Role of irrigation and fertilization in revegetation of cold desert mined lands

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Abstract

This study determined responses of vegetation and soils to different rates and seasonal schedules of first-year irrigation in combination with varied N-P fertilization on cold desert mined lands. Certain irrigation treatments increased soil water content initially, but had no appreciable effects on soil salinity or fertility. Specific rates and schedules of irrigation temporarily benefited total stand and dominant perennial grass establishment and productivity, but treatment effects diminished or reversed over time. Subdominant shrubs and perennial forbs were more persistently enhanced by specific irrigation treatments. Fertilization did not modify plant response to irrigation regimes. Although annual species were positively influenced by fertilization with heavier rates of irrigation, such stimulation proved ephemeral and perennial species never responded to fertilization under any irrigation regime.

Key Words: irrigation, fertilization, revegetation, reclamation, mined lands

Water is a major limiting factor for revegetation of mined lands in the semiarid/arid western United States (May 1975, National Academy of Sciences 1974). In addition, low inherent fertility of minesoils can often hamper revegetation efforts. Irrigation and fertilization frequently have been proposed as direct approaches to alleviate water and nutrient deficiencies. Past reclamation research has demonstrated that both of these cultural practices can significantly influence establishment, productivity and/or composition of vegetation (Ries and Day 1978, Bauer et al. 1978). Despite this, major questions remain on the necessity, modes of application, and effects of irrigation and fertilization on western mined lands (DePuit 1988).

The National Academy of Sciences (1974) suggested that irrigation may be essential to revegetate areas receiving less than 250 mm annual precipitation, but the universality of this premise frequently has been questioned (Grogan 1987, Ferraiuolo and Bokich 1982). Mined land studies in the arid Southwest usually have indicated the benefits (e.g., Bengson 1977, Day and Ludeke 1986, Gould et al. 1975, Ferraiuolo and Bokich 1982) and sometimes the necessity (e.g., Aldon 1978, Day et al. 1983) of irrigation for rapid, reliable, and effective revegetation. Research in the semiarid Northern Great Plains (DePuit et al. 1982, Ries et al. 1977, Rennick and Munshower 1985) also has shown irrigation to influence mined land revegetation, while perhaps not being as important to overall success as in drier regions. Unfortunately, the role of irrigation for plant establishment on northern cold desert mined lands has received little scientific attention.

Plant responses to fertilization have frequently been marginal to nil on arid mined lands (e.g., Gould et al. 1975, Aldon and Springfield 1977), presumably due to an overriding limitation of the water upon which plant fertilizer response is dependent. Relief of water deficiency through irrigation could allow fertilization to play a more influential role in revegetation (Righetti 1982). Conversely, it is also possible that fertilization might accentuate the effects of irrigation on plant growth.

This study evaluated the short-term (i.e., through the first 4 years of reclamation) effects of temporary irrigation on revegetation and fertilization efficacy on cold-desert mined lands. Research was designed to consider 5 working null hypotheses:

- H1—Temporary irrigation is not essential for acceptable plant establishment and productivity over the short term.
- H2—Temporary irrigation will not accelerate plant establishment and growth.
- H3—Variations in temporary irrigation or fertilization will not modify growth form composition of vegetation over the short term.
- H4—Initial effects of irrigation or fertilization on revegetation will not persist over the short term.
- H5—Temporary irrigation will not increase plant response to N-P fertilization, nor will N-P fertilization accentuate plant response to irrigation.

Primary research objectives were to determine plant establishment, productivity, and composition responses to irrigation and fertilization treatments, while secondary objectives related to treatment effects on minesoils.

Methods and Procedures

Study Area

The study was conducted at the Jim Bridger surface coal mine, 45 km northeast of Rock Springs in southwestern Wyoming. The environment is high (2,070–2,163 m elevation), cool (-7 to 20° C mean monthly temperature range), and arid (194 mm mean annual precipitation). Native soils are predominately coarse-textured entisols or aridisols, and are generally moderately saline and alkaline (Parady 1985). Native rangeland vegetation is dominated by xerophytic or halophytic shrubs in association with subdominant cool-season perennial grasses (Vincent 1987, Powell 1988).

Study plots were located on a 1.4-ha minesite following spoil grading to uniform, nearly level topography. Spoils were ripped to 75 cm and covered with 25 cm of subsoil and 15 cm of topsoil direct (i.e., immediately) applied after salvage. Spoil material was classified as a loam, and subsoil and topsoil were sandy loams. All materials were mildly alkaline (pH = 7.8) but not sodic, and subsoil and spoil were mildly saline (EC = 4.7 and 4.3 dS/m, respectively). Macronutrient concentrations were relatively low, with available N (NO_3 + NH_4) ranging from 1.9 to 3.7 ug/g, available P ranging from 4 to 6 ug/g, and extractable K ranging from 68 to 156 ug/g.

