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Effects of Two Years of Irrigation on Revegetation of Coal Surface-mined Land in Southeastern Montana

EDWARD J. DEPUIT, CHESTER L. SKILBRED, AND JOE G. COENENBERG

Abstract

Responses of reseeded vegetation in the first two growing seasons (1978 and 1979) to irrigation on topsoiled sodic mine spoils are presented. In terms of above-ground productivity and stand composition, irrigation significantly promoted growth of seeded perennial grasses and legumes in total. This stimulation was most pronounced in 1979 for the cool-season grasses, slender wheatgrass, smooth brome grass and western wheatgrass and the invading cool-season legume yellow sweetclover. Other cool-season grasses and warm-season grasses were stimulated by initial irrigation, but were either unaffected or retarded (due to competitive relationships) by continued irrigation. Productivity of invading annual weeds was significantly curtailed by irrigation by 1979. Although differences in composition occurred, total stand productivity was similar for irrigated and nonirrigated plots in 1978, a year of above-average precipitation. In 1979, a drier year, total stand productivity was nearly three times higher under irrigation than nonirrigation. In the first year of study (1978), a higher measured index of stand structural diversity occurred under irrigation. This relationship became reversed in 1979, with higher structural diversity in nonirrigated plots. Root biomass was significantly higher in nonirrigated than in irrigated plots. This difference between irrigation and nonirrigation was most pronounced in the applied topsoil zone. Root distribution was skewed towards shallowest soil depths under irrigation to a far greater extent than under nonirrigation.

Impacts of coal surface mining in the western United States will increase during the coming decades, and much mined land will be reclaimed for rangeland use. Moisture availability is often a major factor affecting revegetation of mined land in this region (May 1975). In arid areas irrigation may be the only means to establish vegetation rapidly (Aldon 1978). Success with both sprinkler and drip irrigation systems on mined land has been reported in the Southwest (Bengson 1977; Aldon et al. 1976; DeRemer and Bach

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1977; Gould et al. 1978). Although the semiarid Northern Great Plains coal province receives more precipitation than the Southwest, large seasonal and yearly fluctuations suggest a great utility of irrigation there as well. Mined land research in North Dakota (Ries et al. 1977, Ries et al. 1978) has indicated positive effects of temporary irrigation in terms of initial vegetation establishment, productivity, and species composition.

Ries and Day (1978) and Ries et al. (1976) distinguished between sustained irrigation and irrigation for establishment only, the latter being recommended for establishment of nonirrigated pasture. The objective of temporary irrigation is initially to establish vegetation which will survive when irrigation terminated. Sustained irrigation of mined lands was recommended only for sustained production of a given agricultural crop, or if necessary for leaching of excess soil salts. Irrigation may also be beneficial in extending the seeding season and in promoting growth of warm-season species which in the past have proven difficult to establish. One major concern in using temporary irrigation is vegetation response after irrigation cessation.

This study was conducted to evaluate vegetation responses of seeded coal mined lands to 2 years of summer irrigation. Sustained irrigation was employed rather than initial irrigation due to necessary requisites for concurrent evaluation of four sodic subsoil amendments (DePuit et al. 1979). This report will summarize vegetation data relative to irrigation only. Objectives of this phase of the project included:

- 1) Evaluation of effects of supplemental irrigation on vegetation establishment, structure, composition, diversity and productivity during the first two irrigated growing seasons.
- 2) Definition of effects of irrigation on root biomass and distribution.

Study Area and Methods

This study was conducted on a 1.0 ha topsoiled spoil site at the West Decker coal mine in southeastern Montana. General characteristics of this area were presented by Sindelar et al. (1973). Climate is semiarid continental, with long, cold winters and short, warm summers. Annual precipitation averages 29 cm,¹ and is most

¹At Decker, Montana, from N.O.A.A. records.

concentrated and dependable in the spring months of April through June. Annual precipitation in the years of this study, 1978 and 1979, was 49.2 and 24.4 cm, respectively. The frost-free growing season averages 100 to 105 days, with July typically the warmest month. Most vegetation in the study area is characteristic of northern mixed prairie, although areas of pine woodland and riparian vegetation do occur. Dominant plant species on good condition mixed prairie sites are a diverse mixture of cool-season perennial grasses and forbs, although warm-season species are frequently present in sub-dominant concentrations. Retrogressed and/or harsh sites are usually dominated by various shrub and half-shrub species.

Replaced overburden was considered sodic and moderately saline, with an average sodium adsorption ratio of 22.9 and electrical conductivity of 3.4 mmhos/cm. Approximately 70 cm of non-sodic, nonsaline sandy loam topsoil was applied to all experimental plots in the fall of 1977, after application of five soil amendment treatments (control [nonamended], gypsum, CaCl_2 , gypsum + CaCl_2 + NH_4NO_3 and gypsum + CaCl_2 + NH_4SO_4) to the sodic spoil. Study design was a partially randomized block, with three replications of each amendment treatment under both irrigation and nonirrigation. Treatment/replicate sub-plots measured approximately 12×18 m. Vegetational data relative to irrigation will represent mean data for all five soil amendment treatments under irrigation vs. nonirrigation. No significant differences in vegetation parameters were discerned among amendment treatments during the first 2 years of study.

Following topsoiling, the seedbed was prepared by chisel plowing, disc plowing, and harrowing. A dormant fall seeding of study plots was accomplished on November 14, 1977, using a Brillion "sure stand" grass seeder. The seed mixture was predominately composed of native plant species, and was applied at an overall rate of 28 kg/ha (25 lb/A) of pure live seed. Species seeded were western wheatgrass (*Agropyron smithii*), thickspike wheatgrass (*A. dasystachyum*), slender wheatgrass (*A. trachycaulum*), beardless wheatgrass (*A. inerme*), pubescent wheatgrass (*A. trichophorum*), green needlegrass (*Stipa viridula*), prairie sandreed (*Calamovilfa longifolia*), blue grama (*Bouteloua gracilis*), smooth brome grass (*Bromus inermis*), sainfoin (*Onobrychis viciaefolia*), and fourwing saltbush (*Atriplex canescens*). Following seeding, all plots were hylomulched with wood fiber at a rate of 2242 kg/ha (2000 lb/acre). Study plots were uniformly fertilized at a rate of 30 kg/ha (27 lb/acre) available N and 33 kg/ha (30 lb/acre) available P on June 13 and September 6, 1978.

