TEMPORARY IRRIGATION FOR REVEGETATION OF MINED LANDS UNDER COOL DESERT CONDITIONS[1]

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Abstract.--Temporary (one-season) irrigation was investigated to determine its effects on revegetation of arid coal mined lands in southwestern Wyoming. Treatments included non-irrigation, five irrigation schedules and three irrigation rates. Effects of treatments on vegetation were evaluated during the year of irrigation and two succeeding years. Certain irrigation treatments accelerated initial establishment of dominant, seeded perennial grasses, but benefits largely disappeared by the third growing season. Some irrigation treatments provided longer-term enhancement of subdominant seeded shrubs and perennial forbs. Non-seeded annual species were stimulated by irrigation only during the first growing season. The irrigation schedules implemented were more influential on revegetation than the applied irrigation rates.

INTRODUCTION

Low or unpredictable moisture is one of the chief limiting factors for mined land revegetation in the West (May 1975). Some (e.g., National Academy of Sciences 1974) have in fact questioned the feasibility of adequate revegetation in arid areas receiving less than 25 cm annual precipitation. Progress in revegetation and water conservation technology (Hodder 1977, Parady 1985, and others) has at least partially allayed concerns over ultimate revegetation adequacy on arid mined lands. However, questions remain on the rate and reliability of successful revegetation.

Rapid initial plant establishment is a requisite for success in all succeeding phases of reclamation. As reviewed by Ries and Day (1978), temporary irrigation comprises one means of insuring such rapid plant establishment. Temporary irrigation may provide greater year-to-year reliability of revegetation, may allow greater flexibility in revegetation scheduling, and sometimes may produce beneficial effects on species composition (Ries 1980, Young and Rennick 1982, Gould et al. 1982, DePuit et al. 1982). For such benefits to be realized, irrigation must be applied properly in terms of methods, schedules and rates, and in cognizance of an interrelated array of ecologic and economic factors (Ries and Day 1978, Ries et al. 1976).

While irrigation has proven beneficial to revegetation of semiarid mined lands (e.g., Ries et al. 1977, 1978, Farmer et al. 1974, and others), under arid conditions it sometimes may be essential (Aldon 1978). Mined land irrigation has received considerable research emphasis in the arid southwestern United States (Bengson 1977, Aldon et al. 1976, DeRemer and Bach 1977, Gould et al. 1975, 1982). Unfortunately, little or no published information exists on irrigation of mined lands in northern cool deserts. The present study was implemented to address this dearth of information.

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Objectives

This research was conducted with the primary goals of determining the necessity and effects of temporary irrigation on plant establishment on cool desert mined lands. Pursuant to these goals, specific objectives included evaluation of:

1) Non-irrigation vs. first year irrigation at varied rates, and

2) Non-irrigation vs. first year irrigation at varied seasonal schedules,

in terms of effects on vegetation and, secondarily, soils.

Supplemental studies within this project are also being conducted to evaluate fertilization under non-irrigated and irrigated conditions, effects of irrigation on recolonization by VA mycorrhizal fungi, and effects of irrigation on plant water use and the hydrologic cycle. Results of these studies will be presented in later reports.

The following paper will summarize selected vegetation data from the first three years of this ongoing project. Results must be considered as interim; final, comprehensive interpretation is deferred until study completion.

METHODS

Study Area

This study was initiated in 1984 at the Jim Bridger Mine (Bridger Coal Co.) near Rock Springs in southwestern Wyoming. Parady (1985) provided a brief description of mining and reclamation programs at this locale. The mine is located within the Red Desert, a high, cool and arid environment. Average elevation is 2100 m, the frost free growing season averages 100 days, and annual precipitation ranges between 15 and 20 cm. Native soils are usually entisols or aridisols, coarse-textured and moderately saline. Native vegetation is commonly dominated by cold-desert xerophytic or halophytic shrubs in association with subdominant perennial grasses.

