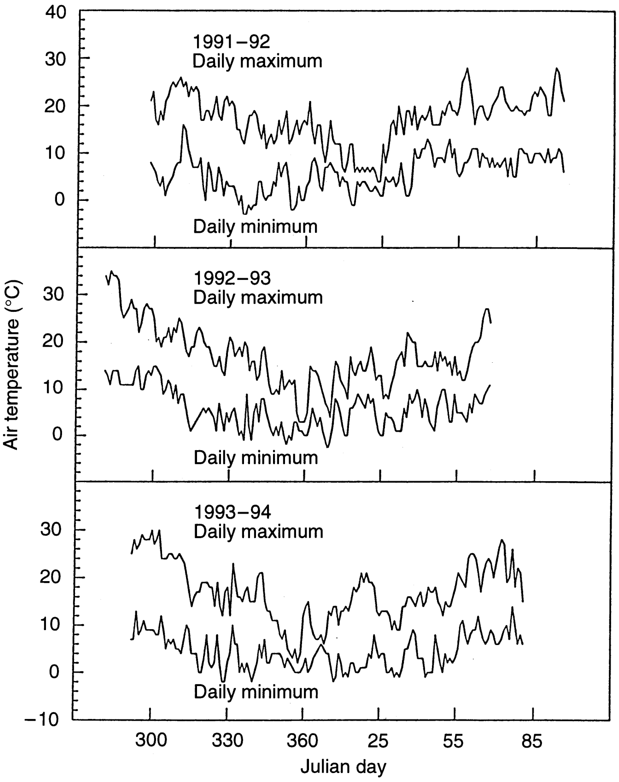

Fig. 1: Daily maximum and minimum air temperatures during winter cover crop growing seasons 1991–92, 1992–93 and 1993–94

Table 3: Quantity and quality of irrigation water applied, rainfall and 30-year average rainfall during winter cover crop growth period

	1992	1993	1994
Total irrigation	46 mm	120 mm	75 mm
Rainfall (Oct–Mar)	166 mm	266 mm	101 mm
Total water	212 mm	386 mm	247 mm
30-year average rain	154		
ECw (dS.m^{-1})	6.8	0.5	0.5

Table 2: Planting and harvest dates and total number of growing days for 1992, 1993 and 1994 experiments

	1992 Saline	1993 Saline	1993 Saline gradient	1994 Saline	1994 Non-saline	1994 Saline gradient
Planting date	25/10/91	8/10/92	22/10/92	19/10/93	20/10/93	26/10/93
Harvest date	5/4/92	9/3/93	10/3/93	22/3/94	24/3/94	29/3/94
Total growing days	166	152	139	154	155	154

Table 4: Soil saturation paste electrical conductivity (ECe) at planting and harvest dates of each experiment. F and SP refer to fall and spring, respectively

	1992 Saline (dS.m^{-1})		1993 Saline (dS.m^{-1})		1994 Saline (dS.m^{-1})		1994 Non-saline (dS.m^{-1})	
Depth	F91	SP92	F92	S93	F93	SP94	F93	SP94
0–15 cm	7.8+0.1	5.6+0.3	5.5+0.4	3.2+0.4	7.7+0.4	7.1+0.4	1.0+0.1	0.7+0.1
15–30 cm	—	5.1+0.2	—	4.6+0.4	5.8+0.2	6.2+0.4	0.6+0.1	0.7+0.1
30–60 cm	4.9+0.4	4.4+0.1	4.9+0.4	4.2+0.2	5.4+0.1	5.6+0.2	0.7+0.1	0.6+0.1
60–90 cm	4.0+0.3	—	4.0+0.3	4.0+0.2	5.0+0.2	5.2+0.3	1.0+0.1	0.8+0.1

be expected after a summer season of saline drainage water irrigations (Tables 4 and 5). Soil surface salinities (0–15 cm) decreased generally during the fall–spring growing period in each year (Table 4), particularly during the 1992–93 high rainfall winter. Salt levels in the 15–30, 30–60, and 60–90 cm increments also tended to be reduced in the 1992–93 experiments, but increased slightly during the 1993–94 lower rainfall season. Periodic visual monitoring indicated that foliar disease was not a factor in any experiment.