A sprinkler irrigation system was established in the spring of 1978 for application of supplemental water to those plots to be irrigated. The period of supplemental irrigation during 1978 extended from June 3 to September 29, and in 1979 from June 12 to September 12. Approximately 10 cm (4 in.) of irrigation water were applied to the irrigated plots over 6 to 7 days during these periods. A total of approximately 70 cm (27.5 in.) of supplemental water was applied during the summer irrigation period in 1978 and 85 cm (33.5 in.) in 1979. Natural precipitation during the growing season (April-September) was above-average in 1978 (33.9 cm) and below-average in 1979 (18.1 cm). Precipitation plus irrigation thus supplied nearly equal amounts of water to irrigated plots during the April-September period in 1978 and 1979 (103.9 and 103.1 cm, respectively).

Aboveground vegetation measurements were conducted in 1978 and 1979 along permanent 22-mm transects established diagonally across each of the 30 experimental subplots. Vegetation was sampled for initial seedling density, canopy cover, frequency, and aerial biomass by means of systematically placed sampling quadrats along these transects.

Initial plant density (plants/m²) was determined on May 27, 1978, by counting the number of seedlings within twenty 20×20 cm quadrats per experimental subplot. Seedlings were counted within each of the following plant classes: perennial grasses, annual

grasses, shrubs, legumes, and forbs.

Plant canopy cover, frequency, and aerial biomass data were collected on July 31–August 1, 1978, and July 30–August 1, 1979. Plant canopy cover was estimated using the techniques of Daubenmire (1970). Plant frequency was based upon canopy cover data. Ten 20×50 cm quadrats were sampled per subplot. Canopy cover was first estimated for five plant classes (i.e., total perennial grasses, annual grasses, shrubs, legumes, and forbs) and then for all individual plant species. Plant community diversity was evaluated using the Shannon-Weiner Function (H' , Shannon and Weaver 1973) as derived from canopy cover values for individual species (Bonham 1974) using specific methods of Munshower and DePuit (1976):

$$H' = \sum P_i \log P_i$$

where P_i is the cover-derived percentage of importance for each species (long base 10 was used in the equation). Higher index values represent higher diversity.

Plant aboveground biomass was estimated by hand harvesting to ground level all live vegetation within seven .25 m² quadrats per subplot. Harvested vegetation was separated into the following plant classes: perennial grasses, annual grasses, shrubs, legumes, weedy forbs, and other forbs. Samples were oven dried and weighed to estimate dry weight of vegetation per unit area.

Belowground (root) biomass was estimated in August, 1979, by extracting 4-cm diameter soil cores using a portable soil auger. Soil cores were segregated into three depth increments within the topsoil (0–22.5, 22.5–45.0, and 45.0–67.5 cm) and sodic subsoil (67.5–90.0, 90.0–112.5, and 112.5–157.5 cm) zones. Two soil core

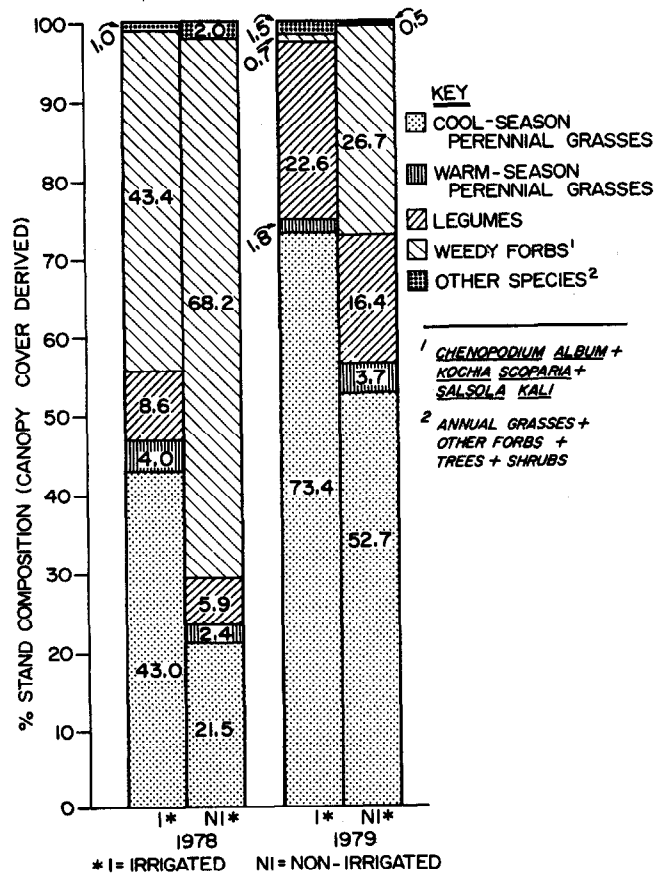


Fig. 1. Stand composition (based upon canopy cover) of irrigated and non-irrigated plots, Soil Amendment-Irrigation Study, Decker, Montana, 1978 and 1979.