The study was implemented on a 1.4 ha minesite. The site was graded to a uniform, nearly level slope, and spoils were double-ripped to 76 cm prior to topsoil application in March, 1984. Approximately 25 cm of subsoil and 15 cm of direct-haul topsoil were applied. Sampling indicated spoil was loamy and saline, subsoil was sandy loam and saline, and topsoil was sandy loam and non-saline. No stratum was strongly sodium-affected.

Following topsoil application, the seedbed was prepared by chisel plowing and roller-harrowing. The site was drill seeded on April 3-4, 1984 to a uniform mixture of 11 cool-season perennial grass, 3 forb and 5 shrub/half-shrub species. The total mixture seeding rate was approximately 27 kg PLS ha^{-1}, which yielded roughly 1930 PLS^{-2}. The site was uniformly mulched with crimped wheat straw at 2242 kg ha^{-1}, and uniformly surficially fertilized with 50 kg actual N ha^{-1} and 57 kg actual P ha^{-1}.

Experimental Design

Variables in this study included non-irrigation (control) and all combinations of the following irrigation treatments:

1) Varied Irrigation Rate:

   a) 5.1 cm
   b) 7.6 cm
   c) 10.2 cm

   of supplemental water per month of irrigation.

2) Varied Irrigation Schedule:

   a) Season-long, 4 mos. (May 15-Sept. 15)
   b) Spring-early summer, 3 mos. (May 15-Aug. 15),
   c) Spring, 2 mos. (May 15-July 15)
   d) Early spring, 1 mo. (May 15-June 15),
   e) Summer, 2 mos. (July 15-Sept. 15).

The irrigation schedule and rate treatments were applied in the field in a randomized strip-plot experimental design (Cockran and Cox 1957). The control and all combinations of the above irrigation treatments yielded 16 specific treatment combinations, which were replicated in three blocks. Each treatment combination plot measured 12.2 by 12.2 m.

Irrigation treatments were applied the first (1984) growing season only, using a solid-set sprinkler system. A single sprinkler head was located in the geometric center of each 12.2 by 12.2 m plot. Water distribution data were collected to determine the concentric zone of most uniform water application within the plot. Irrigation rates were applied based upon amounts of water received within this zone, and all plant and soil sampling was conducted within this zone. Water was obtained from a nearby power plant surge pond, and was of good quality in all respects excepting moderately high salinity (374 to 724 umho cm^{-1}).

Irrigation was initiated in mid-May, 1984, and was continued (depending on schedule treatment) until mid-September. Water was applied (at varied rates) during three, two to three day irrigation events per month, which were separated by 7 to 8 day drying cycles.

Measurements

Climatic, edaphic and vegetation data were collected in 1984 (the year of irrigation), 1985 and 1986. Precipitation and other meteorologic data were obtained from a Bridger Coal Company weather station adjacent to the study site, and were augmented by data from an on-site precipitation gauge and evaporation pan.

Pre-treatment soil sampling was conducted in May, 1984. Post-treatment sampling was accomplished in April, 1985 (and will be conducted again in April, 1987). Composite samples from each of the 48 plots were analyzed for a comprehensive array of physiochemical attributes, with emphasis on fertility and salt-related parameters. Soil water content was gravimetrically determined in each plot throughout each growing season; in 1984 sampling occured three times per month, in 1985 once per month and in 1986 once every 1½ months.

Plant density data, by plant class, were collected twice in 1984 (June and September) by counting all live plants rooted within four 0.25 m^2 quadrats per plot. Density data for shrubs and forbs were collected in June, 1985 and July 1986 in similar fashion, except that in 1986 quadrat size was increased to 0.50 m^2 and supplemental density data were collected using two 3.05 m^2 belt transects per plot. Canopy cover data, by plant class and species, were collected during the period of estimated peak standing crop in 1984 (late July), 1985 (early July) and 1986 (early July) using a modified Daubenmire (1959) technique with four 0.25 m^2 quadrats per plot. Aboveground biomass data, by plant class, were obtained concurrent with cover data each year by hand harvesting all plant material within four quadrats per plot; quadrat size was 0.25 m^2 in 1984 and 1985, and was increased to 0.50 m^2 in 1986. Various additional vegetation descriptors (frequency, richness, diversity indices) were generated from density, cover or biomass data.