Plant growth and productivity

About one third of the species screened produced crop cover in excess of 90 % in each of the 3 years of this experiment (Table 6). Groups of plants with consistently high crop cover percentages include various species/accessions of *Brassica*, *Hedysarum*, cereal grasses, cool-season annual medics, *Medicago polymorpha* and *Medicago truncatula*, and two annual clovers, *Trifolium alexandrium* cv ‘Multicut’ and rose clover (*Trifolium hirtum* cv ‘Hykon’). Low percentages of cover occurred in the *Medicago* spp. *minima*, *rigidula* and *rugosa*, and in the halophytes, *Atriplex canescens* and *nummularia*.

The species evaluated in these experiments varied substantially in plant height (Table 6). In general, the tallest plants were the *Brassica* species, which consistently grew to over 1.4 m. Introduced annual grasses (barley, rye, triticale and wheat) were the second tallest group of plants, averaging about 1.0–1.3 m in each year. Of the legume species screened, plant heights were greatest for *Hedysarum coronarium*, *Trifolium alexandrium*, *Vicia* spp. and *Medicago polymorpha* and *truncatula*, averaging 59, 47, 39, 38 and 37 cm, respectively, over all experiments. *Medicago laciniata*, *Trifolium subterranean*, *Trifolium hirtum* and *Medicago minima* were consistently short, attaining heights of less than 25 cm.

Total above-ground plant dry weights were highest for the *Brassica* species, which produced twice as much biomass as the annual grass species, and roughly four times as much dry matter as any of the legume species. *Hedysarum*, Lana and Namoi woolypod vetch and purple vetch, berseem clover, and several of the annual medic species consistently had the highest biomass productivities among the legumes. Nitrogen content of above-ground plant biomass for plants grown under nonsaline conditions in 1993–94 are given in table 8. Legume species averaged 3.2 % N, while cereal and *Brassica* spp. averaged 1.5 and 2.3 % N, respectively.

Linear regression analyses of plant weight versus plant height, and plant weight versus % cover for the legumes and cereal species screened here indicated that plant height is a better predictor of biomass production than percentage cover for legumes ($R^2 = 0.27$ and 0.18, respectively), but that percentage cover was a slightly better predictor of plant weight for cereals ($R^2 = 0.37$ and 0.32, respectively). Soil salinities were considerably lower in the 1993 saline gradient experiment than in the 1994 gradient trial (Table 5). Increasing salinity reduced vetch biomass production, but had little effect on other species in 1993 (Table 7). Biomass production was reduced by increasing salinity in all species in 1994.

Discussion

This study has identified several promising winter-growing cover crop species with vigorous growth characteristics under moderate, transient soil salinities. These species, which include both legumes and nonlegumes, may be suitable in a range of cropping

Table 5: Soil saturation paste electrical conductivity (ECe) at planting and harvest dates of saline gradient experiments. F and SP refer to fall and spring, respectively

	1993 (dS.m^{-1})						1994 (dS.m^{-1})					
	F92			SP93			F92			SP93		
Depth	Low	Med.	High	Low	Med.	High	Low	Med.	High	Low	Med.	High
0–15	1.1+0.1	2.4+0.1	3.0+0.2	0.8+0.1	0.8+0.1	1.5+0.2	1.0+0.4	6.0+0.3	10.8+0.4	0.8+0.1	4.1+0.3	6.0+0.7
15–30	1.0+0.1	2.3+0.2	2.9+0.1	0.8+0.1	1.4+0.1	1.9+0.2	0.9+0.1	3.6+0.1	7.7+0.6	0.6+0.1	2.6+0.3	3.1+0.1
30–60	1.2+0.1	2.2+0.1	2.8+0.1	0.9+0.1	2.2+0.3	2.6+0.1	1.0+0.1	3.0+0.1	5.4+0.5	0.7+0.1	2.5+0.2	3.1+0.1
60–90	1.2+0.1	2.3+0.1	2.8+0.1	1.2+0.1	2.2+0.3	3.0+0.1	0.9+0.2	3.0+0.1	4.9+0.4	1.0+0.1	2.7+0.2	3.0+0.2