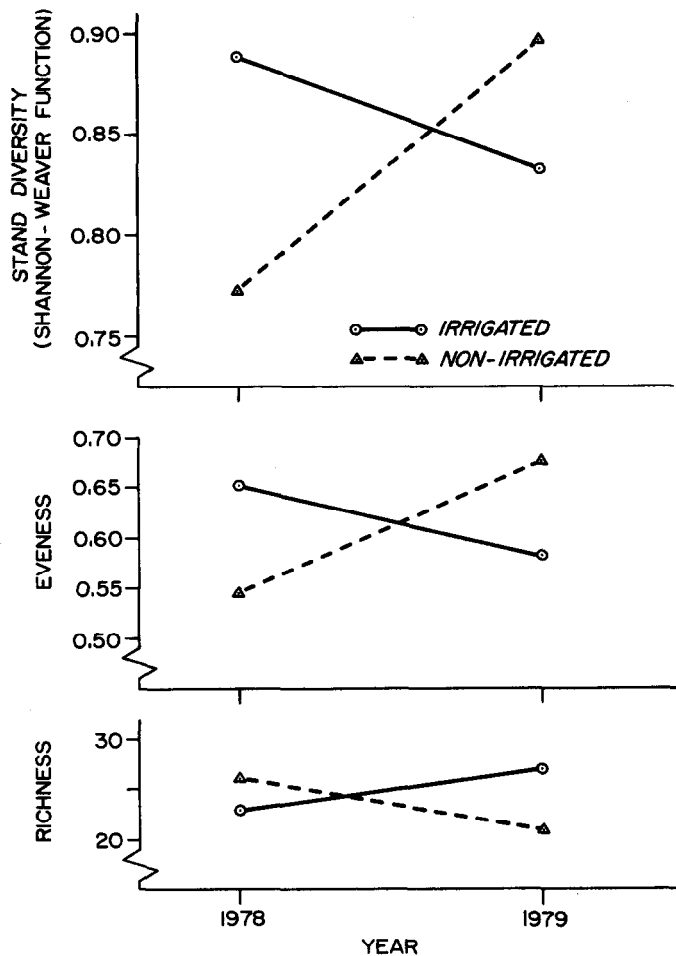


Fig. 2. Stand diversity relationships between irrigated and nonirrigated plots based upon canopy cover in 1978 and 1979, Soil Amendment-Irrigation Study, Decker, Montana.

Table 1. Comparison of mean aboveground plant biomass of all irrigated and non-irrigated plots, Soil Amendment-Irrigation Study, Decker, Montana, July 31, 1978, 1979.

| Plant Category | Dry Aboveground Biomass (Kg/ha) ¹ | | | |
|--------------------------|--|---------------|-----------|---------------|
| | 1978 | | 1979 | |
| | Irrigated | Non-irrigated | Irrigated | Non-irrigated |
| Perennial grasses | 246a | 141b | 4427a | 1196b |
| Annual grasses | 15a | 6a | 11a | 10a |
| Legumes | 41a | 38a | 1531a | 630b |
| Weedy forbs ² | 657a | 765a | 19b | 422a |
| Other forbs | 11a | 11a | 10a | 8a |
| Trees | 0 | 0 | 1a | 0a |
| Total live biomass | 969a | 961a | 5998a | 2266b |
| Standing dead biomass | 0 | 0 | 184 | 306 |
| Ground litter (mulch) | 36 | 2 | 674 | 1095 |

¹Values within hachured blocks followed by same letter not significantly different at 5% level

²*Salsola kali* + *Chenopodium album* + *Kochia scoparia*

locations were sampled per subplot at representative sites which had been harvested previously for aboveground biomass determination. Root material was washed from each core sample, oven-dried and weighed. Root biomass data are presented on a dry weight basis.

Results

General Vegetation Development

Plant germination and initial development were relatively slow and uneven among plots in spring, 1978, despite unusually high precipitation. By midsummer of 1978 establishment of seeded vegetation was judged successful on irrigated plots but only marginal on nonirrigated plots. By late 1978 the study site had become dominated by weedy forbs of family *Chenopodiaceae*, primarily summercypress (*Kochia scoparia*) and Russian thistle (*Salsola kali*). By midsummer of 1979, stand establishment in even the nonirrigated plots was considered successful. Thickspike and slender wheatgrasses were dominant, followed by smooth brome-grass, pubescent wheatgrass and western wheatgrass. Yellow sweetclover (*Melilotus officinalis*) (nonseeded) was the dominant legume. Weeds of *Chenopodiaceae* had largely disappeared from irrigated plots in 1979, but summercypress was still conspicuous in nonirrigated plots.

Treatment Effects on Aboveground Vegetation Development

Analysis of preirrigation initial seedling density data indicated no significant differences in perennial grass, annual grass, legume, and weedy forb density between plots to be subsequently irrigated and nonirrigated.

In 1978 total aboveground biomass was nearly identical for irrigated and nonirrigated plots (Table 1). However, perennial grass biomass (Table 1) and canopy cover (Table 2) were significantly higher in irrigated than in nonirrigated plots. Weedy forb biomass was higher, although not significantly so, in nonirrigated plots.

A greater number of significant differences in biomass and cover between irrigated and nonirrigated plots occurred in 1979 than in 1978 (Tables 1 and 2), possibly due to effects of lower precipitation