After chisel plowing and roller harrowing, the site was drill seeded with 11 cool-season perennial grasses *(Agropyron dasystachyum, A. inerme, A. riparium, A. spicatum, A. trachycaulum, Festuca ovina, Oryzopsis hymenoides, Poa compressa, P. sandbergii, Sitanion hystrix,* and *Stipa comata)*; 3 forbs *(Astragalus cicer, Linum lewisii* and *Penstemon strictus)*; and 5 shrubs/half-shrubs *(Artemisia tridentata* subsp. *wyomingensis, Atriplex gardneri, Ceratoides lanata, Chrysothamnus nauseosus,* and *Eriogonum umbellatum)* at a total mixture seeding rate of 27 kg PLS/ha. Individual species seeding rates (Powell 1988) yielded an average of

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155, 75, and 38 live seeds/m² for each of the 11 grass, 3 forb, and 5 shrub species, respectively. After seeding, the site was mulched with crimped wheat straw at 2,240 kg/ha. Within treatments designated for N-P fertilization, ammonium nitrate and treble superphosphate fertilizers were jointly broadcast at rates to yield 40 kg N/ha and 57 kg P/ha. Seeding, mulching, and fertilizing were accomplished in early April, 1984.

Experimental Design

Irrigation treatments included:

1) *No-Irrigation* (control)

and 2) *First Year Sprinkler Irrigation,* with all combinations of:

a) *Three Irrigation Rates* (5.1, 7.6, and 10.2 cm of supplemental water per month of irrigation)

b) *Five Seasonal Schedules of Irrigation*

–Season-long (15 May–15 Sept., 4 mos.)

–Spring-early summer (15 May–15 Aug., 3 mos.)

–Spring (15 May–15 July, 2 mos.)

–Early spring (15 May–15 June, 1 mo.)

–Summer (15 July–15 Sept., 2 mos.)

All 16 of the above treatment combinations were fertilized with N and P at rates previously described, and comprised the irrigation main study. An irrigation-fertilization substudy was established by creating 4 additional treatments without fertilizer application: nonirrigated, and first-year irrigated (with the season-long schedule) at each of the 3 irrigation rates described above. These 4 unfertilized treatments were considered in concert with their 4 fertilized but otherwise similarly treated counterparts in a separate analysis.

Each of the 20 specific treatment combinations was randomly applied to 1 of an array of 12.2 by 12.2-m subplots, with the irrigated treatment subplots arranged in a strip plot experimental design (Cochran and Cox 1957). All treatment combinations were replicated in 3 blocks, yielding a total of 60 subplots (Vincent 1987, Powell 1988).

Irrigation rate and schedule treatments were applied the first (1984) growing season only, using a solid-set sprinkler system. Water was obtained from a nearby power plant surge pond, and analysis (Vincent 1987) indicated water quality to be suitable for irrigation (EC = 0.5 dS/m, SAR = 1.2). Irrigation commenced in mid-May, 1984, and was continued (depending on schedule treatment) through mid-September. Water was applied during three 2-to-3 day irrigation events per month, within which irrigation was conducted only during windless periods in early morning to minimize spray drift among plots. Irrigation events were separated by 7-to 8-day drying cycles.

Sampling

Vegetation data were collected during the year of seeding, irrigation, and fertilization (1984) and during the second, third, and fourth growing seasons (1985, 1986, and 1987). Canopy cover (by growth form and species) and density (by growth form) were estimated from 4 permanent 0.25-m² quadrats located in a stratified-random manner within each 12.2 by 12.2 m subplot. Canopy cover was estimated ocularly according to the general procedures of Daubenmire (1959). Density was estimated by counting plants rooted within each quadrat. In 1986 and 1987, plant density for more widely distributed shrubs and forbs was also estimated by counting all plants rooted within two-3.05 m² belt transects in each subplot. Aboveground biomass was estimated (by growth form) each year by hand harvesting, oven-drying, and weighing all plant material within 4 quadrats per subplot. Clipping quadrat size was 0.25 m² in 1984 and 1985, and was increased to 0.50 m² in 1986 and 1987 to reduce sample variability. Time of vegetation sampling corresponded to estimated peak standing crop and density each year.

Soils were sampled for pretreatment characteristics in May, 1984, and for post-treatment characteristics in April, 1985, and May, 1987. At each date, samples of topsoil (0–15 cm), subsoil (15–41 cm) and spoil (41–76 cm) were collected separately. Soil analyses included total N, available N (NO_3 and NH_4), available P, extractable K, sodium adsorption ratio (SAR), electrical conductivity (EC), pH and organic matter content (Vincent 1987, Powell 1988). Soil water content was gravimetrically determined at 3 depths (0–15, 15–41, and 41–76 cm) in each subplot at specified intervals during all growing seasons.

