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ALLELOPATHY IN SALINE AGRICULTURAL LAND: VEGETATION SUCCESSIONAL CHANGES AND PATCH DYNAMICS

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Abstract—In reclamation fields of salt-affected wasteland, five plant communities colonized the undisturbed land, represented by *Cynodon dactylon*, *Desmostachya bipinnata*, *Prosopis juliflora*, *Sporobolus arabicus*, and *Suaeda fruticosa*. Kallar grass (*Leptochloa fusca*), a highly salt tolerant plant when cultivated, shared dominance with *Cynodon*, *Desmostachya*, and *Sporobolus* in 15-month-old fields, whereas *Polypogon* was the only dominant species in 30-month-old kallar grass fields. Through successional stages, soil pH, salinity, sodicity, and Na, K, Ca + Mg significantly decreased due to leaching. Electrical conductivity successively changed from 13.0 to 3.0 to 1.0, while soil total nitrogen, NH_4 nitrogen, NO_3 nitrogen and available P significantly increased. In high-density kallar grass fields, six weed species appeared only in well-defined patches and radially eliminated or reduced kallar grass growth. Many soil factors, such as pH, EC, NH_4 nitrogen, NO_3 nitrogen and available P analyzed in patch vegetation soils, were mostly either comparable or significantly better than those of surrounding kallar grass fields. On the other hand, aqueous extracts of all six invading species and kallar grass significantly reduced kallar grass seed germination to varying degrees. Further, decaying leaf powder of allelopathically suspected species significantly reduced kallar grass biomass, which varied from species to species and in most cases corresponded with field data of kallar grass in patch vegetation. It should be strongly pointed out that allelopathic behavior discussed in patch

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dynamics was in areas where soil saline–sodic conditions had improved greatly (e.g., EC = from 13.0 to only 1.0) due to kallar grass plantation. Further, *Suaeda* appeared to be a poor competitor when soil conditions improved for other species as well, and it could not capitalize on its evolutionary strategic trait of performing well in saline–sodic conditions. To our knowledge, this is the first report indicating that allelopathy may be a factor in determining growth and distribution of plants in saline or sodic soils.

Key Words—Revegetation, reclamation, salinity, succession, kallar grass, *Leptochloa fusca*, nutrients, allelopathy.

INTRODUCTION

Due to agricultural practices, salinity is a rapidly growing global problem, predominantly where agriculture has been prominent for centuries. It is paradoxical that the irrigation canal system in Pakistan has resulted in salinization and/or water-logging of irrigated soils, which now exist as wastelands. Reclamation of such wasteland is essential; one effective way is by selecting and growing salt-tolerant plant species (Chaudhri et al., 1964; Kleinkopf et al., 1975; Sandhu and Malik, 1975; Wallace et al., 1982; Naqvi, 1983).

Salt-affected soils are by no means devoid of vegetation. An ecological understanding of such vegetation may provide some useful information regarding the nature and intensity of salinization (Bodhla et al., 1981; Rutter and Sheikh, 1962). Subsequently, new species of economic importance may be introduced. Sandhu and Malik (1975) successfully introduced kallar grass [*Leptochloa fusca* (L.) Kunth.] in these wastelands for increased plant establishment and biomass production. Kallar grass is highly tolerant of salt (Sandhu et al., 1981) and sodicity (Aslam et al., 1979).

Even though the cultivation of kallar grass has clearly improved soil conditions (Malik, 1978), there were no systematic studies found in the literature describing the vegetation and soil properties of the saline lands and successive changes after kallar grass planting. With this in mind, a project was designed to document: (1) vegetation and soil composition of undisturbed areas, (2) successive changes after planting kallar grass and its own productivity, (3) invasion of kallar grass fields by various species, (4) patch dynamics of invading species, and (5) their allelochemic dominance in kallar grass fields. Nomenclature follows Stewart (1972), unless otherwise noted.