Data Analysis

Vegetation data collected from the 15 specific combinations of irrigation rate and schedule treatments were subjected to an analysis of variance for a strip-plot design (Cockran and Cox 1957) to determine occurance of irrigation rate or schedule main effects, or rate-schedule interactions. No interactions were found for the data sets presented below; consequently, only main effects will be discussed.

A second, multiple set of analyses of variance was performed to compare non-irrigated, control plot data to irrigation rate, schedule and rate-schedule combination treatment means. This was necessary because of the lack of varied treatment "levels" for control plots corresponding to those of the irrigation treatments.

Tukey's method for pairwise comparison of means was used to detect significant differences among/between treatments for both sets of analysis of variance, except for 1984 results where missing data necessitated utilizing Scheffe's method (Scheffe 1959). Unless noted otherwise, a 95 % level of probability (i.e., $\alpha = 0.05$) was employed throughout statistical analysis.

RESULTS

Analysis has not been completed for all data collected thus far in this continuing study. However, plant class biomass data from 1984-1986 have been fully analyzed, as have 1986 belt transect density data. These results will be presented and augmented, where appropriate, by references to other data sets still being compiled and tested.

General Trends

Vegetation was dominated by annual species in 1984, the year of seeding and irrigation. Chief among these species were volunteer wheat (_Triticum aestivum_) from the mulch applied and various invading chenopods, most notably Russian thistle (_Salsola kali_). However, seeded perennial grasses replaced annuals as dominant species during the non-irrigated second (1985) and third (1986) growing seasons. While nearly every seeded grass species became established, thickspike (_Agropyron dasystachyum_) and slender (_A. trachycaulum_) wheatgrasses exhibited highest canopy cover.

Perennial forbs and shrubs did not establish as uniformly and prolifically as did grasses. However, certain forb and shrub species established moderately well under specific irrigation treatments (described below), and persisted quite vigorously through the third growing season. Chief among these species were the forbs cicer milkvetch (_Astragalus cicer_) and Rocky Mountain penstemon (_Penstemon strictus_), the shrubs Gardner (_Atriplex gardneri_) and fourwing (_A. canescens_) saltbushes, and the half-shrub winterfat (_Ceratoides lanata_).

Effects of Irrigation Schedule

Figure 1 displays total perennial grass biomass responses to non-irrigation and the five irrigation schedules for the first three years of the study. In the year of seeding and irrigation (1984), there was no significant difference in perennial grass biomass among the five irrigation schedules. However, the season-long, spring-early summer and spring irrigation schedules, which had the highest means, produced significantly more grass biomass than did the non-irrigated control.

In contrast to 1984, significant differences in perennial grass biomass occured among schedules in 1985--the year following termination of irrigation (Fig. 1). Biomass progressively declined from season-long (4 mos.) through early spring (1 mo.) irrigation schedules; mean biomass under season-long irrigation proved significantly greater than that under spring and early spring irrigation, and spring-early summer irrigation biomass was significantly higher than that under esrly spring irrigation.