Data Analysis

Data were subjected to analyses of variance for a strip plot design (Cochran and Cox 1959, Milliken and Johnson 1984). For the irrigation main study, one analysis was conducted on irrigated treatments to determine whether irrigation rate or schedule main effects or rate-schedule interactions occurred within years. A second, multiple set of analyses was performed to compare non-irrigated control plot data to irrigation rate, schedule, or rate-schedule combination means within years. This was necessary because of lack of varied treatment "levels" for control plots corresponding to those of irrigation treatments.

Separate analyses of variance were conducted for the irrigation-fertilization substudy to determine significant main effects of fertilization and irrigation, or fertilization-irrigation interactions within years.

If significant effects were indicated in any of the above within-year analyses, either Scheffe's or Tukey's methods of pairwise comparison were used to detect differences among treatments (Montgomery 1984). Analysis of variance of repeated measures with Tukey's mean separation was used to compare data within a treatment among years. A 90% level of probability ($P<0.10$) was considered indicative of ecologically significant differences among means throughout statistical analysis.

Results and Discussion

Winter-spring (i.e., October through June) precipitation is most critical to forage production in cold-desert plant communities of central Wyoming (Hanson et al. 1984). Winter through spring precipitation at the study site (Table 1) was far below average in the first (1984), second (1985), and fourth (1987) years of the study, and above-average only during the April–June quarter of the third (1986) year.

Table 1. Precipitation (mm) at the study site from January, 1984 to September, 1987 in comparison to long-term average for area.

Period	Long-term Average[1]	Year of study 1984	1985	1986	1987
January–March	36	9	8	16	19
April–June	66	28	34	122	43
July–September	52	67	55	40	37
October–December	40	18	26	13	
Total	194	122	123	191	

[1]From N.O.A.A. weather stations in Wamsutter and Rock Springs, Wyoming.

Soil Responses to Irrigation and Fertilization

Soil water content in 1984 generally increased with moderate and high irrigation rates and with irrigation schedules longer than 2 months (Vincent 1987). This relationship was most pronounced in the topsoil (0–15 cm), and became less evident deeper in the profile. Differences in topsoil moisture among treatments disappeared following termination of irrigation, although some residual increment of deeper (subsoil and spoil) soil water remained in more

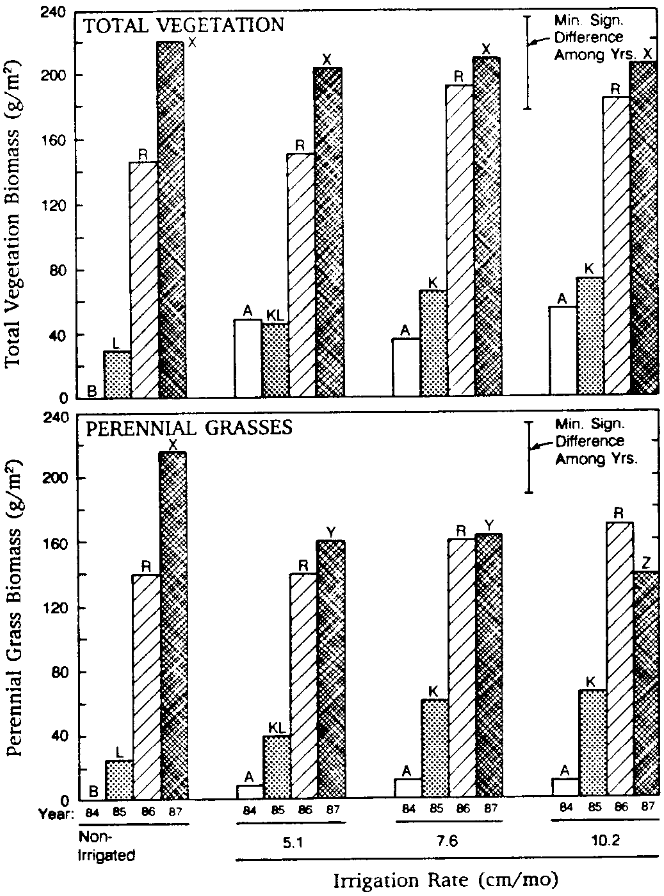

Fig. 1. Responses of total vegetation and perennial grass aboveground biomass to non-irrigation and 3 rates of first-year irrigation in the first (1984), second (1985), third (1986), and fourth (1987) growing seasons. Irrigation rate data are means among 5 irrigation schedules. For each growth form, means within years with same letter are not significantly different ($P<0.10$); the inscribed line represents the minimum significant difference ($P<0.10$) for means among years among all treatments.

heavily or longer irrigated plots early in 1985 (Vincent 1987). By the end of the third (1986) and during the fourth (1987) growing seasons, no differences in soil moisture among treatments remained at any depth (Powell 1988).

Significant effects of irrigation treatments on soil salt and nutrient content were very limited in 1985 and 1987, and the magnitude of the few differences that did emerge was so small that their biological importance was doubtful (Vincent 1987, Powell 1988).