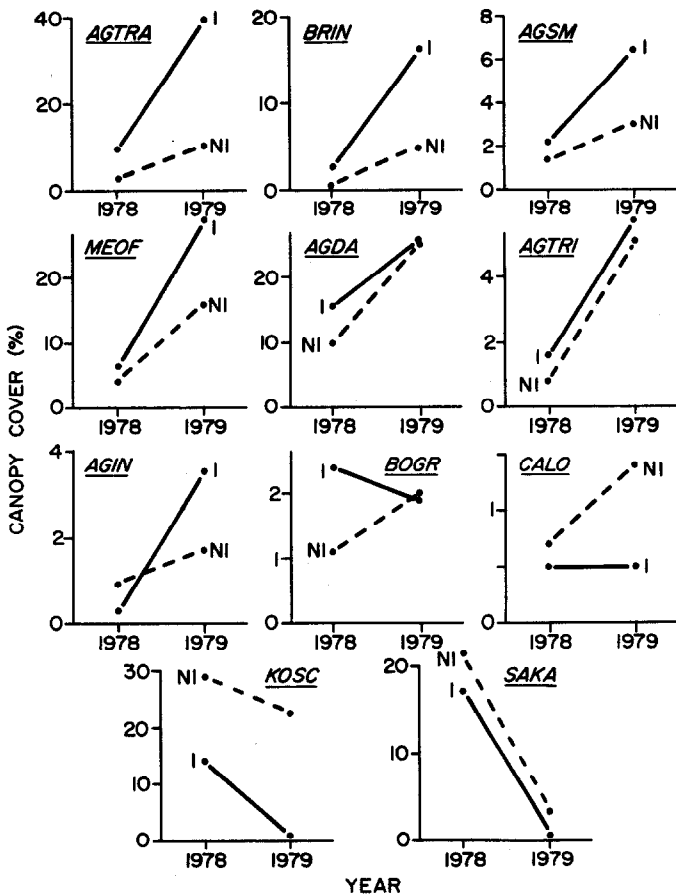


Fig. 3. Canopy cover responses of selected plant species to irrigation (I) and nonirrigation (NI) in 1978 and 1979, Soil Amendment-Irrigation Study, Decker, Montana.¹

¹Species abbreviations are as follows: *Agtra* = *Agropyron trachycaulum*, *Brin* = *Bromus inermis*, *Agsm* = *Agropyron smithii*, *Meof* = *Melilotus officinalis*, *Agda* = *Agropyron dasystachyum*, *Agtri* = *Agropyron trichophorum*, *Agin* = *Agropyron inermis*, *Bogr* = *Bouteloua gracilis*, *Calo* = *Calmavovifla longifolia*, *Kosc* = *Kochia scoparia*, and *Saka* = *Salsola kali*.

in 1979. Total stand biomass in 1979 was significantly higher under irrigation than with no irrigation. Perennial grass biomass of irrigated plots was nearly four times that of nonirrigated plots in 1979. Legume (primarily yellow sweetclover) biomass and cover had also become significantly higher in irrigated plots by 1979. Conversely, 1979 weedy forb biomass and cover declined greatly in irrigated plots, resulting in significantly higher weed biomass in nonirrigated plots.

The irrigated stand contained a higher proportion of cool-season perennial grasses than the nonirrigated stand in 1978 (Fig. 1). This relationship was repeated in 1979, although it was less pronounced due to a greater percent increase in cool-season species in nonirrigated plots from 1978 to 1979. During the first irrigation year (1978) stand composition of warm-season perennial grasses, although small, was higher under irrigation than nonirrigation (Fig. 1). However, in 1979 composition by warm-season grasses was higher in nonirrigated plots.

Legume stand composition was slightly higher in irrigated than in nonirrigated plots in both 1978 and 1979 (Fig. 1). However, weedy forb composition in irrigated plots in 1978 was considerably lower than that in nonirrigated plots. In 1979 this difference in weed composition was accentuated.

Data of Figure 1 show that in 1978 composition was more evenly distributed among plant classes in irrigated than in nonirrigated plots, the latter being largely dominated by weedy forbs. Effects of a second year of irrigation had altered this by 1979, with more even distribution of composition among plant classes in nonirrigated than in irrigated plots. These plant class relationships were mir-

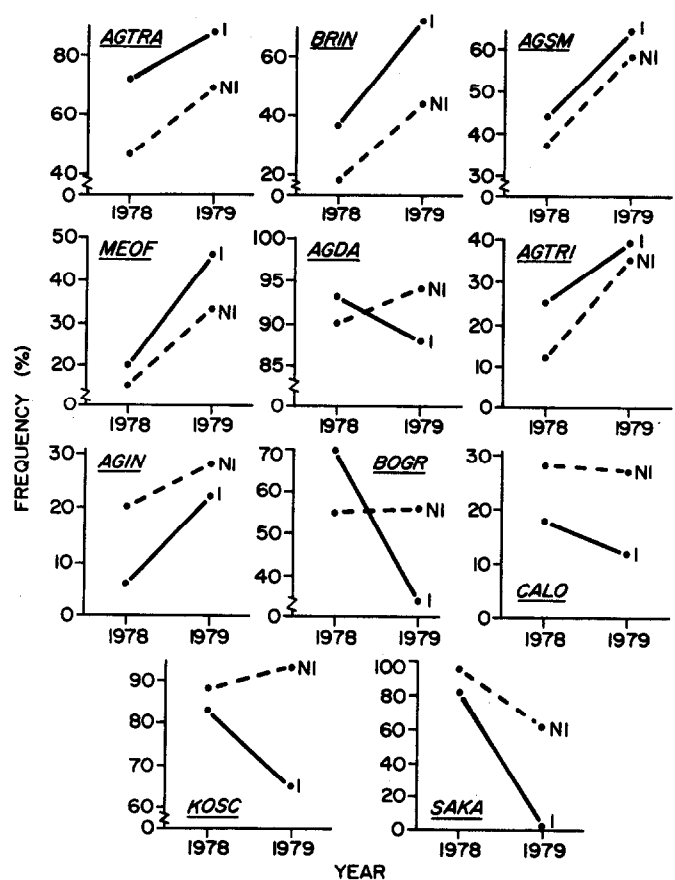


Fig. 4. Plant frequency responses of selected plant species to irrigation (I) and nonirrigation (NI) in 1978 and 1979, Soil Amendment-Irrigation Study, Decker, Montana.¹

¹Species abbreviations are as follows: *Agtra* = *Agropyron trachycaulum*, *Brin* = *Bromus inermis*, *Agsm* = *Agropyron smithii*, *Meof* = *Melilotus officinalis*, *Agda* = *Agropyron dasystachyum*, *Agtri* = *Agropyron trichophorum*, *Agin* = *Agropyron inermis*, *Bogr* = *Bouteloua gracilis*, *Calo* = *Calmavovifla longifolia*, *Kosc* = *Kochia scoparia*, and *Saka* = *Salsola kali*.

rored in diversity as determined by cover of individual species, depicted graphically in Figure 2. In 1978, evenness of cover distribution among species was greater in irrigated than in nonirrigated plots, leading to a higher calculated overall stand diversity (H') in irrigated plots. By 1979, the second year of irrigation, higher evenness and diversity index values occurred in nonirrigated plots.

