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Survival and Growth of Containerized Native Juniper (*Juniperus monosperma*) on Surface-mined Lands in New Mexico

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ABSTRACT

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Containerized native juniper (*Juniperus monosperma* (Engelm.) Sarg.) were planted on three northern New Mexico mine spoils to evaluate cultural treatments including planting date, mulch, drip irrigation, fertilizer regimes and seedling protection. Two years after planting, survival rates of 72%, 70% and 99% were observed for the best treatments at each planting site. July was the superior planting date for the high elevation site and August was superior for the low elevation site. Drip irrigation proved superior to mulch, and triple-superphosphate was significantly better than slow-release fertilizer (Osmocote 18-6-12). Plastic mesh was found to be essential and more effective for rodent protection than animal repellant.

INTRODUCTION

By the year 2000, coal strip-mining in the United States will alter more than 81,000 ha west of the 100th meridian. Revegetation of mined sites in the Southwest is especially difficult because of irregular rainfall, wide temperature extremes, animal depredation and rugged topography (Schubert, 1977). In New Mexico, topography of surface-mined land ranges from flat to rolling hills. Many areas include badlands formed by steep-walled gullies separated by rugged rock ridges. Revegetation can reduce erosion and restore aesthetic values.

Pinon-juniper woodlands occur on 24.3 million ha in Nevada, Utah, Colorado, Arizona and New Mexico and are commonly disturbed by mining (Nat. Acad. Sci., 1973). Although the pinon-juniper type was once frequently destroyed to increase forage production, most land managers now want wood-

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lands conserved and managed for multiple products and uses (Jensen, 1972; Lanner, 1977; Short and McCulloch, 1977).

In the Southwest, native plant species often result in better establishment and more rapid growth than can be achieved with introduced species (Balzer, 1975). Establishing native pinon-juniper woodlands speeds the progression from early seral stage vegetation (annuals and herbaceous perennials) to longer-lived woody species (Wagner et al., 1978).

Revegetation programs do not usually include native western junipers because of unreliable seed germination in nurseries. However, O'Brien and Fisher (1980) recently demonstrated the feasibility of large-scale production of containerized juniper seedlings. This paper focuses on the step that now needs attention, development of juniper revegetation techniques.

Methods for woody plant revegetation in the Southwest

In New Mexico, the biggest problem with spoil rehabilitation may be moisture availability (Aldon and Springfield, 1973). Cultivation, certain types of mulches and drip irrigation can improve infiltration. Cultivation also incorporates organic matter, breaks the surface crust, promotes aeration and helps roots penetrate heavy soils (USDA Forest Service, 1979).

Mulches often improve tree and shrub survival (Springfield, 1972; Carpenter et al., 1978). The ideal mulch in arid and semiarid climates should:
(1) facilitate infiltration and minimize evaporation,
(2) decrease soil temperature extremes,
(3) control wind and water erosion and
(4) be long lasting, inexpensive and easy to apply.
No single material meets these criteria; therefore, it is important to tailor a mulch to site and species. Grass hay or straw is unusually applied at a rate of about 3360 kg ha^{-1}, and is a common standard against which other materials can be evaluated (Berg, 1972).

The effective life of straw and hay mulches varies with climatic conditions, but is usually about one year. Wood residues last longer, are easier to apply, carry no weed seeds and resist wind movement (USDA Forest Service, 1979). Wood chips are often applied to steep slopes (20% or more) where straw mulches are less effective in preventing erosion.

Incorporating straw into soil to a depth of 5 cm retards wind removal. Applied too heavily, a thick cover of organic mulch causes considerable water loss by intercepting precipitation and subsequent evaporation (Hodder, 1974). The incorporating of straw mulch greatly increases the organic matter content of relatively sterile spoil material. Organic matter also increases soil porosity and aggregation (Hodder, 1974).

Supplemental irrigation has significantly increased survival of woody plants in western revegetation plots (Lang, 1971). Drip irrigation resulted in excellent first year survival of *Juniperus scopulorum* (Bjugstad, 1984), and reduced mortality of *Atriplex canescens* (Aldon, 1978). Directed watering reduces weed problems, soil erosion and the total volume of water used. Portable systems can be designed to meet the needs of remote sites (Garcia, 1979).