Fertilization increased available P in the topsoil horizon from a pretreatment concentration of 6 ug/g in 1984 to 20 ug/g in 1985; the latter concentration proved significantly higher than the 6 ug/g of P in nonfertilized topsoil in 1985. Although topsoil P content declined in fertilized plots from 1985 to 1987, concentrations in 1987 (8 ug/g) were still significantly greater than those in nonfertilized plots (4 ug/g). Surface application of P fertilizer never significantly affected P content of deeper subsoil and spoil horizons.

Available N ($NO_3 + NH_4$) increased substantially throughout the minesoil profile from 1984 (pre-treatment, 3 ug/g) to 1985 (15 ug/g) irrespective of fertilization regime. This increase may reflect enhanced N mineralization induced by the soil disturbances of grading, topsoiling, and cultivation. However, no significant differences in available N existed between fertilized and nonfertilized treatments at any depth in 1985, nor were any differences apparent in 1987 by which time available N had again declined to low levels (1 ug/g) at all soil depths in both treatments. This indicates that the N added to fertilized plots in 1984 was either utilized by plants or microbes, or lost from the system before soil sampling in 1985.

Carryover N in reclaimed minesoils is often minimal in years following fertilization (Righetti 1982). Conversely, P is a relatively immobile soil nutrient (Bauer et al. 1978) for which more persistent fertilization enrichment can occur in minesoils (Righetti 1982). The maintained higher P concentration in fertilized topsoil may have been of little benefit to vegetation in the latter years of this study, however, since plants sometimes may not fully respond to increased soil P when N is deficient (Brady 1974).

Plant Responses to Irrigation

Irrigation Rate Effects

Total vegetation and perennial grass aboveground productivities were minimal in the nonirrigated treatment in 1984, and were increased significantly by irrigation at all rates (Fig. 1). Differences among irrigation rates were not significant. Irrigated treatments were dominated by nonseeded annual species (chiefly volunteer wheat from the mulch and various chenopod forbs), with an understory of perennial grass seedlings and very limited growth of shrubs and perennial forbs (Vincent 1987).

Annual species declined from 1984 to 1985 in irrigated treatments (Vincent 1987), and were minor components of the plant community in all treatments thereafter as perennial grasses attained dominance. Therefore, the initial stimulation of annual species by irrigation, which has been noted elsewhere on disturbed lands (Gould et al. 1975), did not persist after the first growing season at this study site.

All seeded perennial grass species ultimately became established on the site. *Agropyron dasystachyum* and *A. trachycaulum* were dominant, followed by *Festuca ovina, Sitanion hystrix* and *Oryzopsis hymenoides.* Perennial grass biomass increased from 1984 to 1985 within the moderate and high irrigation rate treatments, resulting in significantly higher perennial grass and total biomass in these treatments than in the nonirrigated control during 1985 (Fig. 1). This response in the unusually dry 1985 growing season (Table 1) may have been caused by the higher early season soil moisture deeper in the profile carried over from previous year irrigation at the highest 2 rates (Vincent 1987).

Total plant community and perennial grass biomass increased significantly from 1985 to 1986 in all treatments (Fig. 1), in response to high April–June precipitation. The most conspicuous 1985–1986 increment occurred in nonirrigated plots, which resulted in a disappearance of productivity differences among treatments in 1986.

Perennial grass biomass continued to increase in the nonirrigated treatment from 1986 to 1987; in contrast, grass biomass in irrigated treatments remained statistically constant over this time interval (Fig. 1). These relationships resulted in progressive declines in perennial grass biomass from the nonirrigated to low/-moderately irrigated to heavily irrigated treatments in 1987, a near reversal of the treatment responses observed in 1984 and 1985 (Fig. 1). The depressive effect of increasing irrigation rates on grass productivity in 1987 may have been caused, in part, by a corresponding increase in grass density-dependent competition. Vincent (1987) noted that initial grass densities progressively increased with irrigation rate, a pattern that may have eventually accentuated the intensity of grass competition and, thereby, reduced individual plant vigor in the abnormally dry year of 1987. Grass productivity also may have been depressed by increased shrub or perennial forb competition at higher irrigation rates by 1987.

Despite slow initial establishment and limited distribution, growth of shrubs/half-shrubs (chiefly *Atriplex gardneri, Atriplex canescens* and, secondarily, *Ceratoides lanata)* and perennial forbs

Table 2. Responses of canopy cover, density, and biomass of shrubs/half-shrubs and perennial forbs; biomass composition of all growth forms; and growth form diversity indices to non-irrigation and 3 rates of first-year irrigation during the fourth (1987) growing season.[1]

