Factors affecting establishment of one-seed juniper (*Juniperus monosperma*) on surface-mined lands in New Mexico[1]

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Containerized one-seed juniper (*Juniperus monosperma* (Engelm.) Sarg.) were planted on two northern New Mexico mine spoils to evaluate effects of establishment methods and postplanting site conditions on seedling survival and growth. Establishment factors included planting date, mulch, fertilizer regimes, and seedling protection. Wood chip mulch and animal protection provided by rigid plastic mesh tubes or plastic netting improved juniper survival, growth, or both, depending on the study. The forms and rates of fertilizers tested provided no benefits and sometimes decreased survival. Juniper fertilization at planting stimulated the growth of reseeded grass and resulted in greater competition. Perennial weeds that invaded a mechanically cleared planting site also reduced juniper growth and survival. Results point to the need to consider the adverse effects associated with fertilization, time of planting, and order of grass and juniper revegetation.

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Les effets des méthodes d'introduction et des conditions de station après plantation, sur la survie et la croissance, furent évalués avec des semis individuels de Genévrier (*Juniperus monosperma* (Engelm.) Sarg.) produits en récipients et plantés à deux endroits du nord du Nouveau-Mexique sur des résidus miniers. Les facteurs liés à l'introduction comprenaient la date de plantation, l'utilisation d'un paillis, le régime de fertilisation et la protection des semis. L'utilisation de copeaux de bois comme paillis et de tubes rigides en plastique perforé ou de treillis de plastique contre les animaux a amélioré la survie du Genévrier ou sa croissance, ou les deux, selon l'étude. Les types et les taux de fertilisant testés n'ont procuré aucun avantage et ont quelquefois diminué de taux de survie. La fertilisation du Genévrier au moment de la plantation a stimulé la croissance des herbes réintroduites et provoqué une plus forte compétition. Les mauvaises herbes pérennes qui ont envahi le site de la plantation nettoyé mécaniquement ont aussi réduit la croissance et la survie du Genévrier. Les résultats font ressortir la nécessité de tenir compte des effets négatifs de la fertilisation au moment de la plantation et de l'ordre dans lequel sont réintroduits la végétation herbacée et le Genévrier.

[Traduit par la revue]

Introduction

In the western United States, pinyon–juniper woodlands are surface disturbed to extract minerals or cleared to construct major utility power lines across long distances. To restore these disturbed lands to their natural vegetation type, companies must successfully address the site conditions, making revegetation difficult in the arid southwest. Specific factors that threaten plant establishment include irregular rainfall, wide temperature extremes, animal depredation, and weed competition (Schubert 1977). Using native plants to reclaim these lands usually results in better establishment and more rapid growth than can be achieved with introduced species (Balzer 1975). The use of woody native plants also speeds the progression from early seral stage vegetation (annuals and herbaceous perennials) to longer lived woody species (Wagner et al. 1978).

Research was begun in cooperation with the USDA Forest Service in 1981 to determine routine methods for producing one-seed juniper (*Juniperus monosperma*) container planting stock and for revegetating mined woodlands. Thus far, reliable seed germination treatments have been developed (Fisher et al. 1986, 1987) making large-scale juniper seedling production a reality. Also, the effects of various revegetation techniques on early transplant survival have been reported (Fisher et al. 1986). However, the growth rate of native juniper transplants on disturbed sites in the western United States has not been reported. The literature is also devoid of information on juniper transplant response to planting site conditions that occur after site management has ceased. Conceivably, transplants can be adversely impacted by factors such as vegetative competition that were effectively, but only temporarily, eliminated by site preparation techniques.