The two elements most commonly deficient on disturbed land are nitrogen (N) and phosphorus (P) (Berg, 1972). Transplants often fail because soil is so deficient in P that plants do not extend their roots enough to exploit an adequate moisture supply (USDA Forest Service, 1979). Top soils may contain adequate N, but subsoils and geologic materials are usually deficient (USDA Forest Service, 1979).

Fertilizing transplants is generally discouraged because of possible salt injury. Slow-release fertilizers may be less injurious and can provide nutrients for many months. Because release rate is temperature dependent, more nutrients are available when higher soil temperatures are conducive to root growth. Transplant root growth can be greatly increased by providing slow-release fertilizer and superphosphate (Whitcomb, 1977). Conventional fertilizers have given erratic results but, in Montana, they nearly doubled shrub growth and increased root production on a mine spoil (Hodder, 1974). Soil toxicity problems are usually manageable because most New Mexico coals are low in sulfur and iron, and high concentrations of acid water are not produced (Kottlowski and Beaumont, 1971).

Containerization reduces transplant shock and permits planting when summer rains fall in the Southwest. Preliminary studies in northern New Mexico indicate that planting container seedlings in late August and September results in less survival and growth than in July plantings (Fisher and Neumann, personal communication, 1984). For some conifer species, planting in late summer and fall apparently does not allow adequate root development before low soil temperatures reduce further root extension.

Steps are often required to protect transplants from animal browsing. Because poisons, repellents and trapping are either hazardous or unreliable, lightweight polypropylene netting or meshed tubes that physically protect each tree have been developed and appear effective (Campbell, 1969). Tubes are marketed in a variety of gauges and dimensions, and they photodegrade in the field in three to five years.

RESEARCH OBJECTIVES

Research began in cooperation with the US Forest Service in 1981 to determine methods for routine reforestation of junipers on mined sites. Objectives were to relate planting date to growth and survival, and to determine benefits from drip irrigation, mulch, rodent protection and fertilization. Specific research objectives were tailored to each of three test sites in compliance with the most urgent needs and the available resources.

RESULTS

Experiment 1 — York Canyon Mine

Site description

The study site is within the Raton Coal Field in rugged, dissected plateau country. It is 98 km west of Raton, at an elevation of 2194 m. The landscape is mountainous and ranges from gentle to steep slopes. Many west- to northwest-trending canyons extend into the plateau. Mineable lenses in the Raton formation range from 1 to 4 m thick. Coal is extracted by underground and surface mining.

Soils are developing in parent material weathered from sedimentary rocks dominated by sandstone and shale. Good stands of native vegetation occur on all sites except those with shallow soil. Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) are located on north facing slopes; pinon-juniper woodlands reside on the more xeric sites.

The Raton Coal Field receives 360 to 460 mm of annual precipitation (Gould et al., 1975). Winter months are dry, averaging 20 mm per month from November through March. July and August are the wettest months, averaging 76 mm each, and the remaining months receive slightly more than 25 mm each. According to the Kaiser Steel weather records, 280 mm of precipitation were received in 1980 at the mine site. Temperatures averaged $-5°C$ (23°F) in December and January, and 17°C (63°F) in July. Summer maximum temperatures can reach 35°C (95°F).

Materials and methods

The experimental site is level to moderately sloping with 31 to 51 cm of topsoil covering spoil material. Soil pH ranges from 8.2 to 8.8. A split-plot randomized block design with six replications was used. Main plots were drip irrigation and straw mulch. Six subplots (three planting dates $\times$ two fertilizer regimes) were randomly assigned within each main plot. Planting dates were July and August 1981, and May 1982. Fertilizer treatments were 20 kg m^{-3} Osmocote (18-6-12) slow-release fertilizer plus 11 kg m^{-3} triple-superphosphate (0-46-0) mixed with soil in the planting hole, versus no supplemental fertilizer. Each subplot contained 38 seedlings spaced 0.5 m $\times$ 0.9 m. The 13-month-old seedlings were produced in 160-cm^3 Ray Leach tubes.