METHODS AND MATERIALS

Survey of Vegetation. The studies were carried out at the Biosaline Research Station (BSRS) of the Nuclear Institute for Agriculture and Biology, Faisalabad. BSRS is located near the village of Dera Chahl situated on Bedian Road, 30 km from Lahore. The study site had not been cultivated for at least 40 years and remained free of human activities, chiefly due to the salinity. There may have been minor grazing by small wild animals. Therefore, this site will be referred as the undisturbed wasteland. For vegetational analysis, study plots were roughly delimited at five different sites within undisturbed wasteland by their dominant species without reference to the subordinate species. Four line transects, each 20 m long, were placed at random at each site and cover of species along each transect was recorded. Each community was named after the species most representative of the cover. For distribution of weed species in kallar grass fields, a quadrat method was used. Twenty quadrats (1-m^2 size) were randomly placed in fields where kallar grass had been grown for 15 or 30 months. Percent frequency (F) and density (*D*) (number of plants per quadrat) of weed species were recorded. Importance values (*IV*) were calculated as $IV = (F + D)/2$.

During our sampling of kallar grass fields, it was surprisingly obvious that the invading weeds nearly always appeared in well-defined dense patches surrounded by kallar grass. To describe this observation quantitively, five patches of each of such weeds were located and quantified by a line transect method to indicate their range of invasion in kallar grass fields. Cover of weed species and kallar grass was recorded.

To determine kallar grass biomass, four 0.25-m^2 quadrats were randomly located in 15- and 30-month-old fields of kallar grass, and shoot biomass was harvested and dried to constant weight.

Soil Analysis. Four soil samples were collected from each site at the 0- to 15-cm level for physical and chemical analysis of the soil. Soil texture was determined by the hydrometer method (Bouyoucos, 1962) and water holding capacity by the Keen-Reckzoski box method (Piper, 1942). Soil pH was determined by a glass electrode pH meter, electrical conductivity (EC) by the Solu bridge conductivity meter, Na and K by flame photometry, and Ca + Mg by titration with ethylene diamine tetraacetate (EDTA). CO_3 and HCO_3 were determined by titration with H_2SO_4, and Cl by titration with $AgNO_3$ (USDA, 1954). Soil samples were extracted with 2 N KCl and analyzed for NH_4 and NO_3 by steam distillation with Devarda's alloy and MgO (Bremner and Keeney, 1965), and total nitrogen was determined following Bremner (1965). Available phosphorus was determined by the Olsen method (Watanabe and Olsen, 1965), and total phosphorus was determined after digestion with perchloric acid (Ogner et al., 1984).

Allelopathy Studies: Effects of Invading Species on Kallar Grass Seed Germination. To determine the effects of six major species invading kallar grass fields, aqueous extracts of each species and kallar grass were prepared and tested against kallar grass seed germination. Plant material was immersed in hot water (approx. 45°C) for 5 min to stop microbial activity before preparing the bioassay extracts. A 10% aqueous extract of each species was prepared by soaking the shoot material in water for 30 min at 25°C, and diluting to 2.5 and 5.0 (w/

v) percent solutions for experimentation. Final pH of all dilutions was adjusted to 6.0. Fifty kallar grass seeds were planted on filter paper in a Petri plate in triplicate and watered with various concentrations of extracts of all invading species. Seeds were allowed to germinate in the dark at a constant temperature of 25°C. Controls were treated in the same manner, except Petri plates were watered with distilled water. Germination was terminated after six days and recorded as percent germination.

Effects of Decaying Leaves of Invading Species on Kallar Grass Growth. Air-dried shoot material of each of six invading species and kallar grass was mixed in soil at a rate of 2 g/100 g soil and placed in 10-cm-diameter plastic pots. Shoot material was allowed to decay for two weeks and planted with four stubbles of kallar grass in each of four pots for each species. Seedlings were allowed to grow for four weeks, harvested, oven dried, and biomass recorded.

RESULTS

Vegetation. Five plant communities dominated by *Desmostachya bipinnata*, *Sporobolus arabicus*, *Suaeda fruticosa*, *Cynodon dactylon*, and *Prosopis juliflora* were recognized in the non-kallar grass fields in this study (Table 1). Apart from the dominant species, one or more of these five species were found