The aim of our research was to determine transplant survival and growth 5 years after planting, and to identify the principal factors affecting establishment success. More specifically, the goal was to relate survival and growth to planting date, wood chip mulch, animal protection, fertilization, and changes in site conditions after planting. The potential value of these and related treatments for restoring south-

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TABLE 1. *Juniperus monosperma* survival and height response to treatments applied in experiment 1 at the Zia site

Treatment No.	Protection[b]	Mulch	Fertilizer[a] (g/tree)	Survival (%)	Height (cm)
1	PMT	Chips	SRF (10)	58	45.2
2	PMT	Chips	TSP (21)	70	45.8
3	PMT	Chips	None	55	47.4
4	PMT	None	SRF (10)	39	38.0
5	PMT	None	TSP (21)	62	42.2
6	PMT	None	None	64	43.3
7	None	Chips	SRF (10)	18	17.2
8	None	Chips	TSP (21)	6	20.6
9	None	Chips	None	17	16.1
10	None	None	SRF (10)	7	23.9
11	None	None	TSP (21)	20	18.1
12	None	None	None	18	19.5

[a]SRF, slow release fertilizer (Osmocote 18:6:12, N-P-K); TSP, triple-superphosphate 0:46:0 (N-P-K).
[b]PMT, polyethylene mesh tube.

TABLE 2. Analysis of variance of survival and height responses to treatments applied in experiment 1

	All treatments			Protected treatments		
	df	Survival MS (%)[a]	Height MS (cm)	df	Survival MS (%)	Height MS (cm)
Blocks	4	0.58	2 577	4	0.032	4418
Protection (P)	1	3.62***	36 302***	—	—	—
Mulch (M)	1	0.014	660	1	0.027	1749*
Fertilizer (F)	2	0.060	197	2	0.007	292
M×F	2	0.076	7	2	0.050	78
P×M	1	0.032	54	—	—	—
P×F	2	0.049	29	—	—	—
P×M×F	2	0.037	90	—	—	—
Experimental error[b]	44	0.040	359	20	0.033	443
Plot error[c]	1140			570		-

NOTE: ***, significant at the 0.0001 level; *, significant at the 0.05 level; MS values without an asterisk are not significant at the 0.05 level.
[a]Analysis was conducted with arcsine-transformed plot survival data.
[b]Block × treatment.
[c]Because of missing values, for height actual df = 441 (all treatments) and 347 (protected only). For plot survival df = 59 (all treatments) and 29 (protected only).

western woodlands has been reviewed in a recent paper (Fisher et al. 1986). Experimental treatments were tailored to two test sites to address the most urgent research needs at each site with the resources available.

Materials and methods

Experiments 1 and 2: 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 pinyon–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). Experiments 1 and 2 were conducted on this site within a 0.25-ha area from which all standing vegetation was mechanically cleared before planting.

Experiment 1—The study was a 3×2×2 factorial arrangement of 12 treatments (Table 1) in a randomized complete block design with four replications. The design tested three fertilizer treatments, two levels of seedling protection (with and without Vexar tubes[2]), and two levels of wood chip mulch (with and without). Each treatment plot contained 20 seedlings spaced 0.5 m apart within two parallel rows spaced 0.5 m apart. Seedlings used in this study were grown for 12 months in 1456-cm^3 paraffin-coated containers.

Seedlings were auger planted August 18, 1982. Ten grams of Osmocote 18:6:12 (N-P-K) slow release fertilizer (9-month formulation) or 21 g of triple-superphosphate (TSP) 0:46:0 was mixed with the soil that was returned to the planting hole. Vexar tubes were installed as described by Campbell (1969). Weeds were sparse at planting time and were not abundant when seedling survival and height growth were recorded September 15, 1987, approximately 5 years after planting.

For experiments 1-3 (following), survival data were transformed using arcsines before ANOVAs were conducted because data were skewed (Steel and Torrie 1980). General linear models procedures of SAS (SAS Institute Inc., Cary, NC) were used to perform all

[2]Use of trade or company name is for the benefit of the reader, and does not constitute endorsement by the United States Department of Agriculture.