systems including rotations that rely on saline water sources for crop irrigation, as organic soil amendments that upon decomposition, may serve to maintain or improve soil structural quality. Groups of plants with consistently high productivities under the moderate salinities imposed here include Brassicas, annual introduced grasses, woolypod, sweet and purple vetches, berseem clover, and certain accessions of bur and barrel medic, *Medicago polymorpha* and *Medicago truncatula.*

The growth characteristics of plants evaluated in these experiments are generally similar to observations reported previously (Maas and Grattan 1998). Published reports of salt tolerance data exist for the major economic plants screened here, but for relatively few of the less utilized species we evaluated (Maas 1990). With the notable exceptions of the Brassicaceae and *Triticosecale*, which were unaffected by salinity, the moderate soil salinities that were imposed in our saline experiments, and which would develop in saline drainage water reuse irrigation cropping systems, reduced dry matter accumulation and plant height on average by 20–50 %. Despite these reductions, biomass production in several of the more promising species was sufficient to be considered useful for many green manuring applications.

Direct comparisons of our findings with salt tolerance data from other studies are not made easily because of the lack of consistency in experimental conditions used in screening trials (Maas and Grattan 1998). Many of the standard salt tolerance relationships that have been developed apply only to crops exposed to relatively uniform salinities from the period following establishment to maturity (Maas and Grattan 1998). Such conventional salinity tolerance/response relationships/functions do not describe adequately responses of field-grown crops to salinity profiles that exist at seeding and change considerably over time (Maas 1990), such as those investigated here. While crop yields in saline environments are generally dependent on average salinity in the root zone, other important soil, water and climatic factors also influence plant response to salinity (Maas and Grattan 1998). For example, higher winter rainfall amounts with correspondingly greater leaching of soil profile salinities, and warmer early fall season temperatures in our 1992–93 season likely contributed to the generally higher productivity of most species in this trial relative to other years (Table 6). Because the drainage water used to salinize the soil profiles initially in the salinity experiments contained on average 6 p.p.m. B, it is

Table 6: Plant height, plant weight and % cover for legume and non-legume species grown under saline soil conditions in 1991–92, 1992–93 and 1993–94, and under non-saline conditions in 1993–1994. Data for saline trials are means of 1, 2 or 3 years of data that are based on three replicates per each year