TABLE 1. MEAN PERCENTAGE COVER OF PLANT SPECIES IN DIFFERENT COMMUNITY TYPES

	Community type				
Species	*Desmostachya bipinnata*	*Sporobolus arabicus*	*Suaeda fruticosa*	*Prosopis juliflora*	*Cynodon dactylon*
Desmostachya bipinnata	62.04	1.25		1.55	
Sporobolus arabicus	8.54	37.58	10.16	2.66	10.50
Suaeda fruticosa	1.96	6.24	33.74	2.33	10.75
Prosopis juliflora			7.87	61.11	1.00
Cynodon dactylon	0.16	0.67	10.01	19.55	47.05
Kochia indica		1.66	1.50		2.00
Acacia modesta	0.50	1.21	0.50		
Chenopodium album		0.25			
Polypogon monspeliensis		0.16	0.12		
Cyperus rotundus			0.62		0.25
Spergula rubra			0.12		2.37
Dichanthium annulatum					1.37
Senebiera didyma				1.11	0.12
Capparis decidua				0.44	
Bare	26.80	50.98	35.36	11.25	24.59

to be codominant. Kallar grass-introduced fields were invaded by weeds over a 30-month period (Table 2). *C. dactylon*, *D. bipinnata*, *S. arabicus*, and *S. fruticosa* were prominent weeds in 15-month-old kallar grass fields, while *Polypogon monspeliensis* was the principal invader followed by *C. dactylon*, *Kochia indica*, *Cnicus arvensis*, *Cyperus rotundus*, *Scirpus martius*, *Rumex dentatus* and *Spergula rubra* in 30-month-old fields (Table 2).

Six major weeds invaded established kallar grass fields in well-defined patches. Kallar grass growth was very poor and stunted when growing in association with the invading weeds. However, its vigor improved gradiently away from the patch boundaries. Kallar grass biomass in 30-month-old fields was significantly lower than in 15-month-old fields (Table 3).

Soils. The soils in undisturbed sites were generally saline–sodic, and the degree of salinization varied for different plant communities (Figure 1, Table 4). The soils under *Suaeda* were highly saline and sodic, whereas those under *Desmostachya* and *Sporobolus* were moderately saline and highly sodic. *Cynodon* dominated slightly saline and moderately sodic soil, and *Prosopis* nonsaline but moderately sodic soils. The soils associated with *Cynodon* were relatively fine textured and had a higher water-holding capacity compared with soils dom-

TABLE 2. CHANGES IN MEAN IMPORTANCE VALUES OF PLANT SPECIES AT DIFFERENT SUCCESSIONAL STAGES

Species	Undisturbed	Kallar grass	
		15 months	30 months
Polypogon monspeliensis	0.04	1.62	21.47
Desmostachya bipinnata	23.42	6.37	
Sporobolus arabicus	16.42	4.93	0.75
Suaeda fruticosa	12.08	4.66	0.75
Cynodon dactylon	8.61	3.95	1.94
Spergula rubra	0.33	0.93	0.75
Cyperus rotundus	0.19	0.46	0.87
Kochia indica	1.04		0.87
Conyza ambigua			1.50
Cnicus arvensis			0.75
Rumex dentatus			0.75
Blumea membranacea		0.23	
Acacia modesta	0.61		
Dichanthium annulatum	0.17		
Senebiera didyma	0.61		
Chenopodium album	0.03		
Prosopis juliflora	13.99		

TABLE 3. CHANGES IN SOIL PROPERTIES AT DIFFERENT SUCCESSIONAL STAGES (N = 5, MEAN ± SE)

Soil characteristics	No kallar grass (undisturbed)	Kallar grass	
		15 months	30 months
Biomass (g/0.25 m^2)	—	229.0 ± 24.16	85.3 ± 4.09^{c}
pH	10.05 ± 0.11	9.14 ± 0.24^{a}	8.85 ± 0.09^{b}
EC, (mS/cm)	13.08 ± 5.01	2.92 ± 0.37^{a}	1.12 ± 0.07^{b,c}
Ca + Mg (meq/liter)	3.65 ± 0.24	3.00 ± 0.58	1.88 ± 0.35^{b}
Na (meq/liter)	136.75 ± 22.4	57.95 ± 8.52	14.88 ± 1.14^{b,c}
K (meq/liter)	1.26 ± 0.10	0.59 ± 0.16^{a}	0.38 ± 0.03^{b}
Sodium adsorption ratio	100.55 ± 15.2	47.45 ± 7.30^{a}	15.34 ± 1.27^{b}
Exchangeable sodium percentage	59.50 ± 6.1	40.74 ± 5.71	17.65 ± 2.10^{b,c}
Total N (ppm)	202.50 ± 25.62	467.50 ± 35.75^{a}	400.00 ± 21.98^{b}
NH_4 (ppm)	7.47 ± 0.92	14.35 ± 3.40	13.13 ± 1.68^{b}
NO_3 (ppm)	2.02 ± 0.45	4.35 ± 0.51^{a}	1.75 ± 0.20^{b,c}
Total P (ppm)	117.93 ± 25.84	177.75 ± 14.77	188.00 ± 23.10
Olsen P (ppm)	17.01 ± 2.50	7.78 ± 0.77^{a}	9.92 ± 0.85^{b}