Slender wheatgrass was the dominant cool-season species most favored by irrigation. Canopy cover of this species was significantly higher in irrigated than in nonirrigated plots both initially (1978) and in the second year of study (1979) (Table 2). Although it increased in canopy cover from 1978 to 1979 in both irrigated and nonirrigated plots, its rate of increase was greater in irrigated plots (Fig. 3). The stimulation of this species may have been due to both higher vigor of individual species and/or greater distribution, since frequency values were also higher in irrigated plots (Fig. 4). The response of smooth brome grass to irrigation was nearly identical to that of slender wheatgrass, indicating it to be a cool-season species highly responsive to irrigation.

Although cover of the cool-season grass western wheatgrass and legume, yellow sweetclover, were insignificantly higher in irrigated than in nonirrigated plots in 1978, by 1979 they had become significantly stimulated by irrigation (Table 2). Since their patterns of canopy cover and frequency from 1978 to 1979 in irrigated and nonirrigated plots were similar to those of slender wheatgrass and smooth brome grass (Fig. 3 and 4), they must also be considered species highly responsive to irrigation.

Thickspike wheatgrass was a dominant cool-season perennial grass which was significantly stimulated by irrigation in the initial

Table 2. Comparison of mean plant canopy cover and stand diversity (Shannon-Weiner Function) of all irrigated and non-irrigated plots, Soil Amendment Study, Decker, Montana, 1978 and 1979.

| Plant Class | Canopy Cover (%) ³ | | | |
|--|-------------------------------|---------------|-----------|---------------|
| | 1978 | | 1979 | |
| | Irrigated | Non-Irrigated | Irrigated | Non-Irrigated |
| Total perennial grasses | 29.1a | 16.4b | 84.1a | 46.4b |
| Total annual grasses | 0.2 | 0.1 | 0.7 | 0.1 |
| Total shrubs | T | 0 | 0 | 0 |
| Total woody forbs ¹ | 29.1b | 26.5a | 0.8b | 25.5a |
| Total other forbs | 0.9 | 0.4 | 0.9 | 0.4 |
| Total legumes | 6.3 | 4.4 | 30.0a | 15.8b |
| Total trees | 0 | 0 | 0.3 | 0 |
| Plant Species | | | | |
| Perennial grasses: | | | | |
| <i>Agropyron cristatum</i> | 0 | 0 | 1.0 | 0.8 |
| <i>A. dasystachyum</i> | 15.4a | 9.9b | 25.8 | 25.4 |
| <i>A. inermis</i> | 0.3 | 0.9 | 3.5 | 1.7 |
| <i>A. smithii</i> | 2.2 | 1.4 | 6.4a | 3.0b |
| <i>A. spicatum</i> | 0 | 0 | 0 | 0.2 |
| <i>A. trichophorum</i> | 9.3a | 2.6b | 39.4a | 10.0b |
| <i>Bouteloua curtipendula</i> | 1.6 | 0.8 | 5.8 | 5.1 |
| <i>B. gracilis</i> | 0 | 0 | 0 | 0.1 |
| <i>B. gracilis</i> | 2.4a | 1.1b | 1.9 | 2.0 |
| <i>Bromus inermis</i> | 2.5a | 0.9b | 16.2a | 4.7b |
| <i>Calamovilfa longifolia</i> | 0.5 | 0.7 | 0.5b | 1.4a |
| <i>Elymus</i> spp. | 0 | 0 | T | 0 |
| <i>Sporobolus cryptandrus</i> | T | 0 | 0 | 0.1 |
| <i>Stipa comata</i> | 0 | 0 | T | 0 |
| <i>Stipa viridula</i> | T | 0.1 | T | T |
| Annual grasses: | | | | |
| <i>Bromus japonicus</i> | 0.2 | 0.1 | 0.6 | 0.1 |
| <i>B. tectorum</i> | T | T | 0.1 | 0 |
| <i>Echinochloa crusgalli</i> | 0 | T | 0 | 0 |
| <i>Hordeum jubatum</i> | 0 | 0 | T | 0 |
| <i>Setaria viridis</i> | T | 0 | 0 | 0 |
| Legumes: | | | | |
| <i>Astragalus</i> spp. | 0.1 | 0.3 | 0.1 | 0.1 |
| <i>Melilotus officinalis</i> | 6.2 | 4.1 | 29.1a | 15.8b |
| <i>Onobrychis viciifolia</i> | T | 0 | 0.8 | 0 |
| <i>Petalostemon purpureum</i> | 0 | 0 | 0 | 0 |
| Shrubs and Trees: | | | | |
| <i>Atriplex canescens</i> | T | 0 | 0 | 0 |
| <i>Populus deltoides</i> | 0 | 0 | 0.3 | 0 |
| Forbs: | | | | |
| <i>Achillea millefolium</i> | 0 | 0.2 | 0 | 0 |
| <i>Ambrosia psilostachya</i> | 0 | 0.2 | 0.2 | 0.1 |
| <i>Aralium minus</i> | 0 | 0.2 | 0 | 0 |
| <i>Camelina microcarpa</i> | T | 0 | 0 | 0 |
| <i>Chenopodium</i> spp. | 0.1 | T | 0 | 0 |
| <i>Chenopodium album</i> | 0.6 | 0.8 | 0 | 0 |
| <i>Cirsium undulatum</i> | 0 | 0.1 | 0.3 | 0 |
| <i>Helianthus</i> spp. | 0.4 | 0.2 | 0 | 0 |
| <i>Kochia scoparia</i> | 14.1b | 29.0a | 10.8b | 22.5a |
| <i>Lithospermum incisum</i> | 0 | 0 | 0 | 0 |
| <i>Polygonum</i> spp. | 0 | 0.6 | 0 | 0 |
| <i>Salsoala kali</i> | 17.2 | 21.6 | T | 3.3 |
| <i>Stachyrium</i> spp. | 0 | T | T | 0.1 |
| <i>Taraxacum</i> spp. | 0 | 0 | T | 0 |
| <i>Verbena bracteata</i> | 0.1 | T | 0.2 | 0.2 |
| Unknown forbs | T | 0 | 0 | 0 |
| Exposed Bare Ground | 94.9 | 95.0 | 38.3 | 44.6 |
| Ground Litter (Mulch) | 0.1 | T | 56.1 | 50.4 |
| Shannon-Weiner Function (Diversity Index) | | | | |
| | .8861 | .7720 | .8325 | .8957 |