					Saline		Fresh	Saline	Fresh	Saline	Fresh
	Scientific name	Accession	Graves collection number	Life cycle duration	No. of years	Plant height (cm)	Plant height (cm)	Plant weight kg.ha^{-1}	Plant weight kg.ha^{-1}	% cover	% cover
1	*Atriplex canescens*	Marana 476816		Perennial	1	30	15	727		43	51
2	*Agropyron elongaturn*			Perennial	2	49		5551		69	
3	*Atriplex nummulaira*	Oldman Salt Bush		Perennial	1	13	14			5	50
4	*Brassica carinata*	Ethiopian mustard		Annual	3	166	192	16 975	15 353	100	100
5	*Brassica juncea*	Indian mustard 77-1352		Annual	3	147	170	21 440	21 464	100	100
6	*Brassica juncea*	Indian mustard 77-12854		Annual	3	132	170	22 180		100	100
7	*Brassica nigra*	Black mustard		Annual	1	142		7813		100	
8	*Festuca arundinacea*			Perennial	2	49		3886		97	
9	*Eriogorum umbellatum*	Sierra		Perennial	1	13	5			35	15
10	*Hordeum brachyantharum*	Meadow barley		Perennial	1	46				100	
13	*Hedysarum carnosum*	T-46		Annual	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*		GR-249	Perennial			78		7814		100
15	*Hedysarum coronarium*		GR-252	Perennial			73		10 116		100
16	*Hedysarum coronarium*		T-456	Perennial			73		9312		100
17	*Hedysarum coronarium*		T-8113	Perennial			64		7433		100
18	*Hedysarum coronarium*		GR-862	Perennial			64		6293		100
19	*Hedysarum carnosum*		GR-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	10 241	6280	98	100
23	*Lupinus nanus*	Gilpin	LUNA	Annual	1	13				33	
24	*Medicago arborea*	PI504540		Perennial	1	13		1489		52	
25	*Medicago ciliaris*	PI498736	MECI-2	Annual	2	37		2768		97	
26	*Medicago ciliaris*	PI498753	MECI-3	Annual	3	31	41	2003	4588	95	100
27	*Medicago ciliaris*	PI368928	MECI-1	Annual	3	24	40	2126	4036	89	100
28	*Medicago ciliaris*		GR-852	Annual	1	36		1178		100	
29	*Medicago ciliaris*		GR-841	Annual	1	23				67	
30	*Medicago ciliaris*		GR-372	Annual	1	23				92	
31	*Medicago ciliaris*		GR-825	Annual	1	18				67	
32	*Medicago discoformis*	PI487333	MEDI-1	Annual	2	19				76	
33	*Medicago doliata*	PI495293	MEDO-1	Annual	1	15		2554		73	
34	*Medicago doliata*	M-5704	MEDO-2	Annual	1	13				65	

Table 6: (*Continued*)

					Saline		Fresh	Saline	Fresh	Saline	Fresh
	Scientific name	Accession	Graves collection number	Life cycle duration	No. of years	Plant height (cm)	Plant height (cm)	Plant weight kg.ha^{-1}	Plant weight kg.ha^{-1}	% cover	% cover
35	*Medicago doliata*	PI495293		Annual	1	48		3629		100	
39	*Melilotus indica*	SCS9059045		Biennial	1	8				30	
40	*Medicago littoralis*	cv Harbinger	ML-1	Annual	3	36	48	4390	6650	90	100
41	*Medicago laciniata*	PI498888	MLA-17	Annual	2	28				89	
42	*Medicago lacinata*	PI498874	MLA-16	Annual	2	22				78	
44	*Medicago laciniata*	PI498871	MLA-15	Annual	1	15		1432		68	
45	*Medicago laciniata*	PI498851	MLA-13	Annual	2	18		2641		90	
46	*Medicago laciniata*	M-5668	MLA-19	Annual	2	21				82	
47	*Medicago laciniata*	PI498889	MLA-18	Annual	1	28				100	
48	*Medicago laciniata*	PI498852	MLA-14	Annual	1	28				100	
51	*Medicago minima*	PI498986	MMI-14	Annual	2	18				84	
52	*Medicago minima*	GR-548	MMI-4	Annual	1	13		1462		57	
53	*Medicago minima*	PI490005	MMI-15	Annual	2	18	29	2137	3646	85	98
54	*Medicago minima*	GR-129	MMI-6	Annual	1	13		1219		40	
56	*Medicago minima*	GR-585	MMI-9	Annual	1	13		1438		70	
57	*Medicago minima*	PI499020	MMI-16	Annual	2	14				67	
58	*Medicago minima*	GR-451R	MMI-2	Annual	2	21		2450		68	
60	*Medicago minima*	GR-127	MMI-1	Annual	1	8				55	
61	*Medicago minima*	GR-126	MMI-8	Annual	1	5				32	
50	*Medicago murex*	cv Zodiac	MMU-1	Annual	3	21	43	3174	4543	71	100
62	*Medicago polymorpha*	SCO 9001	MP-5	Annual	3	42	59	5684	4949	98	100
63	*Medicago polymorpha*	PI493293/378530 mix	MP-12	Annual	2	29	46	3240	8300	93	100
64	*Medicago polymorpha*	PI282428	MP-11	Annual	3	38	50	3074	8283	100	100
65	*Medicago polymorpha*	PI292418	MP-10	Annual	2	22	59	1817	4929	97	100
66	*Medicago polymorpha*	PI197539	MP-8	Annual	3	33	48	4017	7193	82	100
67	*Medicago polymorpha*	SCS9041018	MP-3	Annual	2	22	53	2804	7400	63	100
68	*Medicago polymorpha*	cy 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*	PI283656	MP-9	Annual	3	31	45	2871	7331	96	100
71	*Medicago polymorpha*	PI1493293	MP-13	Annual	3	30	48		8300	92	100
72	*Medicago polymorpha*	cv 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*	PI441949	MERI-4	Annual	1	10		1489		52	
79	*Medicago rigidula*	PI441996	MERI-6	Annual	1	8				7	