[a] Significantly different (t value, ≤0.05 or better) between undisturbed and 15-month-old field.
[b] Significantly different (t value, ≤0.05 or better) between undisturbed and 30-month-old field.
[c] Significantly different (t value, ≤0.05 or better) between undisturbed and 15-month-old fields and 30-month-old fields.

inated by the rest of the species. All soils were alkaline. The predominant anions were CO_3 and HCO_3 (Table 4).

Through successional stages, soil conditions improved remarkably from natural to 15-month- and 30-month-old kallar grass fields. Importantly, soil pH, salinity sodicity, Na, K, and Ca + Mg, significantly decreased, whereas soil total nitrogen, NH_4-N, NO_3-N, and available phosphorus significantly increased in 15-month- and 30-month-old kallar grass fields (Table 3). Electrical conductivity significantly correlated with pH, Na, K and available P, but not with Ca + Mg, NO_3-N, NH_4-N, total N, and total P (r = 0.91, 0.97, 0.80, 0.71, 0.57, 0.32, −0.51, −0.66, −0.33, respectively). Consequently, all factors correlated with EC also improved as EC decreased from 13.0 to 2.9 to 1.1 in three respective chronological periods (Table 3).

The soil conditions in patch vegetation associated with kallar grass fields did not show any definite trends to explain reduced kallar grass growth. Soils associated with *Desmostachya*, *Kochia*, and *Sporobolus* were moderately saline and highly sodic, and soils under *Polypogon* and *Suaeda* were nonsaline and nonsodic. *Cynodon* soils were nonsaline and moderately sodic. Soil pH values in all patches were comparable to surrounding kallar grass fields with some significant variations (Table 5). pH values in *Suaeda* and *Polypogon* and EC

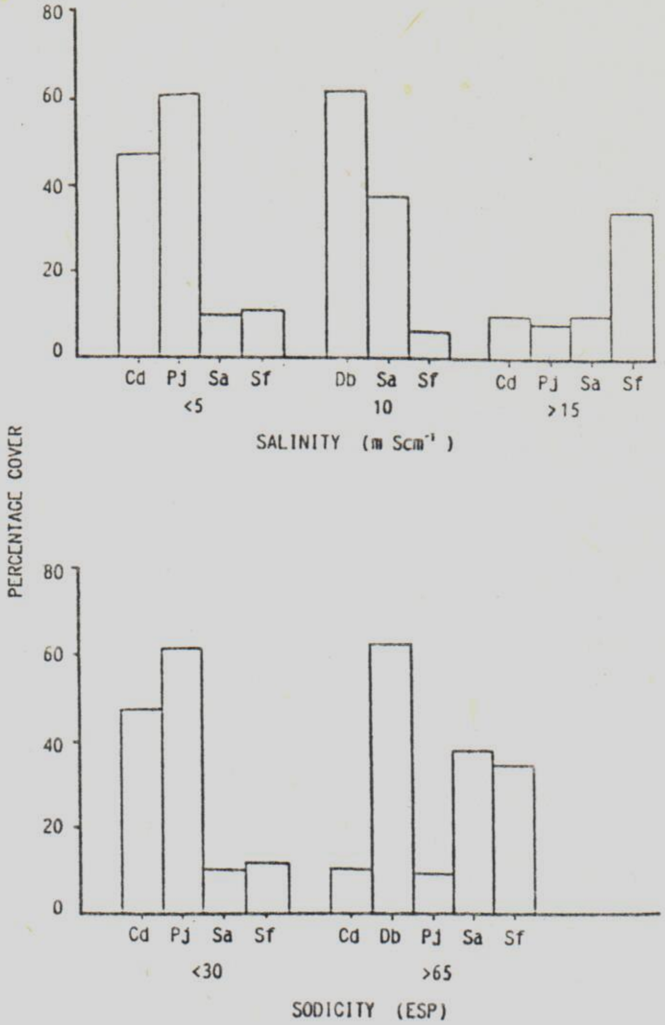

FIG. 1. Percentage cover of different plant species in relation to soil salinity and sodicity. Cd = *Cynodon dactylon*, Db = *Desmostachya bipinnata*, Pj = *Prospis juliflora*, Sa = *Sporobolus arabicus*, Sf = *Suaeda fruticosa*.