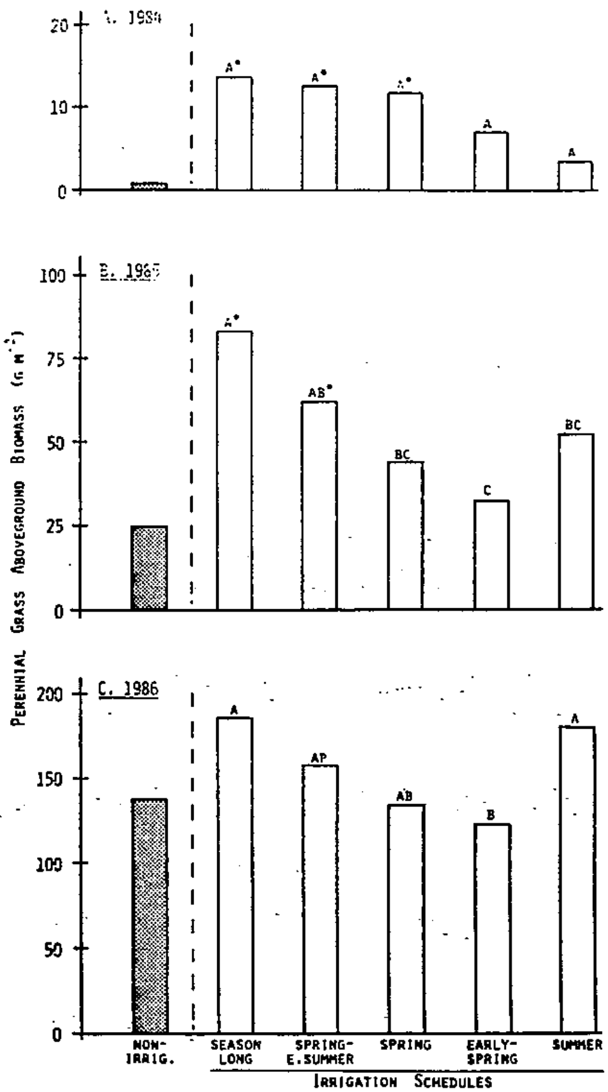

Figure 1.--Perennial grass aboveground biomass responses to non-irrigation and five schedules of first-year irrigation during the first (1984), second (1985) and third (1986) growing seasons. Schedule means with same letter are not significantly different ($\alpha = 0.05$); schedule means with asterisk (*) are significantly different from the non-irrigated control ($\alpha = 0.05$).

In summer irrigated plots, perennial grass biomass increased dramatically from 1984 to 1985; this was partially due to the fact that this schedule had not been fully implemented at the time of biomass sampling in 1984. Although significantly lower than that under season-long irrigation, perennial grass biomass under summer irrigation was statistically similar to that under all other schedule treatments at $\alpha = 0.05$ (Fig. 1); at $\alpha = 0.10$ (not indicated in Fig. 1) it was significantly higher than that under one month of early spring irrigation and non-irrigation.

Perennial grass biomass increased at a proportionately greater rate from 1984 to 1985 in the non-irrigated treatment than in any of the irrigated treatments. As a result, 1985 non-irrigated perennial grass biomass became similar to that under spring irrigation and remained similar to that under early spring irrigation (Fig. 1). However, season-long and spring-early summer irrigation still produced significantly more perennial grass biomass than that with non-irrigation in 1985.

Fewer significant differences in perennial grass biomass were apparent among irrigation schedules in the third growing season (1986), despite the similarity of relationships among treatments to those of 1985 (Fig. 1). Season-long and summer irrigation produced significantly higher biomass than that under early spring irrigation; differences among all other irrigation schedules were statistically insignificant. Furthermore, perennial grass biomass under non-irrigation continued to increase from 1985 to 1986 at a higher rate than that for any irrigated treatment, resulting in no significant difference between the non-irrigated and any irrigation schedule treatment in 1986.

In 1984, the year of irrigation, total biomass of non-seeded annual species was higher under all irrigation schedules than for the non-irrigated control; the season-long, spring-early summer and spring schedules produced significantly higher annual species biomass than the control (Fig. 2). These three schedules also yielded substantially higher annual species biomass than the early-spring and summer schedules; however, only spring-early summer biomass proved significantly higher at $\alpha = 0.05$.

Annual species biomass declined dramatically from 1984 to 1985 in all irrigated treatments, resulting in no significant differences among irrigation schedules nor between schedules and the non-irrigated control in 1985 (Fig. 2). Annual species biomass in 1986 (not shown) declined further to inconsequential levels and, again, no significant differences among treatments occured.

No significant differences in shrub or perennial forb biomass were detected among treatments in any year. Shrubs and forbs were more widely dispersed than other species, resulting in high variability among biomass samples within treatments which may partially explain the lack of significant differences. Biomass sample variation remained high in 1986, despite a doubling of harvest quadrat size to 0.50 m^2. However, shrub and forb density data were collected in 1986 using a much larger (3.05 m^2) belt transect. This approach reduced sample variability within treatments sufficiently to reveal significant differences in density among treatments.