Table 6: (*Continued*)

					Saline		Fresh	Saline	Fresh	Saline	Fresh
	Scientific name	Accession	Graves collection number	Life cycle duration	No. of years	Plant height (cm)	Plant height (cm)	Plant weight kg.ha^{-1}	Plant weight kg.ha^{-1}	% cover	% cover
94	*Medicago rigidula*	PI441950	MERI-5	Annual	1	10				42	
55	*Medicago rugosa*	cv Sapo	MRU-2	Annual	1	13				33	
59	*Medicago rugosa*	cv Papaponto	MRU-3	Annual	1	13	30		3379	18	58
76	*Medicago rugosa*	cv Paragosa	MERU-1	Annual	1	23				52	
77	*Medicago rugosa*	GR-67	MRU-5	Annual	1	18				55	
81	*Medicago scutellata*	cv Sava	MS-3	Annual	2	36		2377		100	
82	*Medicago scutellata*	SCS9041678	MS-2	Annual	2	44				100	
83	*Medicago scutellata*	cv Kelson	MS-1	Annual	2	44	55	4099	7008	91	100
86	*Medicago tornata*	cv Rivoli	MTO-1	Annual	3	38	44	4219	7172	99	99
84	*Medicago truncatula*	cv Parabinga	MTR-1	Annual	2	38	2662			100	
87	*Medicago truncatula*	cv Jemalong	MTR-4	Annual	3	32	44	6318	7198	85	100
88	*Medicago truncatula*	cv Paraggio	MTR-2	Annual	3	30	44	2391	5775	82	100
89	*Medicago truncatula*	cv Saphl	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 tye		Annual	3	135	170	10 505	12 063	99	100
97	*Triticum aestivum*	Wheat		Annual	3	85	102	8308	10 758	96	100
98	*Trifolium alexandrium*	cv multicut		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*	cv Hykon	TH-1	Annual	3	27	35	2102	3984	89	90
101	*Trifolium hirtum*	cv 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*	cv Wilton	TH-5	Annual	2	26	28	3885	2829	69	98
104	*Trifolium incarnata*	cv Flame	TI	Annual	2	29				74	
105	*Trifolium resupinatum*	cv Marar			1	43				83	
106	*Trifolium resupinatum*	cv Kyambro			1	33				100	
108	*Trifolium subterranean*	cv Koaka	TSB-3	Annual	2	26		842		77	100
109	*Trifolium subterranean*	T-43F	TSB-11	Annual	2	21				78	
110	*Trifolium subterranean*	cv Rosedale	TSB-2	Annual	2	19				61	
111	*Trifolium subterranean*	cv 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*	cv Larisa	TSY-2	Annual	1	8				43	

Table 6: (*Continued*)