	Treatments			
	Non-	Irrigation rate (cm/mo)		
Plant attribute/growth form	irrigated	5.1	7.6	10.2
A. CANOPY COVER (%):				
Shrubs/half-shrubs	1b	3b	3b	8a
Perennial forbs	<1b	6a	7a	9a
B. DENSITY (no./m²):				
Shrubs/half-shrubs	0.1b	0.3ab	0.5a	0.5a
Perennial forbs	0.7c	2.6bc	4.5ab	6.1a
C. BIOMASS (g/m²):				
Shrubs/half-shrubs	2a	35a	32a	59a
Perennial forbs	1c	10ab	15a	9b
D. BIOMASS COMPOSITION (%):				
Perennial grasses	97.1a	82.0b	79.2b	76.3b
Shrubs/half-shrubs	0.9b	12.6ab	12.8ab	19.5a
Perennial forbs	1.3c	4.6ab	7.4a	3.9bc
Annual species	0.7a	0.8a	0.6a	0.3a
E. GROWTH FORM DIVERSITY INDEX (H')[2]	0.07	0.26	0.29	0.29

[1]Means within plant attributes and growth forms followed by same letter are not significantly different ($P<0.1$).
[2]Shannon-Wiener Function (Shannon and Weaver 1963), based upon biomass composition data.

(chiefly *Astragalus cicer* and, secondarily, *Penstemon strictus*) increased considerably in 1986 and 1987. Shrub/half-shrub density was greater in the moderate and high irrigation rate treatments than in the nonirrigated control in 1987, the final year of study (Table 2). Shrub canopy cover was greatest at the highest irrigation rate in 1987, although high data variability precluded detection of a similar statistical relationship for shrub biomass. Perennial forb densities were also increased at the 2 highest irrigation rates in 1987 (Table 2). All irrigation rates produced significantly higher forb biomass and canopy cover than that with nonirrigation, and forb biomass was highest in the moderate rate treatment.

Fourth year (1987) growth form composition was still dominated by perennial grasses in all treatments (Table 2), but perennial grass composition was significantly lower in all irrigation rate treatments than with nonirrigation. The reduction in grass and stimulation of shrub and/or forb composition by irrigation rate treatments resulted in greater indices of growth form diversity (H', Shannon and Weaver 1963) than that with non-irrigation.

Irrigation Schedule Effects

All irrigation schedules were not fully applied until 15 September 1984, 2 months after first year vegetation sampling. Therefore, only second (1985), third (1986), and fourth (1987) year data are indicative of plant responses to the complete array of irrigation schedules.

In 1985, the year after irrigation ceased, total vegetation and dominant perennial grass productivities were significantly higher under season-long, spring-early summer and summer irrigation schedules than with no irrigation (Fig. 2). Among the 5 schedules, biomass tended to progressively decline from the longest (4 month) season-long schedule through the shortest (1 month) early spring schedule. These relationships suggest little benefit of 1 to 2 months of early-season irrigation for initial establishment of perennial grasses. They also are consistent with soil water relationships in 1984 and early 1985 (Vincent 1987), when only longer/later irrigation schedules increased soil water content above that in the control.

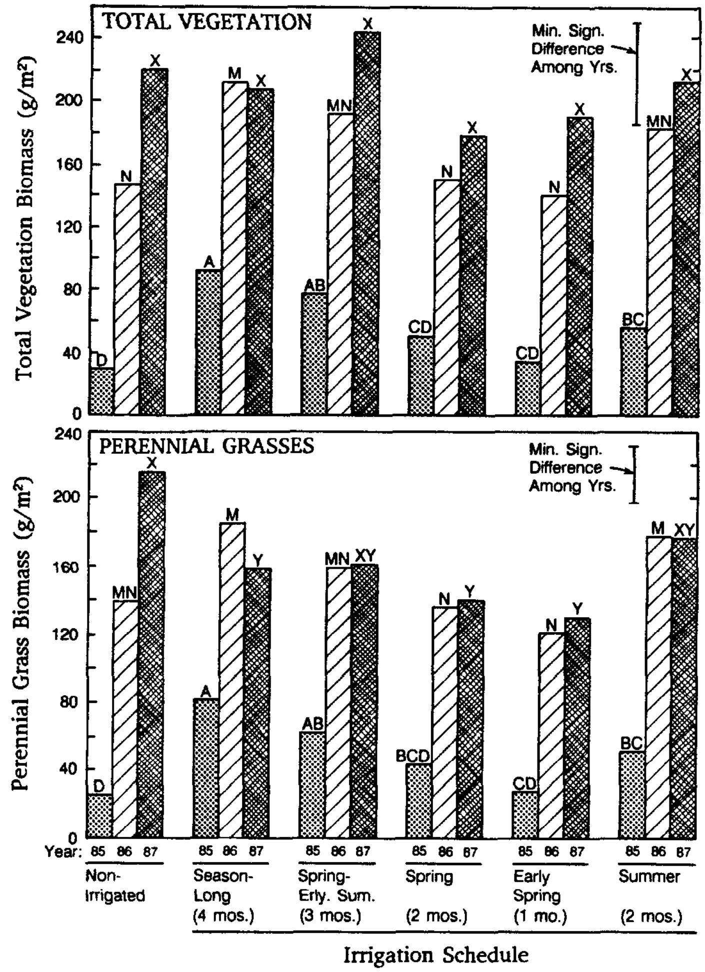

Fig. 2. Responses of total vegetation and perennial grass aboveground biomass to nonirrigation and 5 schedules of first-year irrigation in the second (1985), third (1986), and fourth (1987) growing seasons. Irrigation schedule data are means among 3 irrigation rates. For each growth form, means within years with same letter are not significantly different ($P<0.10$); the inscribed line represents the minimum significant difference ($P<0.10$) for means among years among all treatments.