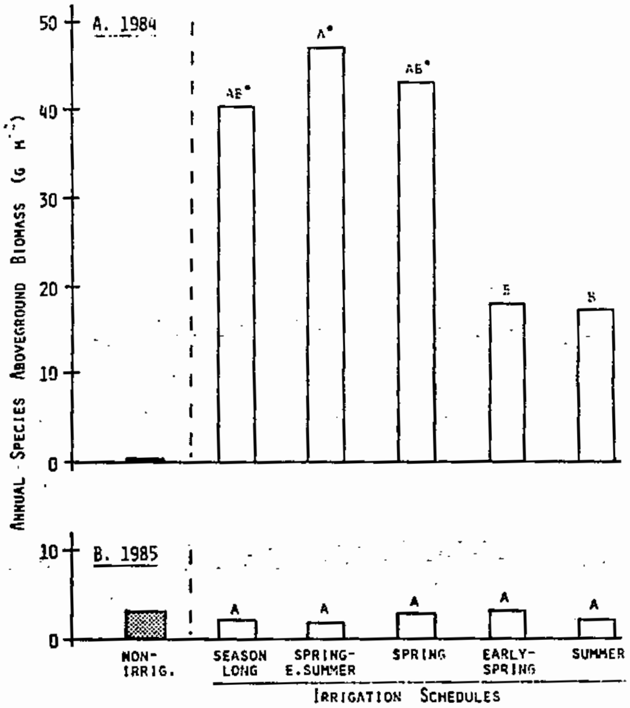

Figure 2.--Annual species aboveground biomass responses to non-irrigation and five schedules of first-year irrigation during the first (1984) and second (1985) growing seasons. Schedule means with same letter are not significantly different ($\alpha = 0.05$); schedule means with asterisk (*) are significantly different from the non-irrigated control ($\alpha = 0.05$).

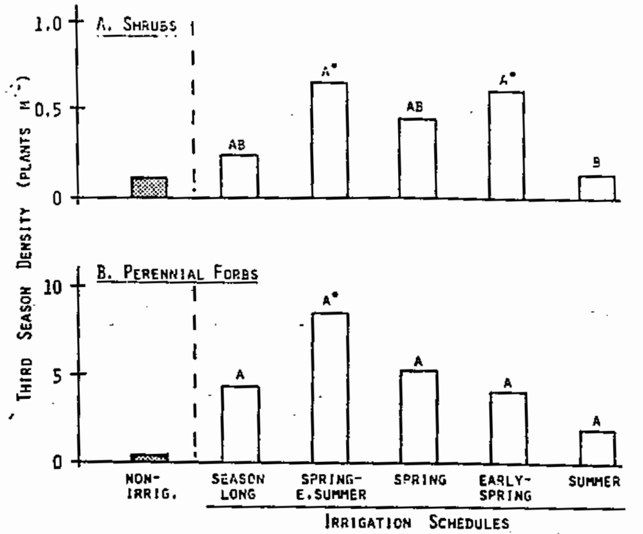

Figure 3.--Shrub and perennial forb density responses to non-irrigation and five schedules of first-year irrigation during the third (1986) growing season. Schedule means with same letter are not significantly different ($\alpha = 0.05$); schedule means with asterisk (*) are significantly different from non-irrigated control ($\alpha = 0.05$).

Third growing season (1986) shrub densities were highest for the spring-early summer and early spring irrigation schedules (Fig. 3). Both of these treatments produced significantly greater shrub densities than those under non-irrigation and summer irrigation at $\alpha = 0.05$; at $\alpha = 0.10$ (not indicated in Fig. 3) they also exhibited significantly higher density than under season-long irrigation. It is noteworthy that the two irrigation schedules with lowest shrub density, season-long and summer (Fig. 3), were the schedules with highest perennial grass biomass in 1986 (Fig. 1).

Figure 3 indicates that perennial forb density in the third growing season was substantially higher under most irrigation schedules than that with no irrigation; however, only the spring-early summer irrigation schedule produced significantly greater forb density than that with no irrigation. No significant differences in forb density occured among irrigation schedules, despite the higher mean density under spring-early summer irrigation than under other irrigation schedules. Perennial forb biomass data in 1986 (not shown) exhibited patterns and relationships similar to these for density.