					Saline		Fresh	Saline	Fresh	Saline	Fresh
	Scientific name	Accession	Graves collection number	Life cycle duration	No. of years	Plant height (cm)	Plant height (cm)	Plant weight kg.ha^{-1}	Plant weight kg.ha^{-1}	% cover	% cover
126	*Trifolium subterranean*	cv Nuba	TSB	Annual	1	36				100	
117	*Trifolium subterranean*	cv Koala	TSB-3	Annual	1	33		842		91	
118	*Trifolium subterranean*	cv Clare	TSB-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	10 233	12 228	97	100
122	*Vicla benghalensis*	Purple vetch	V-3	Annual	3	50	62	3131	8495	79	98
123	*Vicia sativa*	cv Blanchfluer	V-1	Annual	1	23	61	532	3669	27	94
124	*Vicia villosa* subsp. *varia*	cv Lana	V-4	Annual	3	59	60	5734	6629	98	100
125	*Vica faba*	Horsebean		Annual	1	46		1057		40	
126	*Vicia villosa* subsp. *varia*	cv Namol	V-2	Annual	3	61	58	4284	7652	98	100
128	*Vicia sativa*	2541			1	41	50		4604	100	100

also conceivable that high soil boron may have contributed to the specific growth responses seen in our experiments.

Several of the species screened here possess characteristics desirable for winter cover crops in saline production environments (i.e. rapid establishment, vigorous winter growth, weed suppressiveness, and late flowering). Species of the genus *Brassica* may be particularly suitable for such areas because of their rapid growth under cool conditions. Members of the Brassicaceae have been successfully grown as winter oil crops in other areas including Pakistan, India and Bangladesh, and this potential for oil production has also been investigated in California (Knowles et al. 1981). *Brassica* species are being evaluated currently as reclamation tools in areas with high soil selenium levels (Banuelos et al. 1993). But Jackson et al. (1993) found that the large taproots of *Brassica* spp. may make incorporation difficult, particularly if accomplished on prepared beds with buried drip irrigation systems. Moreover, some members of this genus act as hosts for diseases such as turnip mosaic potyvirus and therefore limit their suitability in certain cropping systems. Bugg et al. (1993) similarly concluded that growth of black mustard (*Brassica nigra*) may be too vigorous for vineyard cover crop applications. Further consideration of *Brassica* spp. as potential cover crops is warranted however, particularly if soil conditions allow early spring mowing and incorporation to arrest the aggressive winter growth of these species.

A number of the gramineous species/winter cereals, notably barley (*Hordeum vulgare*), triticale (*Triticosecale*), rye (*Secale cereale*) and wheat (*Triticum aestivum*) also grew well under the moderate soil salinities of these experiments. Soil salinities (ECes) at which yield reductions might be expected for barley, rye and wheat are 8.0, 7.6, and 4.5, respectively, though these threshold values again may have little bearing on productivity under transient soil salinity conditions (Maas and Grattan 1998). Although yields of barley were reduced by 28 %, rye by 58 % and wheat by 55 % in our severest saline experiment (1994), relative to the 1994 nonsaline trial, the amount of total plant dry matter produced by these entries was substantial enough that improvements in such soil structure-dependent properties as water infiltration may be expected (Williams and Doneen 1960, Williams 1966). Thus, any or all of these species could play a potential role in cover crops in saline water reuse cropping systems.

Table 7: Dry matter production (kg.ha^{-1}) of *Hedysarum coronarium*, *Triticale*, *Vicia villosa* subsp. *varia*, *Trifolium alexandrium* and *Vicia benghalensis* at low, medium and high soil salinities in 1993 and 1994

	1993			1994		
	Low	Medium	High	Low	Medium	High
Hedysarum coronarium	1807 ± 214	1398 ± 138	1570 ± 170	3997 ± 290	1839 ± 700	2202 ± 837
Triticale	11960 ± 748	11390 ± 736	12218 ± 1032	4767 ± 344	2948 ± 338	2785 ± 286
Vicia villosa subsp. *varia*	3990 ± 277	3313 ± 264	3345 ± 164	2331 ± 251	1991 ± 200	1589 ± 282
Vicia benghalensis				2500 ± 322	2009 ± 496	1876 ± 290
Trifolium alexandrium	2474 ± 239	2753 ± 340	2162 ± 170			