Relationships among treatments changed considerably during 1986 and 1987 (Fig. 2). Total vegetation and perennial grass biomass increased from 1985 to the unusually wet 1986 in all treatments, and differences among treatments diminished. Biomass continued to increase from 1986 to the abnormally dry 1987 only in the nonirrigated treatment. No differences in total biomass remained among treatments in 1987, and perennial grass biomass was higher in the nonirrigated treatment than that in 3 of the 5 irrigation schedules (i.e., season-long, spring, and early spring). These relationships indicate that the initial benefits of the longer/later irrigation schedules to overall revegetation were short-term, and that certain irrigation schedules eventually proved detrimental to dominant perennial grasses. As discussed earlier for irrigation rates, the eventually suppressed growth of grasses in specific irrigation schedule treatments may have been related to increased expression of grass-forb-shrub competition effects under those schedules.

Differences in shrub/half-shrub and perennial forb canopy cover among irrigation schedule and nonirrigation treatments were not statistically significant in any year. However, perennial forb (primarily *Astragalus cicer*) densities were higher with the spring-early summer schedule than with no irrigation in 1985 and 1986 (Powell 1988), a relationship that persisted into 1987 (Table

Table 3. Responses of density and biomass of shrubs/half-shrubs and perennial forbs, biomass composition of all growth forms, and growth form diversity indices to non-irrigation and 5 schedules of first-year irrigation during the fourth (1987) growing season.[1]

Plant attribute/growth form	Non-Irrigated	Season-long	Spring-early Summer	Spring	Early Spring	Summer
		Treatments: Irrigation schedule				
A. DENSITY (no/m²)						
Shrubs/half-shrubs	0.1b	0.4ab	0.6a	0.4ab	0.6ab	0.2ab
Perennial forbs	0.7b	5.1ab	8.0a	3.9ab	2.6ab	2.0ab
B. BIOMASS (g/m²)						
Shrubs/half-shrubs	2a	27a	68a	28a	54a	32a
Perennial forbs	1b	22a	15ab	9ab	6ab	4ab
C. BIOMASS COMPOSITION (%):						
Perennial Grasses	97.1a	80.5a	72.6a	85.2a	72.3a	85.4a
Shrubs/half-shrubs	0.9a	8.4a	20.6a	9.4a	24.0a	12.5a
Perennial forbs	1.3b	10.7a	6.3ab	4.5ab	3.0ab	1.8b
Annual species	0.7a	0.4a	0.5a	0.9a	0.7a	0.3a
D. GROWTH FORM DIVERISTY INDEX (H')[2]	0.07	0.28	0.33	0.23	0.31	0.21

[1]Means within plant attributes and growth forms followed by same letter are not significantly different ($P<0.1$).
[2]Shannon-Wiener Function (Shannon and Weaver 1963), based upon biomass composition data.

3). This schedule also yielded maximum forb biomass in 1986 (Powell 1988), but by 1987 the season-long schedule produced highest forb biomass and percent biomass composition (Table 3). This increase in perennial forb growth may have suppressed perennial grasses within the season-long treatment in 1987.

Shrub/half-shrub densities were statistically similar among treatments in 1985, but by 1986 (Powell 1988) and 1987 (Table 3) became highest in the spring-early summer and, secondarily, early spring schedules. The magnitude of shrub biomass and biomass composition differences with the nonirrigated control suggested a similar stimulation of shrub productivity by these 2 irrigation schedules (Table 3), but high data variability and consequent lack of statistical significance preclude accepting this relationship.

Statistically significant differences in perennial grass, shrub and perennial forb biomass composition among treatments were rare in 1987 (Table 3). The equity of composition among these growth forms, however, was somewhat higher with irrigation. Consequently, growth form diversity index values were substantially higher for irrigation schedule treatments than for nonirrigation.

Plant Responses to Fertilization

Perennial species did not respond to N-P fertilization in 1984 under any irrigation rate regime, presumably because of limited first year growth. Biomass of initially dominant annual species was reduced in 1984 by an accidental, partial grazing of vegetation by feral horses, whose preferential foraging on annuals (Vincent 1987) may have precluded detection of fertilization responses. Despite the reduction of standing crop by grazing, however, significant fertilization-irrigation rate interactions emerged for canoy cover of annual species in 1984 (Fig. 3).