Effects of Irrigation Rate

Although mean perennial grass biomass tended to increase with increasing irrigation rate, there were no significant differences among the three rates in any year (Fig. 4). However, during the year of irrigation (1984) all irrigation rates produced significantly greater perennial grass biomass than did the non-irrigated control. This relationship became less pronounced in 1985, when only the highest irrigation rate significantly increased grass biomass over that of the control at $\alpha = 0.05$ (Fig. 4); the intermediate rate also increased grass biomass over the control in 1985, but the level of significance was reduced (i.e., to $\alpha = 0.10$, not indicated in Fig. 4). By 1986, no significant differences in perennial grass biomass were apparent between the non-irrigated and any of the irrigation rate treatments.

Annual species biomass responses to irrigation rate (not shown) were similar to those for perennial grasses in 1984; annual species biomass was significantly higher under all irrigation rates than with non-irrigation, but no significant differences occured among rates. In 1985 and 1986, annual species biomass was low and, usually, statistically similar among treatments.

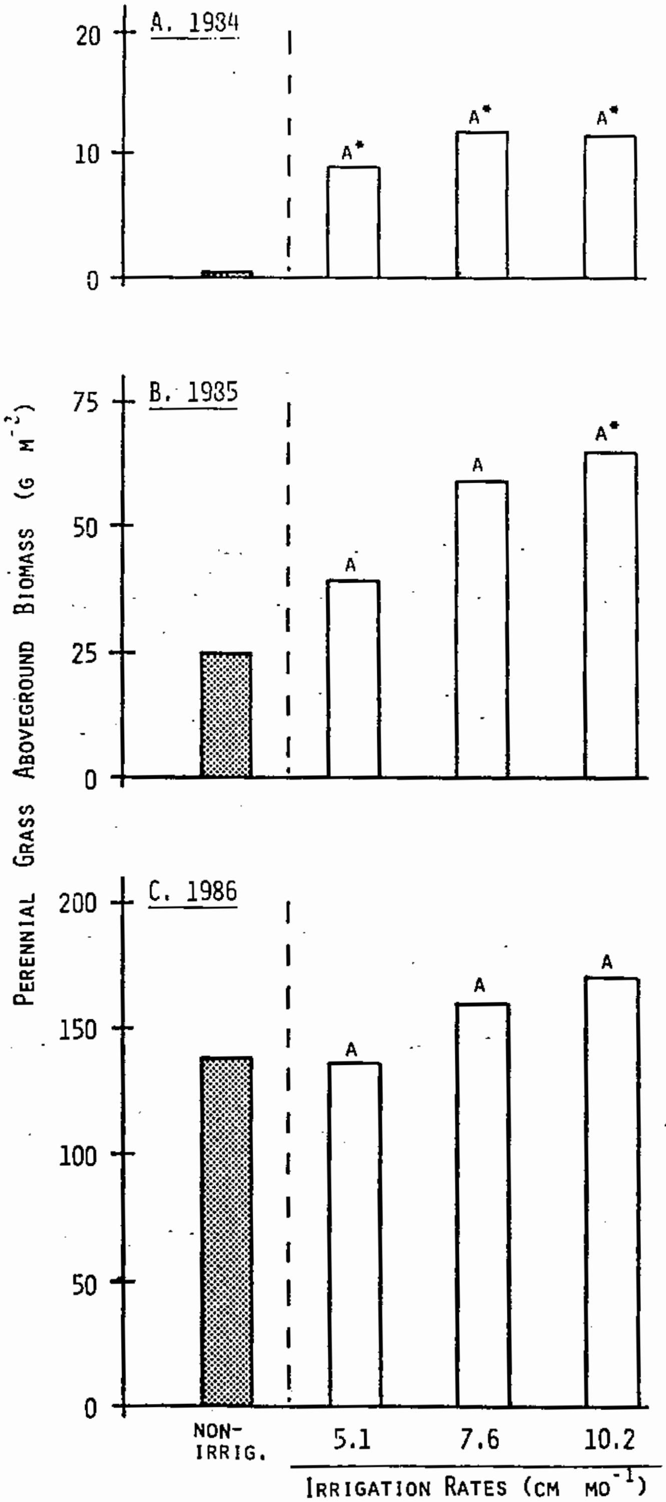

Figure 4.--Perennial grass aboveground biomass responses to non-irrigation and three rates of first-year irrigation during the first (1984), second (1985) and third (1986) growing seasons. Rate means with same letter are not significantly different (α = 0.05); rate means with asterisk (*) are significantly different from the non-irrigated control (α = 0.05).

No significant influence of irrigation rate was apparent in any year for shrub and perennial forb biomass, again largely due to high sample variability for these species. Belt transect density data for shrubs and forbs in 1986 (Fig. 5) also indicated no significant differences among the three irrigation rates. However, all three rates produced significantly higher forb densities than did non-irrigation at α = 0.05 (Fig. 5). At a lower level of probability (α = 0.10, not indicated in Fig. 5), shrub densities were significantly higher at the two heaviest rates of irrigation (7.6 and 10.2 cm mo^{-1}) than under non-irrigation.