The year-to-year variation in dry matter accumulation in barley points to the importance in cultivar selection for specific cover crop applications. The high barley biomass yields in 1992 and 1993 were achieved by the tall commercial grain cultivar 'Fiesta.' The lower yields in 1994 trials resulted from the more compact 'Faschop' variety, developed for recurrent cuttings as 'green chop'. Triticale (*Triticosecale*) is a species that has not been recognized adequately for its use as a cover crop, especially under saline conditions (Miller et al. 1989, Ingels et al. 1994). Biomass production for triticale was reduced by only 18 % in the 1994 saline experiment relative to production under 1994 nonsaline conditions. Early fall planting of this crop is important however, because productivity drops markedly with later planting dates. In the 1994 saline gradient experiment, planted 7 days later than both the 1994 saline and nonsaline trials, yields of plants in nonsaline plots dropped to 39 %, 24 % and 23 % in the low, medium and high salt plots of those in the earlier-planted nonsaline trial.

As a group, leguminous species were far less productive generally under the moderate soil salinities imposed here than were either the grasses or the mustards. These findings conform generally to published data on salt tolerance of these groups (Maas and Grattan 1998). Very few of the legumes consistently produced dry matter yields in excess of 3000 kg ha^{-1}, or attained heights greater than 30 cm. The most outstanding legumes included Lana and Namoi vetch (*Vicia villosa* subsp. *varia*), berseem clover (*Trifolium alexandrium*) and the bur clover accession, *Medicago polymorpha* cv SCO 9001, and these warrant further study. The ability of legumes to fix atmospheric nitrogen and increase soil N content upon incorporation may be an important attribute of these species, and so the nitrogen content of above-ground biomass was determined for several of the most exceptional species. However, symbiotic N-fixation likely plays a lesser role in saline drainage water reuse systems because the NO_3 content of these waters is already very high (Mitchell et al. 1991).

The work reported here was designed to evaluate winter-growing species as cover crops in rotations that periodically rely on saline agricultural drainage waters for irrigation. While the major growth characteristics monitored here are important as basic screening criteria for cropping systems, other agronomic traits such as ease of incorporation, weed and disease suppression and insectary value are also needed.

Zusammenfassung

Zwischensaaten für versalzte Böden

Eine Dreijahresuntersuchung wurde im Central Valley of California durchgeführt, um 125 mögliche Winterzwischenfrüchte hinsichtlich des Wachstums und der Stickstoffproduktivität in versalzten Böden zu untersuchen. Die gesättigten Bodenproben wiesen eine durchschnittliche elektrische Konduktivität (ECes) in der Oberfläche bis 15 cm von 7 dS m^{-1} zur Herbstbestellung und 5,3 dS m^{-1} für Sommererntedaten in jedem der Experimente auf. Die untersuchten Arten variierten substanziell in der Pflanzenhöhe. Grundsätzlich waren die höchsten Pflanzen *Brassica*-Arten, welche regelmäßig über 1,4 hoch wurden. Einjährige Gräser (Gerste, Roggen, *Triticale* und Weizen) erreichten 1,0 bis 1,3 m im Jahr. Von den ausgewählten Leguminosenarten zeigten in allen Experimenten die größten Höhen *Hedysarum coronarium*, *Trifolium alexandrium*, *Vicia* spp. und *Medicago polymorpha* und *Medicago truncatula* mit durchschnittlich 59, 47, 39, 38 und 38 cm. Etwa 1/3 aller Arten produzierte Bestandesabdeckungen von mehr als 90 % in jedem Jahr. Gruppen von Pflanzen mit regelmäßig hohen Bestandesdeckungsprozentsätzen umfassen verschiedene Arten/Accessionen von *Brassica Hedysarum*, einjährigen Gräsern, an Kühlebedingungen angepaßte einjährige