TABLE 3. *Juniperus monosperma* survival and height response to treatments applied in experiment 2 at the Zia site

Treatment			% survival		Results 4 years after planting			
No.	Mulch	Fertilizer[a] (g/tree)	1 year[b]	4 years[c]	Height (cm)	Crown width (cm)	Stem diam. (mm)[d]	Weed cover (%)
1	Chips	None	92.5*ab*	70.0 (10.4)	33.7	24.1	13.4	31.0
2	Chips	TSP(21)	98.8*a*	73.8 (22.9)	34.3	24.4	13.7	30.8
3	Chips	SRF(10.1)+TSP(21)	97.5*a*	85.0 (7.4)	34.5	23.4	13.5	30.0
4	Chips	SRF(20.2)+TSP(21)	93.8*ab*	85.0 (6.2)	30.6	22.8	12.2	26.8
5	None	TSP(21)	83.8*b*	46.3 (16.8)	33.0	22.9	10.8	46.0
6	None	SRF(10.1)+TSP(21)	88.8*ab*	63.8 (16.1)	32.0	22.7	13.0	34.8
7	None	SRF(20.2)+TSP(21)	95.0*ab*	70.0 (9.4)	31.7	21.8	13.1	47.3
8	None	None	88.8*ab*	68.8 (10.9)	32.1	24.9	13.1	24.5
9	None	None[e]	85.0*b*	78.8 (2.4)	18.3	16.8	10.0	56.5

[a]TSP, triple-superphosphate 0:46:0 (N-P-K); SRF, slow release fertilizer (Osmocote 18:6:12, N-P-K).
[b]Values followed by different letters are significantly different at the 0.05 level. Data are from Fisher et al. (1986).
[c]Values in parentheses represent 1 SE of the treatment means (four replications).
[d]Unlike other treatment mean values, stem basal diameter means are based on two rather than four replications.
[e]Unlike other treatments, treatment 9 lacked animal protection.

TABLE 4. Analysis of variance of treatment effects on survival and growth of *Juniperus monosperma* 4 years after planting at the Zia site (experiment 2)

		MS				
	df	Survival (%)[a]	Height (cm)	Crown width (cm)	df	MS stem caliper (mm)
Blocks	3	0.85	256.8	613.2	1	31.8
Factorial	7				7	
Mulch (M)	1	0.55*	83.6	25.1	1	34.6
Fertilizer (F)	3	0.05	86.0	34.4	3	14.9
M×F	3	0.10	99.2	77.9	3	33.6
3 (T1,T8) vs. (T2–T7)	1	0.03	33.6	2.3	1	26.5
2 (T2,T5) vs. (T3,T4,T6,T7)	1	0.09	35.4	3.2	1	4.5
T3,T6 vs. T4,T7	1	0.03	189.0	97.8	1	13.7
Protection (T9 vs. all)[b]	1	0.02	10 657.0***	2338.7***	1	245.9**
Experimental error[c]	24	0.09	161.2	103.9	7	9.2
Plot error[d]	684				342	

NOTE: ***, significant at the 0.0001 level; **, significant at the 0.001 level; *, significant at the 0.05 level; MS values without an asterisk are not significant at the 0.05 level.
[a]Analysis was conducted with arcsine-transformed survival date.
[b]Compares treatment 9 with treatments 1–8 in balanced factorial.
[c]Block × treatment.
[d]Because of missing values or unequal sampling, actual df = 512 for height and crown width and 284 for stem caliper. For plot survival df = 31.

analysis of variance tests and regressions. Given some imbalance due to mortality, a least squares analysis was used to calculate type III sums of squares in each study. Models assumed that effects were fixed in each of the three studies.

Experiment 2 — Seedlings were grown for 9 months in 160-cm^3 Ray Leach containers before being planted at the site in September 1983. Trees were spaced 0.5 × 0.5 m in 20-tree rectangular plots. A 2 × 4 factorial experiment was conducted in a randomized complete block design. Two mulch levels (with and without) and four fertilizer treatments (Table 3) were evaluated. The factorial was augmented by the addition of treatment 9, providing no rodent protection. All other treatments were protected from rodents with a lightweight plastic mesh that could be cut to the desired length and attached to the trees before planting. The nine treatments were replicated four times.

Planned contrasts compared protection(T1–T8) versus no protection (T9); fertilizer (T2–T7) versus no fertilizer (T1,T8); TSP with (T3,T4,T6,T7) and without (T2,T5) Osmocote (18:6:12); and 10.1 g/tree (T3,T6) versus 20.2 g/tree Osmocote (T4,T7), both with TSP.