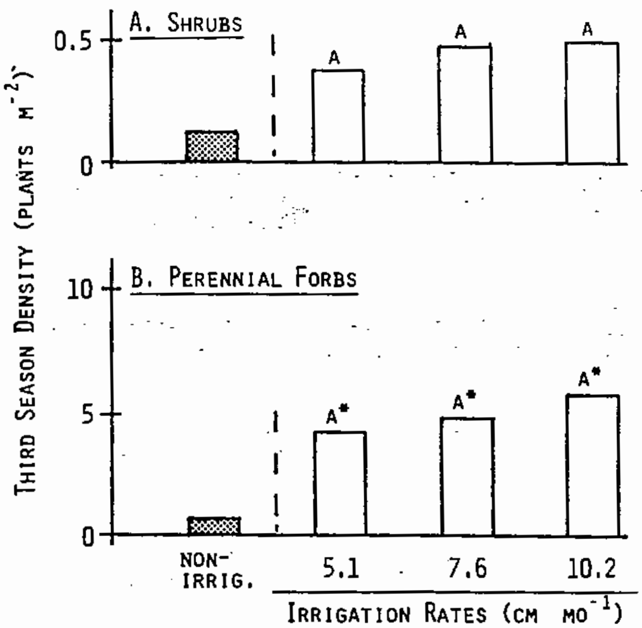

Figure 5.--Shrub and perennial forb density responses to non-irrigation and three rates of first-year irrigation during the third (1986) growing season. Rate means with same letter are not significantly different (α = 0.05); rate means with asterisk (*) are significantly different from the non-irrigated control (α = 0.05).

DISCUSSION

Significant differences in vegetation attributes were more numerous and persistent among the five irrigation schedules than among the three irrigation rates. This indicates that the scheduling of irrigation may have far greater influence on revegetation than the rate of water application.

An initial concern in the use of irrigation for arid land revegetation involves the possible overstimulation of aggressive, weedy species to the detriment of seeded perennials. Although certain irrigation schedules and all irrigation rates did in fact significantly increase annual species productivity during the first growing season, this effect proved very temporary. This may be largely attributed to concurrent stimulation of seeded perennial grasses, which became the dominant life-form on the site during the second and third growing seasons as annual species declined.

Certain irrigation treatments significantly improved perennial grass establishment over that with non-irrigation during the first and second growing seasons. However, the identity of irrigation schedules and the number of irrigation rates that stimulated grasses changed between the two years. By the third growing season, no irrigation treatment yielded significantly higher grass productivity than that in non-irrigated plots. These relationships suggest that although proper irrigation may accelerate establishment of dominant perennial grasses, grass productivity may be expected to converge between irrigated and non-irrigated plots over time. The period of convergence in this study was quite short (3 years).