values in *Cynodon* and *Polypogon* were significantly lower than in kallar grass fields (Table 5). Electrical conductivity in *Suaeda* patch soils was not significantly different when compared with kallar grass soils. Available phosphorus and available nitrogen ($NH_4 + NO_3$) were always higher in patch soils than in kallar grass soils. Of the two available nitrogen sources measured, NO_3-N was always significantly higher in patch soils, whereas NH_4-N was lower in two

TABLE 4. SOIL ANALYSES OF UNDISTURBED PLANT COMMUNITIES (MEAN ± SE)

	Community type				
Soil factors	*Desmostachya bipinnata*	*Sporobolus arabicus*	*Suaeda fruticosa*	SO *Propis juliflora*	*Cynodon dactylon*
Sand (%)	61.6 ± 4.53	57.0 ± 2.71	61.0 ± 4.72	67.0 ± 2.71	55.0 ± 1.90
Silt (%)	24.3 ± 2.87	28.0 ± 1.31	26.0 ± 2.10	18.6 ± 0.95	25.5 ± 1.71
Clay (%)	13.9 ± 0.69	15.0 ± 1.20	13.0 ± 1.12	14.3 ± 0.71	19.50 ± 0.85
Textural class	Loam to Sandy loam	Loam to Sandy Clay loam	Loam to Sandy loam	Loam to Sandy Clay loam	Clay Loam to Sandy Clay loam
Water-holding capacity (% soil oven dry wt)	28.7 ± 1.32	29.3 ± 0.95	31.9 ± 0.95	31.6 ± 1.73	36.94 ± 1.00
pH	10.1 ± 0.14	9.6 ± 0.13	9.6 ± 0.20	7.8 ± 0.03	8.5 ± 0.45
EC (mS/cm)	10.8 ± 1.84	10.1 ± 1.50	15.0 ± 1.72	2.3 ± 0.52	4.72 ± 1.42
Soluble cations (meq/liter)					
Ca + Mg	2.3 ± 0.13	1.7 ± 0.37	1.9 ± 0.39	1.00 ± 0.04	2.6 ± 0.81
K	1.5 ± 0.10	1.0 ± 0.25	2.6 ± 0.56	0.90 ± 0.25	1.0 ± 0.25
Na	180.0 ± 12.33	99.0 ± 11.7	139.8 ± 27.1	13.2 ± 2.05	26.25 ± 3.10
Sodium adsorption ratio	170.2 ± 10.87	126.9 ± 9.71	181.8 ± 20.61	26.6 ± 3.58	24.71 ± 3.21
Exchangeable sodium percentage	71.4 ± 3.92	65.0 ± 5.73	73.5 ± 2.53	22.5 ± 3.05	25.8 ± 4.12
Soluble anions (meq/liter)					
Cl	23.47 ± 5.16	32.9 ± 1.10	40.8 ± 3.49	5.4 ± 0.90	10.5 ± 2.52
HCO_3	11.99 ± 1.26	23.7 ± 6.41	39.2 ± 5.44	6.2 ± 0.96	10.4 ± 2.20
CO_3	47.33 ± 10.47	36.6 ± 7.94	24.3 ± 7.66	3.6 ± 0.27	3.33 ± 2.10

Table 5. Analysis of Soils from Patch Vegetation and Comparison with Surrounding Kallar Grass Fields
($N = 4$, Mean ± SE)

Sites	pH	EC	Amount (ppm)		
			NH_4-N	NO_3-N	Available P
Kallar grass	9.14 ± 0.24	2.92 ± 0.37	14.35 ± 3.40	4.35 ± 0.51	7.78 ± 0.77
Suaeda	8.57 ± 0.17^a	3.27 ± 0.26	15.71 ± 2.01	6.83 ± 1.47^a	14.79 ± 1.47^a
Cynodon	9.06 ± 0.11	1.91 ± 0.14^a	26.95 ± 2.70^a	7.70 ± 2.87^a	17.30 ± 3.46^a
Desmostachya	9.78 ± 0.07^a	7.16 ± 2.38^a	8.75 ± 2.24^a	7.53 ± 2.78^a	19.09 ± 3.17^a
Sporobolus	10.41 ± 0.03^a	9.46 ± 1.14^a	3.68 ± 0.44^a	16.10 ± 2.11^a	17.35 ± 2.54^a
Kochia	10.39 ± 0.03^a	12.34 ± 1.04^a	8.72 ± 0.81^a	9.63 ± 1.75^a	22.21 ± 1.89^a
Polypogon	8.71 ± 0.8^a	1.23 ± 0.02^a	4.55 ± 0.61^a	5.25 ± 0.83^a	11.80 ± 1.15^a