The study site was roto-tilled to a depth of 10 cm before planting to improve moisture infiltration and remove weeds. Seedlings were auger planted. Straw mulch was spread by hand and incorporated into the top 5 to 10 cm of soil to avoid wind displacement. The drip system supplied each seedling with enough moisture to wet the soil around it to a depth of 30 cm. Drip plots were irrigated bi-monthly from May through September. Weeds were controlled by hand cultivation.

Results

July planting resulted in the highest survival (73%) and was statistically superior ($P<0.05$) to May at 55% and August at 48%. Survival in all treatments decreased little from the 5th to the 15th month after planting, suggesting planting success or failure may be determined one year or less after establishment.

The drip/no fertilizer subtreatment was significantly better than all other subtreatments for each planting date, except August where it was equivalent to mulch/no fertilizer (Fig. 1). Drip-irrigated plots (84% survival) were superior to mulched plots (64% survival) for the July planting.

Fertilization significantly increased seedling mortality within each planting date. Respective survivals for fertilized versus unfertilized plots were 22% versus 88% for May, 62% versus 86% for July, and 3% versus 95% for August.

Experiment 2 — McKinley Mine

Site description

Operated by Pittsburg and Midway Coal Company, the McKinley Mine is in northwestern New Mexico near Gallup. The mine is situated within the southeastern end of the Great Basin desert shrub region, dominated mostly by big sagebrush. Pinon (*Pinus edulis*) and one-seed juniper are co-dominants on slopes and ridges. Most of the area is composed of sandstone of the Mesa Verde group of the upper Cretaceous period (Wagner et al., 1978). The mine is at an elevation of 2070 m and receives 280 to 380 mm of annual precipitation.

The study site is on level land within the confines of the North McKinley mine. Top soil depth ranges from 20 to 30 cm, and the site has been successfully reseeded with grasses within three to five years.

Materials and methods

The experiment included 12 treatments (three planting dates × two fertilizer regimes × two rodent protection treatments). Planting dates were August, September and November 1982. Fertilizer regimes were 3.6 kg m^{-3} Osmocote (18-

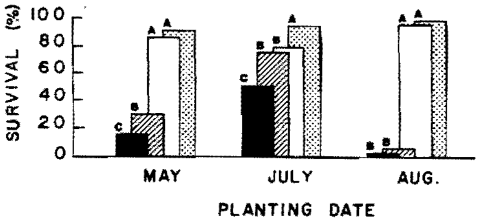

Fig. 1. Fifteen-month survival at the York Canyon Mine site. Treatments are mulch/fertilizer (solid), drip irrigation/fertilizer (striped), mulch/no fertilizer (open) and drip irrigation/no fertilizer (dotted). Values with the same letter are not significantly different ($P<0.05$).

6-12) plus 7.1 kg m^{-3} triple-superphosphate (0-46-0)) incorporated into planting hole soil versus no supplemental fertilizer. Rodent protection included rigid polypropylene mesh tubes (10 cm × 40 cm) versus no protection. A completely randomized block experimental design with six replications was used. The experimental unit was 20 juniper seedlings planted 0.5 m apart within rows on contours separated by 1 m. Seedlings used in this study were grown in 1456 cm^3 (90 in^3) paraffin-coated containers.

Results

Two years after planting, survival in August plots (47%) was significantly greater ($P < 0.05$) than that in September (16%) and November (14%) plots. There were no significant differences in survival between the September and November planting dates. The mesh/no fertilizer subtreatment resulted in significantly better survival than all other subtreatments across all planting dates, except September where it was equivalent to mesh/fertilizer (Fig. 2).

Respective survivals for mesh-protected versus unprotected plots were 59% versus 35% for August, 25% versus 9% for September, and 20% versus 8% for November. Differences were significant in September and November.

Fertilizer had no impact on survival in August- and September-planted plots, but reduced survival in November plots from 21% for unfertilized trees to 7% for fertilized trees.

Experiment 3 — Zia Mine

Site description

Located within the Cibola National Forest near Grants, New Mexico, the Zia Mine is at an elevation of 2194 m on La Jora Mesa. The test site is surrounded by pinon-juniper woodland and is an abandoned uranium spoil maintained by the Zia Mine. Annual precipitation is 130 to 230 mm, and soil pH is about 8. The soil is derived from Dakota sandstone, a prominent mesa soil in the area (Griswold, 1971).