Fertilizers were applied at the rates shown in Table 3 in shallow pockets, about 6 cm deep and 10 cm to each side of the trees. Fifth-year seedling survival and growth were recorded September 15, 1987. Growth parameters measured included height, crown width at point of greatest spread, and stem basal diameter at ground level. The line intercept method (Greig-Smith 1957) was used to determine the proportion of ground cover area occupied by plant canopy. The competing vegetation intercepting a single 4.8-m line transect over the center of the entire plot was recorded by species.

Experiment 3: McKinley Mine

Site description

Operated by Pittsburg and Midway Coal Company, the McKinley Mine is in northwestern New Mexico near Gallup. The mine is within the southeastern end of the Great Basin desert shrub region, dominated mostly by big sagebrush. Pinyon (*Pinus edulis*)

TABLE 5. Canopy cover and relative abundance of perennial weeds present at the Zia site on September 15, 1987, 4 years after planting (experiment 2)

	Ground area occupied (%)
Gutierrezia sarothrae (Pursh) Britt. & Rusby (broom snakeweed)	13.0
Oryzopsis hymenoides (Roem. & Schult.) Ricker (Indian ricegrass)	7.0
Ceratoides lanata (Pursh) J.T. Howell (winterfat)	4.0
Heterotheca villosa (Pursh) Shinners (hairy goldaster)	3.0
Sphaeralcea coccinea (Pursh) Rydb. (scarlet globemallow)	2.0
Cirsium arvense (L.) Scop. (Canada thistle)	2.0
Bouteloua eriopoda (Torr.) Torr. (black grama)	0.5
Sporobolus asper (Michx.) Kunth (tall dropseed)	0.5
Total	32.0

and one-seed juniper are codominants on slopes and ridges. Most of the area is composed of sandstone of the Mesa Verde group of the Late Cretaceous period (Wagner et al. 1978). The mine is at an elevation of 2070 m and receives 280 to 380 mm of precipitation annually. The study site is on level land within the confines of the McKinley Mine, North. Topsoil depth ranges from 20 to 30 cm.

Experiment 3 involved a 3×2×2 factorial in a randomized complete block design. The 12 treatments (Table 6) were replicated six times and included three planting dates × two fertilizer regimes × two rodent protection treatments. Planting dates were August, September, and November 1982. Fertilizer regimes were 10.1 g Osmocote 18:6:12 plus 21 g TSP 0:46:0 incorporated into the planting hole soil versus no supplemental fertilizer. Table 6 shows fertilizer rates on a per tree basis. Rodent protection included rigid polypropylene mesh tubes (10 × 40 cm) versus no protection. 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 12 months in 1456-cm^3 paraffin-coated containers.

Five-year survival and growth data were recorded September 14, 1987. Growth parameters were measured as described in experiment 2. The line intercept method was used as described in experiment 2 to determine the proportion of ground cover occupied by individual competing plant species along a 4.4-m transect. Vegetation that existed on the experimental area in 1982 through 1987 was primarily fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.) and western wheatgrass (*Agropyron smithii* Rydb.). Seed of these two species was sown 3 years before planting. The grass was well established in 1982, but the shrub was less than 0.25 m tall. All standing vegetation within 0.5 m of trees was mechanically cleared during the planting operation. By 1987, some shrubs exceeded 1.5 m in height.

Western wheatgrass is a cool season, perennial, sod-forming grass (Gay and Dwyer 1984) routinely used for reclamation in the northwestern section of New Mexico. Fourwing saltbush occurs in every region of the state on grassy uplands, sandy deserts, and alkali flats. This evergreen shrub can reach a height of 7.5 m, and its roots have been found to penetrate soil to 6 m (Stubbendieck et al. 1986). This drought-tolerant species is one of the most preferred rangeland shrubs of the southwest (Gay and Dyer 1984) and is used in reseeding deteriorated ranges and disturbed sites.

Results

Zia Mine

Experiment 1

Protection greatly improved seedling survival and height growth (Tables 1 and 2). However, neither seedling survival nor height was influenced by mulch or fertilizer main effects, or by interactions among protection, mulch, and fertilization treatments (Table 2). When the analysis was restricted to only protected seedlings, survival and growth did not differ between fertilized and nonfertilized plots. Mulch increased the height growth of protected seedlings 12% but did not influence their survival (Table 2). Among protected seedlings, height was not affected by mulch × fertilizer interaction. In these and subsequent statements, the reported absence of treatment effects means no significant effects were detected at the 0.05 level.