Canopy cover of annual grasses (primarily wheat volunteering from straw mulch) was similar between fertilized and non-fertilized treatments with no irrigation and light to moderate irrigation rates, but became higher in fertilized plots under the heaviest rate of irrigation (Fig. 3). Thus, fertilizer responsiveness of annual grasses was expressed only under highest water availability. Irrigation rate response was also enhanced by fertilization, since annual grass cover increased from moderate to heavy irrigation rates only in the fertilized treatment.

A different canopy cover response was apparent for annual forbs in 1984 (Fig. 3). No difference in cover existed between the fertilized and nonfertilized treatments with no or light rate irrigation, but cover was greater in fertilized plots with the moderate rate of irrigation. This suggests that increased water provided by the moderate irrigation rate allowed annual forbs to respond to added fertilizer. The latter relationship, however, disappeared with the heavy irrigation rate, where cover again became similar between fertilization treatments. The unexpected elimination of annual forb fertilizer response under heaviest irrigation may have been caused by increased competitive pressure to forbs from annual grasses in that treatment.

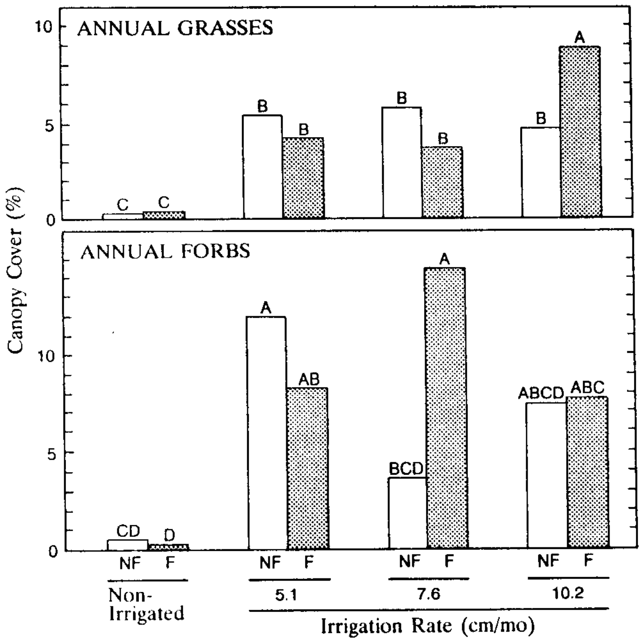

Fig. 3. Interactive effects of fertilization (F) vs. nonfertilization (NF) and nonirrigation vs. 3 rates of season long first year irrigation on canopy cover of annual grasses and annual forbs during the first (1984) growing season. Within each growth form, means with the same letter are not significantly different at $P<0.10$.

All interactive effects of fertilization and irrigation on annual species disappeared in the second and subsequent growing seasons, as annuals declined to be replaced by perennial species. Perennial grasses, forbs and shrubs were not significantly influenced by fertilization or any interaction of fertilization and irrigation regime in any year.

Discussion

Findings favor accepting our first null hypothesis that temporary irrigation was not essential for eventual revegetation of the arid minesite. Productivity of desirable, dominant perennial grasses in non-irrigated plots either equaled or exceeded that under specific irrigation rates and schedules by the fourth growing season, despite the fact that precipitation was unusually low during 3 of the first 4 years of study.

Although irrigation may not be essential, the fact that certain irrigation treatments significantly improved plant establishment and productivity during the first 2 years of the study is evidence for an acceleration (albeit temporary) of revegetation by irrigation. This forces rejection of our second null hypothesis, and concurs with findings of previous irrigation studies (Doerr and Redente 1983).

Our third working hypothesis was that irrigation or fertilization treatments would not modify growth form composition of vegetation over the short term. This hypothesis can be accepted for fertilization, but must be rejected for irrigation. Specific irrigation rates and schedules were beneficial to perennial grasses and annual species initially, determined to perennial grasses ultimately, and eventually beneficial to shrubs and perennial forbs. Growth form diversity appeared to be enhanced by certain irrigation treatments by the fourth year. These findings support the contention (e.g., DePuit et al. 1982, Ries 1980) that varied irrigation may be a means of manipulating plant composition and diversity on mined lands, at least over the short-term.

The stimulation of shrubs by proper rates and schedules of irrigation is of particular importance. Shrubs are well-adapted, dominant components of area rangelands, and have historically proven more difficult to re-establish on mined lands than other growth forms (DePuit 1988). Competition from grasses often has been suggested as a major detriment to shrub establishment (Ferguson and Frischknecht 1981, Kiger et al. 1987). It is therefore surprising that both the high rate and spring-early summer schedule of irrigation proved beneficial to shrubs, since these treatments also initially enhanced grass productivity. This suggests that germination-related difficulties, such as low moisture in the year of establishment, may be major obstacles to shrub ecesis in the arid environment of the study site, with competition relatively less important.