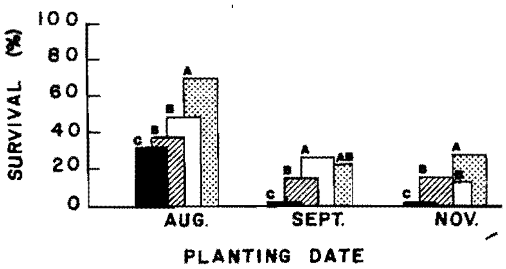

Fig. 2. June, 1984 survival at the McKinley Mine site. Treatments are no protection/fertilizer (solid), no protection/no fertilizer (striped), mesh protection/fertilizer (open) and mesh protection/no fertilizer (dotted). Values with the same letter are not significantly different ($P < 0.05$).

Materials and methods

Seedlings were grown for nine months in 160-cm^3 Ray Leach containers before being planted at the site in September 1983. Trees were spaced 0.5 m × 0.5 m in 20-tree rectangular plots. The nine treatments (Table 1) were replicated four times in a randomized complete block design.

The Zia Mine test evaluated slow-release (Osmocote 18-6-12) and 0-46-0 triple-superphosphate fertilizers along with wood chip mulch or the lack of it. Fertilizers were applied in shallow pockets — about 6 cm deep and 10 cm to each side of the trees. All seedlings, except those in one of the controls (treatment 9), were protected from rodents with a lightweight plastic mesh that was much less rigid than that used at the McKinley mine and could be cut to the desired length and attached to the trees before planting.

Results

Treatments 2 and 3 were superior ($P<0.01$) to treatments 5 and 9 (Table 1). Mulched plots showed significantly higher ($P<0.05$) survival (96%) than the non-mulched plots (89%) Wood chips less than 2.5 cm^2 were often blown from the site by wind.

Although survival was 85% for treatment 9, nearly all seedlings in that treatment had been severely browsed by rodents. The plastic mesh used in all other treatments protected the trees from serious animal damage.

DISCUSSION AND CONCLUSIONS

Containerized seedlings can be planted with satisfactory to excellent success on spoil banks. Planting date proved to be important because environmental

TABLE 1

One-year survivals for treatments at the Zia Mine site

Number	Mulch	Fertilizer [(g/tree) type]	Survival (%)
1	chips	none	92.5 AB[1]
2	chips	(21) TSP[2]	98.8 A
3	chips	(10.1) SRF[3] + (21) TSP	97.5 A
4	chips	(20.2) SRF + (21) TSP	93.8 AB
5	none	(21) TSP	83.8 B
6	none	(10.1) SRF + (21) TSP	88.8 AB
7	none	(20.2)SRF + (21)TSP	95.0 AB
8	none	none	88.8 AB
9[4]	none	none	85.0 B

[1]Values with the same letter are not significantly different at $P=0.05$.
[2]Triple-superphosphate (0-46-0).
[3]Slow release fertilizer (Osmocote 18-6-12).
[4]Unlike all other treatments, treatment 9 lacked rodent protection.

conditions changed from one site to the next. July was better for the higher elevation and more mesic site (York Canyon); August was the superior planting date for the lower elevation and more xeric site (McKinley). In both cases, it was critical that trees be planted after the June drought.

Dryland plantings in arid regions require some method, like organic mulching, to conserve soil moisture. Mulched trees had survival rates better than those of unmulched trees, and often equivalent to those of irrigated trees. When mulching with wood chips, chips at least 2.5 cm square are required to prevent blowing. Drip irrigation increases survival over mulching, and may be required on extremely harsh sites.

Fertilization can provide a benefit, especially if combined with irrigation. Fertilizer should be applied in shallow pockets near the tree, not directly into the planting hole.

Seedling protectors are essential for success on sites where rodent populations are substantial. The lighter weight, smaller gauge (six mil) mesh used at the Zia site is recommended over rigid mesh (50 mil) tubes because the former is less expensive, can be attached before going to the field, stays in place longer and photodegrades in about one year. Twelve mil mesh is available and would extend protection beyond one year.

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