The numerous pack rat excavations and rabbit droppings observed in the immediate area indicated that small mammals were abundant and probably caused the shoot damage recorded.

Experiment 2

Overall, seedling survival (Table 3) decreased from 91.5%, 1 year after planting (Fisher et al. 1986) to 71.3% after 4 years. Essentially, 1 year after planting, survival exceeded 92% among protected seedlings. Survival was greater in mulched plots (96%) than in nonmulched plots (89%) after 1 year and remained higher in mulched (78.5%) than in nonmulched (62.2%) plots after 4 years (Table 4). Seedling growth was not affected by the mulch–fertilizer interaction (Table 4). Protection increased height, crown spread, and basal stem caliper but had no effect on survival (Table 4). Fertilization had no effect on survival or growth, as examined within planned contrasts. More specifically, seedling growth was similar after fertilization with either TSP (TSP 0:46:0) alone or a formulation including both TSP and the slow-release fertilizer. Also, seedling growth did not respond differently to the two levels of slow-release fertilizer, both applied with the same level of TSP.

Eight perennial plant species (Table 5) had invaded juniper plots since planting. A correlation analysis was used to determine the relation between weed competition and juniper survival and growth. The analysis employed plot sums for weed cover, crown width, height, and stem caliper and plot mean values for each growth variable. The matrix also included percent survival and mean canopy volume. The equation used to calculate crown volume was

$$V = \frac{1}{3}\,\frac{CW^2}{2}\,h$$

where V = volume, CW = crown width, and h = transplant height. An inverse correlation (Pearson $r = -0.48$), significant at $P \leq 0.0002$, was determined when plot survival values across treatments were plotted against plot weed canopy cover. Weed cover was inversely related to plot mean crown width (Pearson $r = -0.75$, $P \leq 0.0001$) and plot mean seedling height (Pearson $r = -0.44$, $P \leq 0.007$). Plot weed sum cover was also inversely related to plot mean juniper canopy volume ($r = -0.68$), plot sum juniper height ($r = -0.61$), and plot sum crown width ($r = -0.65$), with each of these three correlations being significant at $P = 0.0001$.

TABLE 6. *Juniperus monosperma* survival and growth response to treatments applied in experiment 3 at the McKinley site (weed cov
was determined September 14, 1987)

Treatment				% survival		5-year results					
						Height	Crown width	Stem diam.	% cover		
No.	Planting date	Protection[b]	Fertilizer[a] (g/tree)	2 years[c]	5 years	(cm)	(cm)	(mm)	Grass	Shrub	Combine
1	Aug.	None	None	37.7	33.3	24.9	16.5	8.8	21.4	16.2	37.6
2	Aug.	None	SRF(10.1)+TSP(21)	32.3	23.3	27.5	17.3	10.0	54.2	3.5	57.7
3	Aug.	PMT	None	69.3	54.2	29.9	17.6	9.4	14.5	13.4	27.9
4	Aug.	PMT	SRF(10.1)+TSP(21)	46.9	35.8	28.5	16.0	8.4	40.5	9.3	49.8
5	Sept.	None	None	15.4	11.7	18.1	14.1	7.2	43.1	13.7	56.8
6	Sept.	None	SRF(10.1)+TSP(21)	2.3	0.8	9.0	5.0	4.0	46.3	5.5	51.8
7	Sept.	PMT	None	22.6	22.5	20.0	11.7	6.7	41.9	18.2	60.1
8	Sept.	PMT	SRP(10.1)+TSP(21)	26.2	22.5	18.9	12.5	6.1	30.1	12.1	42.2
9	Nov.	None	None	15.4	10.8	18.9	15.5	6.8	48.9	14.9	63.8
10	Nov.	None	SRF(10.1)+TSP(21)	1.9	0.8	18.0	18.0	8.0	55.7	11.4	67.1
11	Nov.	PMT	None	27.7	20.0	26.9	17.6	8.5	51.5	8.0	59.5
12	Nov.	PMT	SRF(10.1)+TSP(21)	13.1	10.0	23.5	12.0	5.9	48.9	4.6	53.5

[a]SRF, slow release fertilizer (Osmocote 18:6:12, N-P-K); TSP, triple-superphosphate 0:46:0 (N-P-K).
[b]PMT, polyethylene mesh tube.
[c]Data from Fisher et al. (1986).