¹ *Chenopodium album* + *Kochia scoparia* + *Salsoala Kali*

² T = trace (<0.12)

³ Canopy cover values within hachured blocks followed by different letters, significantly different at the 5% level.

year of this study (1978) (Table 2). However, by the second year of irrigation (1979) cover was nearly identical (insignificant difference) between irrigated and nonirrigated plots (Table 2, Fig. 3). Furthermore, distribution of this species (frequency, Fig. 4) declined from 1978 to 1979 in irrigated plots while increasing in nonirrigated plots. These data indicate that although thickspike wheatgrass may be stimulated by initial irrigation, continuance of irrigation may have no beneficial effect. The higher rate of cover increase in nonirrigated plots (Fig. 3) and decline in frequency in irrigated plots (Fig. 4) from 1978 to 1979 would suggest a possible detrimental effect of continued irrigation on this species, probably due to increased competition from more responsive species. Pubescent wheatgrass exhibited a canopy cover irrigation response pattern somewhat similar to that of thickspike wheatgrass.

Table 2 (and Figs. 3 and 4) indicate that the initial (1978) promotion of warm-season grass composition by irrigation was primarily due to blue grama, which exhibited significantly higher cover in irrigated plots. From 1978 to 1979, however, cover of this species declined in irrigated and increased in nonirrigated plots, leading to nearly identical cover in the two treatments by 1979. Frequency of blue grama declined substantially in irrigated plots from 1978 to 1979, while remaining nearly constant in nonirrigated plots. These data indicate that although this species was signifi-

cantly stimulated by initial irrigation, continued irrigation exerted definite negative effects. Competitive exclusion of blue grama by cool-season species more responsive to continued irrigation is a logical cause.

Prairie sandreed, another warm-season perennial grass, exhibited low cover in 1978, and no significant differences occurred between irrigated and nonirrigated plots. However, from 1978 to 1979 cover increased substantially in nonirrigated plots, while remaining constant in irrigated plots (Fig. 3). This led to significantly higher cover under nonirrigation in 1979 (Table 2). Frequency of this species was higher in nonirrigated plots both in 1978 and 1979 (Fig. 4).

Data of Table 2 and Figures 3 and 4 indicate that differences in weed composition and growth between irrigated and nonirrigated treatments were primarily related to responses of summercypress, a warm-season annual forb. Summercypress cover was significantly higher in nonirrigated than in irrigated plots in both 1978 and 1979 (Table 2). Although cover declined under both treatments from 1978 to 1979, the rate of decline was far greater in irrigated plots, with negligible cover of this species under irrigation by 1979 (Fig. 3). Furthermore, frequency declined drastically from 1978 to 1979 in irrigated plots while increasing slightly in nonirrigated plots. These data indicate that both vigor and distribution of summercypress were reduced under the irrigation program of this study. This was probably due to increased competition from irrigation-responsive, cool-season, perennial grasses and the legume yellow sweetclover.

Cover and frequency of another warm-season annual weed, Russian thistle, were high and statistically similar in irrigated and nonirrigated treatments in 1978. Cover and frequency declined from 1978 to 1979 in both irrigated and nonirrigated treatments. The rate of 1978-1979 frequency decline was more rapid in irrigated plots (Fig. 4), and 1979 cover by this species under irrigation was negligible (Fig. 3). These data suggest a somewhat similar retardation of this species by irrigation to that for summercypress. However, the lack of significant differences between treatments in 1978 and 1979 shows Russian thistle to have been less specifically reduced by irrigation than summercypress.

Treatment Effects on Below-Ground Biomass

Root biomass data were collected in 1979 only. In interpreting root data it must be recognized that biomass figures represent total live plus dead root material. Thus, these biomass figures cannot be considered estimates of current year (1979) productivity, but are more properly comparative indices of overall 2-year productivity between irrigation treatments.

Figure 5A presents 1979 root biomass data by soil depth increment for irrigated and nonirrigated lots. Total profile root biomass was significantly higher in nonirrigated plots. Fig. 5A shows this to have been due to biomass differences in the topsoil zone. Root biomass at deeper soil depths (i.e., in the subsoil zone) was still higher in nonirrigated plots, but generally not significantly. Percent root distribution data of Figure 5B indicate that a higher proportion of total root biomass occurred in the topsoil zone closest to the soil surface (0-22.5 cm) in irrigated than in nonirrigated plots. Conversely, proportion of total biomass in lower portions of the topsoil and in subsoil zones was higher in nonirrigated plots. These data show that although absolute biomass was much higher in upper portions of the profile in nonirrigated plots, distribution of roots among soil depths was far more even than in irrigated plots. Root distribution in irrigated plots was more markedly skewed toward the shallowest (0-22.5 cm) depth range, presumably due to higher water availability near the soil surface with irrigation.