Table 8: Nitrogen content (%) of winter cover crop species. Each value is a mean of three replicates ± standard error

Species	Accession	Nitrogen content (%)
Secale cereale	Merced rye	1.44 ± 0.20
Vicia sativa	acc. 2541	4.33 ± 0.34
Trifolium alexandrium	Multicut	3.58 ± 0.18
Medicago polymorpha	TAH	3.13 ± 0.40
Triticum aestivum	Wheat	1.53 ± 0.08
Medicago truncatula	Jemalong	3.41 ± 0.11
Vicia benghalensis	Purple vetch	4.38 ± 0.87
Medicago rugosa	Paragosa	3.34 ± 0.18
Medicago rugosa	Paraponto	3.17 ± 0.13
Medicago scutellata	Kelson	3.20 ± 0.16
Medicago tornata	Rivoli	3.72 ± 0.32
Medicago truncatula	Paraggio	3.82 ± 0.27
Medicago truncatula	Sephi	3.75 ± 0.12
Medicago truncatula	Ascot	3.97 ± 0.29
Medicago truncatula	Caliph	3.91 ± 0.68
Hedysarum caronsum	Sweet vetch	3.85 ± 0.56
Vicia sativa	Blanchfleur	4.10 ± 0.42
Medicago truncatula	Borung	2.93 ± 0.15
Medicago truncatula	Mogul	3.30 ± 0.43
Medicago truncatula	Caliph	3.30 ± 0.17
Medicago ciliaris	PI368928	3.49 ± 0.12
Triticosecale	*Triticale*	1.48 ± 0.25
Medicago ciliaris	PI498753	3.44 ± 0.30
Medicago littoralis	Harbinger	3.51 ± 0.28
Medicago minima	PI499005	3.72 ± 0.58
Medicago murex	Zodiac	3.63 ± 0.23
Medicago polymorpha	Serena	2.90 ± 0.23
Medicago polymorpha	Santiago	3.26 ± 0.15
Medicago polymorpha	PI9041018	3.58 ± 0.14
Medicago polymorpha	Circle Valley	3.31 ± 0.07
Medicago polymorpha	SCO 9001	3.39 ± 0.27
Medicago polymorpha	PI197539	3.64 ± 0.17
Medicago polymorpha	PI292418	3.50 ± 0.20
Medicago polymorpha	PI292428	3.40 ± 0.20
Medicago polymorpha	PI4932931	3.72 ± 0.20
Medicago polymorpha	PI493293	2.93 ± 0.23
Vicia villosa subsp. *varia*	Naomi	3.76 ± 0.18
Trifolium balansae	Paradana	3.31 ± 0.09
Vicia villosa subsp. *varia*	Lana	3.51 ± 0.43
Trifolium hirtum	Hykon	3.13 ± 0.14
Trifolium hirtum	Wilton	3.41 ± 0.04
Trifolium hirtum	RH-18	3.17 ± 0.07
Hedysarum coronarium	GR456	3.33 ± 0.11
Hedysarum coronarium	GR8113	3.37 ± 0.15
Hedysarum coronarium	GR252	3.18 ± 0.48
Hedysarum coronarium	GR115	3.56 ± 0.15
Brassica juncea	77-1356	2.35 ± 0.73

Medicago-Arten wie *Medicago polymorpha* und *Medicago truncatula* und zwei einjährige Kleearten, *Trifolium alexandrinum* cv. ‚Multicut' und *Trifolium hirtum* cv. ‚Hykon'. Die gesamten oberirdischen Pflanzentrockenmassen waren bei *Brassica* am höchsten, wobei zweimal soviel Biomasse wie bei den einjährigen Grasarten erzeugt wurde und rund viermal soviel Trockenmasse im Vergleich zu Leguminosenarten. *Hedysarum*, Lana und Namoi rauhsamige Vogelwicke, persischer Klee und zahlreiche einjährige Medicagoarten wiesen regelmäßig die höchsten Biomasseerträge innerhalb der Leguminosen auf.

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