TABLE 7. Analysis of variance of treatment effects on survival and growth of *Juniperus monosperma* 5 years after planting (experiment 3, McKinley site)

		MS			
	df	Survival[a]	Height (cm)	Crown width (cm)	Stem caliper (mm)
Blocks	5	0.056	302.5	138.4	38.4
Date (D)	2	0.611***	617.4*	144.3*	42.2*
Protection (P)	1	0.483**	152.3	13.1	2.9
Fertilizer (F)	1	0.269*	6.4	26.3	2.8
D×P	2	0.033	26.2	39.3	4.5
D×F	2	0.033	72.2	35.7	6.1
P×F	1	0.001	17.7	1.0	2.2
D×P×F	2	0.037	4.6	52.8	4.3
Experimental error[b]	55	0.064	153.3	41.8	9.5
Plot error[c]	1368				

NOTE: ***, significant at the 0.001 level; **, significant at the 0.01 level; *, significant at the 0.05 level; MS values without an asterisk are not significant at the 0.10 level.
[a]Analysis was conducted with arcsine-transformed plot survival data.
[b]Block × treatment.
[c]Because of missing vlaues, df = 294 for height, crown width, and stem caliper. For plot survival df = 71.

TABLE 8. *Juniperus monosperma* survival and growth response to planting date and fertilization main effects (data shown are mean values from experiment 3, McKinley site)

	Survival (%)[a]	Height (cm)	Crown width (cm)	Stem basal diam. (mm)
Planting date				
Aug.	36.7***	28.0*	16.9*	9.1**
Sept.	14.4	19.0	12.4	6.5
Nov.	10.4	23.8	15.7	7.7
Fertilizer treatment[b]				
SRF+TSP	15.5*	25.1ns	15.0ns	7.9ns
None	26.1	25.3	16.1	8.4

NOTE: ***, values within a column and section are significantly different at the 0.0001 level; **, significantly different at the 0.01 level; *, significantly different at the 0.05 level; ns, not significantly different at the 0.05 level.
[a]Analysis conducted with arcsine-transformed plot survival data.
[b]SRF, slow release fertilizer (Osmocote 18:6:12, N-P-K); TSP, triple-superphosphate 0:46:0 (N-P-K).

Experiment 3: McKinley Mine

Overall, mean survival decreased 5.4% from 2 to 5 year after planting (Table 6). Protection increased 5-year surviva from 13.9 to 27.5% but did not influence seedling growt (Tables 6 and 7). Although fertilization did not affe growth (Table 7), mean survival in fertilized plots was abou 40% less than in nonfertilized plots (Table 8). Planting dat affected seedling survival and growth (Table 7), with Augus having the highest mean values for each response variabl (Table 8). Among protected plots, 5-year survival was 45% for August, 22.5% for September, and 15.0% for November Also, fertilization did not affect the growth of seedlings i protected plots. For all plots, neither survival nor growt was related to two- or three-way interactions among the thre major factors studied (i.e., protection, fertilizer, and plan ing dates).

Percent survival was related to grass and combined cove (Table 9), although these parameters accounted for less tha

TABLE 9. Correlation matrix between *Juniperus monosperma* growth parameters and ground area occupied by grass, shrub, and combined grass and shrub cover (data are from experiment 3, McKinley site; weed cover was determined on September 14, 1987)

Cover (cm)	Survival (%)	Height (cm)	Crown width (cm)	Stem basal diam. (mm)	Grass cover (cm)
Combined	−0.43**	−0.36*	ns	−0.31*	
Grass	−0.29*	ns	ns	ns	
Shrub	ns	−0.30*	−0.27*	−0.35*	−0.36**

NOTE: **, *r* is significantly different from 0 ($p \leq 0.002$); *, *r* is significantly different from 0 ($p \leq 0.04$); ns, *r* is not significantly different from 0 ($p \geq 0.05$).