Figure 5A shows that biomass was significantly higher in the topsoil than in the subsoil depth zones in both irrigated and nonirrigated treatments. The drastic decline in root biomass across the topsoil-soil interface (i.e., from 45.0-67.5 cm to 67.5-90.0 cm depth ranges) was probably partially due to rooting habits of

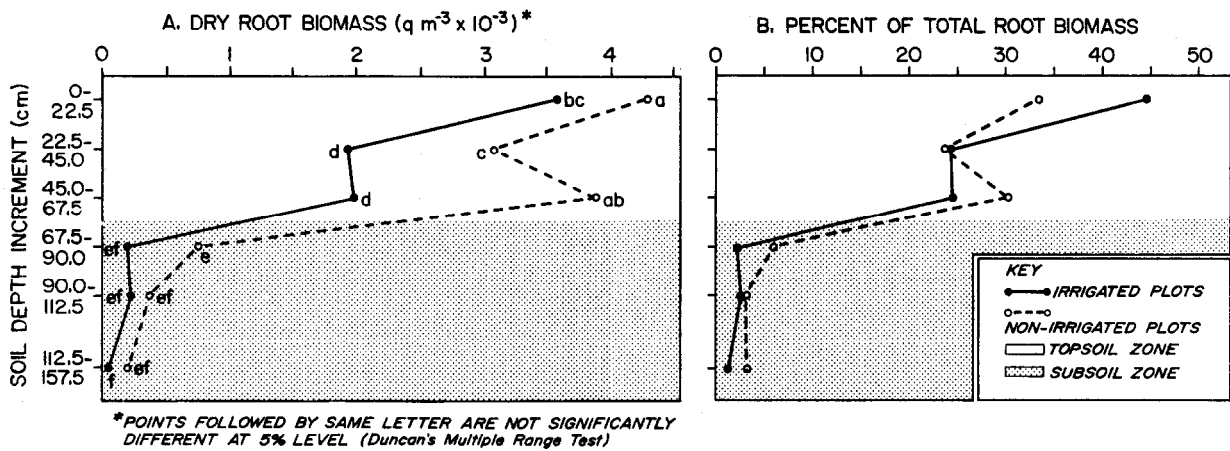


Fig. 5. Graphic portrayal of mean dry root biomass (A) and percent distribution of root biomass (B) by soil depth for irrigated and nonirrigated plots, Soil Amendment-Irrigation Study, Decker, Montana, 1979.

seeded mixed prairie grassland plant species, which generally concentrate most root growth in the upper 2 feet (60 cm) of soil. However, certain inimical physical and chemical characteristics of the sodic-saline subsoil may also have directly affected root penetration and growth. Within the topsoil zone in the nonirrigated treatment, there occurred a significant rise in root biomass from the 22.5–45.0 cm to the 45.0–67.5 cm zone immediately overlaying the sodic subsoil (Fig. 5A). Although this pattern was somewhat mirrored in the irrigated treatment, the subsequent increase was slight and not significant. The relatively high concentration of roots in the topsoil zone immediately above the sodic subsoil in nonirrigated plots may have been related to increased lateral spreading of roots in the former zone in lieu of deeper penetration into the subsoil. This would suggest that increased root distribution at deeper depths may have occurred under non-sodic subsoil conditions.

Discussion

Initial (1978) summer irrigation in this study significantly promoted first-year establishment of seeded perennial grasses in total. The fact that this promotion occurred during an abnormally "wet" year would indicate that even greater benefits might be expected during drier years and/or in more arid regions. Results showing positive effects of irrigation are similar to those of other revegetation studies in this region (Ries et al. 1978, Farmer et al. 1974).

First-year summer irrigation significantly stimulated development of the warm-season perennial grass blue grama. Beneficial effects of supplemental water on this species have been noted in other revegetation trials (Ries et al. 1978) and in certain native range studies (Klages and Ryerson 1965, Detling 1979, Bokhari and Dyer 1973). Promotion of establishment and growth of this and other warm-season species by summer irrigation would be expected due to effects of higher moisture availability in the summer when such species exhibit maximal growth (Perry 1976). Initial summer irrigation may be an effective means of promoting establishment of warm-season species on mined lands in the Northern Great Plains, as suggested by Power (1978). Such species have proved exceptionally difficult to establish in preceding mined land studies in this region (DePuit et al. 1978; DePuit and Coenberg 1979). Ries et al. (1977) noted that use of temporary mined land irrigation effectively lengthens the season of seeding, and that use of irrigation may greatly influence species composition of the established stand—especially in relation to season of seeding. Later (i.e., June–July) seeding dates, made possible by temporary irrigation, could further promote development of warm-season grasses. This possibility is being researched in a concurrent mined land study in southeastern Montana.

Data of this study showed reduced weed development in irri-

gated plots. This indicates that with adequate initial establishment, perennial grasses may out-compete weeds for supplemental irrigation water. Ries et al. (1978) further suggested that weed growth on mined spoils could be reduced by a combination of later seeding date (July) with supplemental irrigation.

Sustained irrigation during the second year of this study (1979) was also accomplished during the summer, and again significantly promoted perennial grass and legume productivity. However, important changes in species composition from 1978 to 1979 occurred which were attributable to effects of prolonged irrigation. Such changes were also noted in certain earlier studies on semiarid rangeland (e.g., Hubbell and Gardner 1944, Klages and Ryerson 1965). Composition by warm-season grasses and less irrigation-responsive cool-season grasses was reduced by competitive inhibition from a limited number of highly responsive cool-season species. This led to reduced evenness of cover distribution among species and lowered stand diversity under irrigation in 1979.