[a] *t* values significantly different from kallar grass values at $P \le 0.05$ level.

cases of patch vegetation when compared with kallar grass soils (Table 5). Overall, patch soil chemistry was more hospitable than the surrounding kallar grass fields, whereas the percent cover of kallar grass was severely reduced in all patches, with maximum reduction in the *Cynodon* patch followed by the *Suaeda*, *Desmostachya*, *Kochia*, *Sporobolus*, and *Polypogon* patches (Table 6).

Table 6. Percentage Cover of Plant Species of Patch Vegetation in Kallar Grass Fields ($N = 5$, Mean ± SE)

Species	Patch vegetation					
	Polypogon	*Kochia*	*Suaeda*	*Cynodon*	*Desmostachya*	*Sporobolus*
Polypogon monspeliensis	40.0 ± 1.5					
Kochia indica		60.4 ± 6.8				
Suaeda fruticosa			76.5 ± 4.8	0.79 ± 0.5	1.3 ± 1.3	1.0 ± 1.0
Cynodon dactylon	2.00 ± 2.0		3.8 ± 1.0	79.4 ± 4.3	1.2 ± 1.2	1.5 ± 1.5
Desmostachya bipinnata					71.8 ± 5.4	
Sporobolus arabicus			2.9 ± 1.1	3.2 ± 3.2	0.8 ± 0.6	61.8 ± 2.2
Leptachloa fusca	46.41 ± 3.8	20.2 ± 5.4	9.6 ± 2.2	8.8 ± 1.7	14.3 ± 3.0	21.2 ± 1.1
Cyperus rotundus				4.1 ± 2.8		
Bare	11.6 ± 3.9	19.4 ± 6.6	7.2 ± 2.0	3.8 ± 1.5	10.6 ± 3.1	14.4 ± 3.2

Allelopathy Studies. Aqueous extracts of five of the six invading species and kallar grass were significantly inhibitory to kallar grass seed germination, at least at one test concentration (Figure 2). *Cynodon* extracts were an exception, where kallar grass seed germination was not significantly different from control. Kallar grass seed germination was affected significantly in varying degrees depending on the species, extract concentrations, species × concentration, and overall factors (Figure 2).

Decaying material from shoots of all six invading species, kallar grass, and farm manure significantly reduced shoot dry weight of kallar grass (Table 7). Maximum growth inhibition of kallar grass was caused by *Suaeda*, followed by kallar grass, *Desmostachya*, *Cynodon*, *Sporobolus*, *Kochia*, *Polypogon*, and farm manure (Table 7). Degree of inhibition of kallar grass varied significantly between allelopathically invading species and, in most cases, corresponded with the field data of kallar grass cover in patch vegetation (Tables 6 and 7).

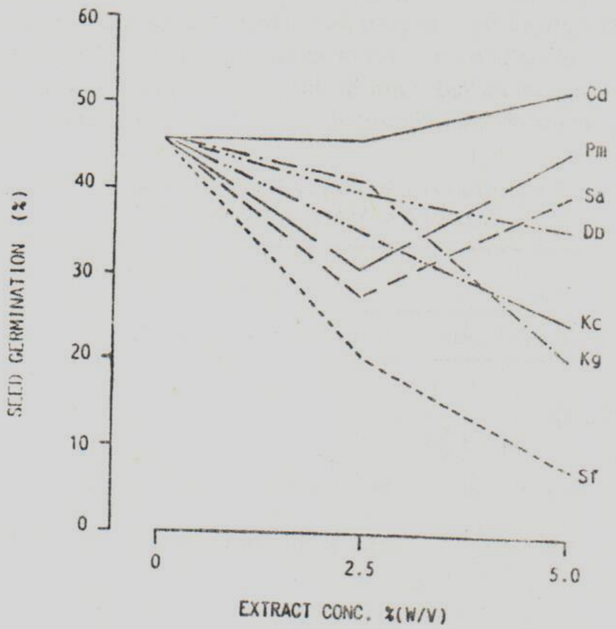

FIG. 2. The effects of aqueous extracts of different species on kallar grass seed germination. ANOVA. $P \leq 0.05$ or better; species LSD = 13.8; concentration LSD = 5.25; species × concentration LSD = 19.63; overall LSD = 13.88. Legends in addition to those in Figure 1, Pm = *Polypogon monspeliensis*, Kc = *Kochia indica*, Kg = kallar grass.