Research on semiarid disturbed lands by Doerr and Redente (1983) indicated that improvements in plant productivity from temporary irrigation and fertilization disappeared within 4 years, and the fourth null hypothesis of our study stated that initial effects of irrigation or fertilization on aridland revegetation would prove similarly ephemeral. This hypothesis can be accepted for fertilization, since the limited stimulation of annual species by N-P fertilization in irrigated plots was not maintained after the first growing season. However, results allow neither complete acceptance nor complete rejection of this hypothesis for irrigation. Certain early benefits of irrigation to shrubs and forbs (Vincent 1987) did persist oer the short-term (i.e., through year 4). However, other initial effects of irrigation either disappeared (e.g., early stimulation of total vegetation and annual species of productivity) or changed (e.g., ultimate reversal of perennial grass responses) by the fourth growth season.

The eventual reduction of dominant perennial grasses under certain irrigation regimes was a somewhat anticipated response. Klages and Ryerson (1965) recognized the risk of vegetation retrogression on previously irrigated rangelands when exposed to ambient precipitation. Berg (1975) and Ries and Day (1978) predicted that overly dense or productive vegetation produced by initial irrigation of reclaimed lands could be expected to decline later in adjustment to arid/semiarid climate. Doerr and Redente (1983) noted biomass of seeded perennial grasses to decline over the first 4 growing seasons in previously irrigated plots while increasing in non-irrigated plots on a semiarid site, a pattern identical to that on our arid site.

Fertilizer responsiveness of plants usually increases with increasing water availability and, conversely, higher nutrient availability often increases water use efficiency of plants (Tisdale and Nelson 1975, Smika et al. 1965). Our final null hypothesis, however, challenged these relationships by stating that irrigation would not increase plant response to N-P fertilization, nor would N-P fertilization enhance plant response to irrigation on the arid study site. Results proved inconclusive in terms of this hypothesis. First year (1984) canopy cover data indicated that fertilizer stimulated either annual grasses or forbs only at moderate to heavy rates of irrigation, suggesting that increased water was essential for fertilization response by these initially dominant species. However, these relationships disappeared after the first growing season, were not exhibited in productivity data, and were never expressed for ultimately dominant perennial species.

First year canopy cover data also indicated enhanced irrigation rate response of annual grasses under fertilized conditions, which would suggest that fertilization increased irrigation effectiveness. This relationship was apparent only for annual grasses in the first growing season, however. Other plant growth forms responded similarly to irrigation rates each year under both fertilized and nonfertilized treatments.

Several explanations are possible for the paucity of fertilization effects on perennial species in this study. In 1984, when fertilization effects were most likely due to increased water availability in irrigated treatments, perennial species may not have responded because the then-dominant annual species may have more efficiently sequestered added nutrients. Lack of fertilizer response by perennials in the second (1985) growing season may have been due to limited carryover fertilizer N in the soil, or to a masking of any residual fertilizer N by the apparently high degree of post-soil disturbance N mineralization evident in both fertilized and unfertilized treatments. The most likely explanation for lack of plant fertilizer response from the second through fourth growing seasons, however, is that water may have again become an overriding limitation under ambient, arid climatic conditions. Plant response to elevated soil P in fertilized plots in the abnormally dry second (1985) growing season did not occur even though soil N was relatively abundant. In 1987, plant response to higher residual P in fertilized plots may have been precluded by both low moisture and low soil N.

Conclusions

Certain rates and schedules of temporary irrigation were beneficial but not essential for establishing a productive plant community on cold desert mined lands. Benefits of irrigation included an acceleration of overall revegetation and a persistant enhancement of shrubs and perennial forbs. The stimulation of total plant productivity by irrigation was temporary, however, and productivity of dominant perennial grasses was eventually depressed under certain irrigation regimes.

The differences that existed among irrigation rates and schedules indicated the importance of properly designing irrigation programs for achievement of revegetation goals. With study site goals of rapid soil stabilization, vegetation productivity and growth form diversity in mind, 3 months of spring-early summer irrigation at a rate of 10 cm/month can be recommended as the optimum combination of the treatments imposed. Both the rate and schedule of this treatment combination improved early establishment of dominant perennial grasses, leading to more rapid soil stabilization. This was the optimum treatment combination for

for enhancing shrubs (the dominant growth form of native plant communities of the area), and also increased perennial forb establishment—factors that maximized fourth year growth form diversity with no concommitant reduction in total stand productivity.

Initial N-P fertilization had no influence on establishment, early growth and composition of perennial plant species even when first-year water availability was improved through temporary irrigation. Irrigation did induce a fertilizer response of volunteer annual species the first growing season, but this stimulation was ephemeral. These findings cast doubt upon the short-term effectiveness of fertilization as a reclamation practice on topsoiled, arid minesites, regardless of irrigation regime.

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