First growing season biomass data do not fully reflect treatment effects on initial perennial grass establishment because not all irrigation treatments had been fully applied at the time of data collection in mid-summer. Second year data indicate that while variations among irrigation rates proved statistically insignificant, certain irrigation schedules were more effective than others in accelerating grass establishment and growth. Season-long irrigation was most effective, followed respectively by three months of spring-early summer, two months of spring or summer, and one month of early spring irrigation. However, by the third growing season significant differences in perennial grass biomass among the five irrigation schedules had nearly disappeared. Effects of irrigation scheduling on perennial grasses thus appear transitory, being limited to the establishment phase and declining as plant community development proceeds.

The temporary nature of irrigation's benefits to dominant perennial grasses, suggested by the above relationships, would seem to make the expense of irrigating arid mined lands unjustified. However, other factors must be considered before reaching such a conclusion. For example, the year-to-year reliability of adequate initial plant establishment must be taken into account. In this study, 1984 was characterized by below average winter-spring precipitation; first year perennial grass establishment without irrigation was limited, but nonetheless sufficient to enable an eventual third year equilibration of productivity with irrigated plots. However, whether this usually can be expected to occur remains an open question. Even if it can, the more rapid achievement of full perennial grass revegetation possible with proper irrigation may sometimes still justify the practice because of the attendant benefits of accelerated soil stabilization and development. Lastly, short and longer-term effects of irrigation on plant species and growth form composition must be considered in any comprehensive evaluation of the practice. Third growing season density data of this study for subdominant shrubs and perennial forbs provide some insight on this question.

Xerophytic shrubs are usually dominant or co-dominant species on native sites in arid regions, but have often proved more difficult to rapidly establish from seed on arid mined lands than perennial grasses. Results of the present study certainly support the latter generalization. However, third growing season shrub densities were consistantly higher under irrigation than non-irrigation, and the stimulation of shrub establishment proved significant for certain irrigation treatments (i.e., spring-early summer and early spring schedules, and at $\alpha = 0.10$, the two heaviest irrigation rates). Thus, proper irrigation may be used to enhance establishment of shrubs otherwise difficult to introduce from seed. Irrigation treatments which produced lowest third season shrub densities (season-long and summer schedules) were those that yielded highest productivity of dominant perennial grasses, suggesting that irrigation to maximize grass productivity may not always be desirable due to competitive retardation of shrubs.

Perennial forbs are typically less conspicuous components of arid land plant communities than grasses or shrubs, but still may fill important niches. Similar to shrubs, they often have proven relatively difficult to establish from seed on arid mined lands, and were generally stimulated by irrigation in this study. Third year forb density was significantly higher under all irrigation rates and under the spring -early summer irrigation schedule than that in non-irrigated plots.

Shrub and perennial forb density data thus indicate that proper irrigation may have value in enhancing these difficult-to-establish classes of species on mined lands. "Proper" irrigation in this case would specifically appear to be the spring-early summer schedule of irrigation, since this treatment significantly stimulated both shrubs and forbs without overly promoting the growth of competitive perennial grasses. The fact that differences in shrub and forb density attributable to irrigation occurred during the third growing season indicates that effects of irrigation on these growth forms were not limited to the initial plant establishment phase only. These density data also suggest that certain irrigation treatments may increase growth form and, possibly, species diversity. The validity of this premise, however, will be determinable only when analyses of floristic composition data from the first three and fourth (1987) growing seasons have been completed.

CONCLUSIONS

Interim results of this study indicate that temporary irrigation can be used to accelerate establishment of seeded perennial grasses on arid mined lands, but that the benefits of irrigation to grasses may only be short-term. Proper seasonal scheduling of irrigation appears to be more important than rates of water application, at least among treatments evaluated. Maximum short-term enhancement of perennial grass establishment was most efficiently achieved with three months of spring-early summer irrigation; however, maximum longer-term productivity was most efficiently achieved with the less water-consumptive two-month spring and summer schedules.

Proper temporary irrigation also increased densities of subdominant shrubs and perennial forbs on arid mined lands, suggesting a role of this reclamation practice for enhancing growth form diversity. Three months of spring-early summer irrigation appeared to be the best schedule treatment for achieving this.

Links to cited papers are on the bottom

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