TABLE 7. EFFECTS OF DECAYING SHOOT MATERIALS OF DIFFERENT PLANT SPECIES ON GROWTH OF KALLAR GRASS ($N = 4$, MEAN = mg/plant)

Treatment	Shoot dry wt.[a]	% of control
Control	257.50e	
Farm manure	193.50d	75.29
Cynodon	121.00b	47.08
Kallar grass	101.25b	39.39
Kochia	137.75bc	53.59
Polypogon	177.25cd	68.96
Suaeda	45.75a	17.80
Desmostachya	117.25b	45.62
Sporobolus	132.25b	51.45

[a] Means followed by the same letter are not significantly different, Duncan's multiple-range test, $P \leq 0.05$.

DISCUSSION

Vegetation of an area is governed by a complex of environmental factors, both physical and biological. In a particular area, climate controls the general distribution of vegetation, whereas microenvironmental conditions determine if a species can survive. Soil plays an important role in this regard as it affects plant growth and distribution.

Cynodon dactylon, *Desmostachya bipinnata*, *Prosopis julifora*, *Sporobolus arabicus*, and *Suaeda fruticosa* were dominant in the five community types recognized in undisturbed areas (Table 1). *Cynodon* had appreciably high cover in slightly saline and moderately sodic soils (Figure 1, Table 4). The species may extend into high salinity areas, although with smaller cover values (Rutter and Sheikh, 1962; Sheikh and Irshad, 1980). Although slight salinity on the surface does not appear to harm *Cynodon*, salinity in the root zone disturbs its nutritive functions, causing a reduction in yield (Malik et al., 1984).

The soils under *Prosopis* were nonsaline and moderately sodic (Figure 1, Table 4). Other *Prosopis* species are reported to dominate salt- and sodium-free soils (Kayani and Sheikh, 1981). The lower salinity and sodicity may be due to enhanced leaching of salts in the *Prosopis* covered area as the sodium adsorption ratio was significantly lower at the center of tree canopies than in soil between trees (Virginia and Jarrell, 1983). *Desmostachya* was restricted to moderately saline but highly sodic soils and had a high cover value (Figure 1, Table 4). The species is known to occur on soils with a range of salinities from 2.7 to 27.0 mS/cm (Rutter and Sheikh, 1962). *Desmostachya* is an arid zone species, normally occupying nonsaline soils, but it also manages to tolerate or avoid salinity. The species has a wide ecological amplitude and cannot be depended upon as an indicator of specific soil conditions (Malik et al., 1984).

Sporobolus arabicus was a common species throughout the study area (Table 1). The soils of the *Sporobolus* community were moderately saline and highly sodic (Figure 1, Table 4). The species is reported to occupy a wide range of soils with reference to salinity and sodicity (Rutter and Sheikh, 1962; Sheikh and Mahmood, 1986). Occasionally, *Sporobolus* may grow where salinity exceeds 35 mS/cm, although with smaller cover values than those it attains at low salinity (Rutter and Sheikh, 1962; Malik et al., 1984). Saline and nonsodic soil conditions seem more hospitable for *Sporobolus* (Sheikh and Mahmood, 1986).

Suaeda has been reported to be dominant on very highly saline (45–80 mS/cm) and sodic soils (Rutter and Sheikh, 1962, Malik et al., 1984). The species constitutes the main natural vegetation on saline–sodic sand dunes and is also present on soils free from salinity and sodicity (Din and Farooq, 1975). The species was also found at low salinity, although with smaller cover values than those it attained at high salinity, suggesting that *Suaeda* is a poor competitor when soil conditions were improved for other species (Figure 1, Table 4). Sheikh and Mahmood (1986) reported that soil under *Suaeda* was marginally saline because of leaching of salts to a lower depth in the soil profile. Additionally, low soil surface salinity may be due to the fact that a dense stand of *S. fruticosa* can accumulate approximately 2.5 tons/hectare of NaCl annually (Chaudhri et al., 1964). Clearly, salinity does seem to play a major role in distribution of plant species in the area and correlates with several soil factors (Table 4).