Certain early water spreading studies in Montana and elsewhere in the Northern Plains on mixed western wheatgrass-blue grama ranges (Branson 1956, Houston 1960, Hubbard and Smoliak 1953) found that while total stand productivity was stimulated by supplemental water, stand composition was altered by a strong favoring of western wheatgrass over blue grama. This relationship is certainly supported by second-year (1979) data of the present study.

Stimulation of western wheatgrass and smooth brome by irrigation on rangelands in the Northern Plains region has often been noted (e.g. Hanson et al. 1976). Slender wheatgrass is a short-lived cool-season grass that often matures late enough to be classed as drought intolerant. This species is often found naturally on relatively moist sites on semiarid western rangelands (Morris et al. 1950, Miller et al. 1969) and possess a relatively inextensive root system (Pavlychenko 1937). Its promotion by irrigation in this study is therefore not unexpected.

In their review of water availability effects on root and shoot growth, Peters and Runkles (1967) stated that both the rate and extent of root growth is controlled by water stress. They concluded that both above- and belowground plant growth tend to diminish with increasing water stress, but that root growth is less reduced than shoot growth. Aboveground biomass data of the present study concur with this. However, greater root growth under higher water stress in the nonirrigated treatment would appear to contradict the above generalization. It should be noted that low rates of water infiltration were the rule during irrigation, resulting in frequent surface saturation and ponding. It is possible that excessive soil moisture near the soil surface in irrigated plots may have retarded root growth due to reduced soil aeration (Danielson 1967, Kramer 1969).

A major concern in use of temporary or sustained irrigation as a reclamation practice is response of vegetation after irrigation is

stopped. Klages and Ryerson (1965) noted adverse effects on productivity (and changes in species composition) of a native rangeland plant community 2 years after termination of sustained (3-year) irrigation. Results of a spent oil shale revegetation study in Colorado (Harbert and Berg 1978) indicated a slight reduction in vegetation cover the first year following cessation of temporary (1-year) irrigation. However, this cover reduction was followed by progressively increasing cover in subsequent years.

Plant response following irrigation termination may be largely governed by rooting patterns as affected by supplemental water (Ries and Day 1978). Danielson (1967) noted that deep and/or extensive rooting should be encouraged by varying the specific design (timing, duration, etc.) of irrigation to lessen probability of drought damage to vegetation if irrigation is terminated. The generalization of higher root production relative to shoot production with more xeric soil conditions in grassland ecosystems has often been made (e.g., Peters and Runkles 1967, Weaver 1958). Certain studies have shown increased root-shoot ratios of herbaceous plants with increasing dryness of the soil (Bray 1963; Struick 1965; Struick and Bray 1970), although exceptions to this pattern have been noted (Sims and Singh 1971). Madison and Hagan (1962) noted fewer and shallower roots of bluegrass turf under frequent irrigation.

Data of this study after 2 years of irrigation demonstrated significantly lower total root biomass (and correspondingly lower belowground:aboveground plant biomass ratios) in irrigated than in nonirrigated plots. Furthermore, a higher proportion of roots occurred in shallowest soil depths under irrigation. Whether or not this reduced, shallower root development with sustained irrigation will result in decreased ultimate plant survival and productivity will only be determinable after sampling in future years when irrigation has been terminated. It may well be, as suggested earlier, that shorter irrigation durations (i.e. one summer season or less) will be more desirable in terms of achievement of revegetation goals.

The sudden drastic decline in root biomass across the topsoil:subsoil interface in the present study was somewhat atypical in its degree. It may have been related to the more compacted condition and/or slightly higher clay contents in subsoil, which would tend to inhibit root penetration. A more likely explanation involves effects of the higher sodium concentration in the subsoil zone. Effects of excess soil salts in inhibition of root elongation and hastening of root maturation have long been noted (Kramer 1969).

Conclusions

While it is recognized that much additional research is required to fully evaluate the use of irrigation as a practice in revegetating mined lands in semiarid regions, results of this study allow the following conclusions to be drawn:

- (1) One year of supplemental summer irrigation significantly stimulated first-year productivity of seeded perennial grasses, promoted warm-season perennial grass development, and increased stand diversity. Significantly stimulated species included thick-spike wheatgrass, slender wheatgrass, smooth bromegrass, and blue grama. Initial summer irrigation for establishment can thus be tentatively recommended if reestablishment of a diverse and productive plant community is a reclamation goal.
- (2) Sustained (2-year) summer irrigation significantly promoted productivity of the total stand, perennial grasses and legumes. However, evenness of cover distribution among seeded species was reduced as highly irrigation-responsive species competitively inhibited less responsive species, leading to a reduction in stand diversity. Species highly stimulated by 2 years of irrigation were exclusively cool-season: slender wheatgrass, western wheatgrass, smooth bromegrass, and yellow sweetclover. The warm-season species prairie sandreed and blue grama were especially retarded by 2 years of irrigation. Sustained irrigation can only be recommended in terms of increased total aboveground productivity.
- (3) Irrigation significantly depressed productivity of invading

warm-season annual weeds, which were competitively inhibited by stimulated seeded perennial grasses. Summercypress was curtailed to the greatest extent under irrigation, although Russian thistle was also reduced. Irrigation may have utility in terms of weed control.

(4) Two years of irrigation caused development of significantly reduced, more shallow root systems and lower belowground:aboveground biomass ratios than those under nonirrigation. Effects of termination of irrigation on vegetation characteristics in relation to these root growth patterns must be assessed by future measurements.

(5) Root biomass was significantly higher in the applied topsoil zone (0-57.5 cm) than in the sodic subsoil zone, the former of which contained 88 to 94% of all root material. Lack of deeper root penetration into the subsoil may have been partially attributable to normal root distribution patterns of the rangeland plant species, but was probably also affected by the sodic condition of the subsoil.

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