In general, the undisturbed soils were saline, sodic, and alkaline (Table 4). A direct relationship between pH and sodicity of soil has been suggested (Fireman and Wadleigh, 1951; Rutter and Sheikh, 1962). The presence of high concentrations of CO_3 and HCO_3 seem responsible for high alkalinity. If soils are affected by sodium and potassium salts capable of alkaline hydrolysis, e.g., $NaHCO_3$ and Na_2CO_3, sodicity and alkalinity will occur together (Szabolcs, 1979).

Soil pH, salinity, and sodicity appreciably decreased, while total nitrogen, NH_4-N, NO_3-N, and available phosphorus increased in 15- and 30-month-old kallar grass fields (Table 3). Such nutritional changes through succession have been reported in natural communities (Rice et al., 1960) and in surface coal mining areas (Lodhi, 1979), allowing nonannual species to invade and revegetate these areas. Similarly, kallar grass fields were successively invaded by plant species not recorded in undisturbed fields, in addition to the species found in undisturbed areas (Table 2). Chaudhri (1952) reported that the vegetation of the fields under reclamation was a mixture of exotic species and natural flora, the latter being replaced by the former depending on the degree of reclamation.

The species invading kallar grass fields clearly appeared in dominant patches and radially eliminated or reduced kallar grass cover in all patches, with lowest cover in the *Cynodon* patch followed by *Suaeda*, *Desmostachya*, *Kochia*, *Sporobolus*, and *Polypogon* patches (Table 6). On the other hand, soils associated with various vegetational patches did not show any definite trend with nutritional status. In *Cynodon* and *Polypogon* patches, where kallar grass cover was the lowest and the highest respectively, the associated soil pH and EC were significantly lower than the surrounding kallar grass fields (Table 5). However, EC and pH in *Desmostachya*, *Sporobolus*, and *Kochia* patches were significantly higher than in kallar grass fields. Further, salinity–sodicity factors were not unsuitable for kallar grass growth because the species is highly tolerant to salinity (Sandhu et al., 1981) and sodicity (Aslam et al., 1979). Additionally, available P, NH_4-N, and NO_3-N amounts were always significantly higher in all patches as compared to kallar grass field soils, with the exception of NH_4-N in *Sporobolus* and *Polypogon* patches which were significantly lower (Table 5). Thus, the elimination of kallar grass from the weed patches cannot be attributed to the soil factors analyzed, while it failed to persist in patch-associated species (Table 5, 6).

Plant interactions are known to play an important role in distribution and coexistence of species in both natural and agroecosystems. Competition for necessary growth factors (allelospoly) and addition of toxic substances to the environment (allelopathy) can play a major role in plant growth (Szczepanski, 1977; Rice, 1984). Our preliminary data indicated, based on soil analyses, that competition may not be the leading cause of kallar grass elimination from patch vegetation. On the other hand, aqueous extracts and decaying leaf material of all six invading species and kallar grass significantly reduced kallar grass seed germination (Figure 2) and shoot growth (Table 7). The allelopathic influence on kallar grass varied from species to species and in most cases clearly corresponded with field data (Table 6, 7). It should be strongly pointed out that allelopathic behavior discussed in patch dynamics was in areas where soil saline–sodic conditions had improved greatly (review Table 3, and correlations discussed in results) due to kallar grass cultivation. Further, *Suaeda* appeared to be a poor competitor (Table 2) when soil conditions improved for other species as well, and it could not capitalize on its evolutionary strategy of performing well in high saline–sodic conditions. Therefore, growth inhibition in kallar grass caused by *Suaeda* was due to allelopathy, perhaps somewhat accentuated by ions in its shoot tissue. Our ongoing research indicates that relatively ion-free *Suaeda* extract retained its allelochemic influence. In general, species competing for a limited growth factor can allelopathically influence the growth of other species to minimize competition (Tremmel and Peterson, 1983; Rice, 1984). Such interactions can only accentuate the invasion by incoming species. Detailed investigations are in progress to ascertain the relative importance of patch dynamics relating to kallar grass susceptibility to competition and allelopathy.

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