50% of the variation in survival among all plots. Combined cover was also inversely related to height and stem basal diameter growth, and all growth parameters were inversely correlated with shrub cover (Table 9). A negative correlation was also found between grass cover and shrub cover.

The severity of competition from grass and combined cover was affected by experimental treatments (Table 10). Fertilized plots had 126% more grass cover than unfertilized plots (46.9 vs. 36.5%). Also, competition from grass and combined cover was least for August-planted plots. Although the planting date × fertilizer treatment interaction was not significant for survival (Table 7), this interaction did influence grass and combined cover (Table 11). A notable feature of this relationship is that the absence of fertilizer in the August planting resulted in the least grass coverage.

Discussion and conclusions

Results from these experiments show that seedling growth and survival 4 to 5 years after planting are influenced by several factors. Protection markedly improved survival in experiments 1 and 3, and growth in experiments 1 and 2. Mulch increased survival in experiment 2 and the height growth of protected seedlings in experiment 1. This factor was not studied in experiment 3. Overall, fertilization either did not influence establishment or greatly reduced survival (McKinley site). Fertilization did not affect growth. In a separate study (Raton, New Mexico), fertilizer increased juniper transplant mortality on a surface-disturbed site (Fisher et al. 1986). Fertilization reduced survival at McKinley and increased reseeded grass cover. Effects of this stimulation on grass growth became increasingly obvious years after the fertilizer application. Also, experiment 3 demonstrated that the time of application can greatly affect the magnitude of the stimulation effect (Table 11). Although fertilization with August planting greatly increased grass cover over no fertilization, applications in September and November did not result in large increases. Possibly, the grass was more responsive to August fertilization because it was vigorous and space was available.

Planting date affected seedling survival and growth, and grass cover. For unknown reasons, grass cover among the McKinley site test plots was least among those planted in August. Possibly, the effects associated with mechanical damage to grass during the August 1982 planting were most evident in August plots because grass plants were less mature. However, it is likely that August rather than September or November planting also provides more time for juniper root establishment before low soil temperatures prevail. Evidence for the independent influence of planting

TABLE 10. Analysis of variance of treatment effects on competing vegetation (percent canopy cover) recorded in experiment 3 (McKinley site)

	df	MS Grass	MS Shrub	MS Combined[a]
Blocks	5	11 095	7 951	10 569
Protection (P)	1	16 120	1.4	18 789
Date (D)	2	38 206***	858	34 318**
Fertilizer (F)	1	29 353**	13 745	4 222
D×P	2	2 444	4 499	523
D×F	2	36 641***	752	28 785**
P×F	1	9 830	1 114	2 967
D×P×F	2	475	564	1 262
Experimental error[b]	55	6 120	4 879	7 973
Plot error	71			

NOTE: ***, significant at the 0.005 level; **, significant at the 0.03 level; MS values without an asterisk are not significant at the 0.05 level.
[a]Total of grass and shrub cover.
[b]Block × treatment.

date is found in the analysis of planting date main effects. At the Raton site cited above, July was clearly a superior planting date over August, presumably because cold temperatures at the high elevation site restict fall root growth.

Perennial weed competition was inversely related to percent survival and crown growth of juniper in experiment 2 at the Zia site. Juniper crown area decreased exponentially as weed cover increased. In experiment 3, grass cover and combined vegetation were inversely related to juniper survival. The absence of a significant correlation between shrub cover and survival seems to underscore the importance of the relationship between survival and grass cover, considered alone, as a dominant component of combined vegetation. However, shrub cover was related to growth. In this vein, Lanini and Radosevich (1986) demonstrated that soil moisture availability at a depth of 100 cm and subsequent growth of three coniferous species were inversely correlated with shrub canopy volume. Similar effects of vegetation and moisture availability on tree growth have been found for numerous tree species (Eissenstat and Mitchell 1983; Radosevich and Osteryoung 1987).

Significant inferences derived from the studies described are as follows. Seedling growth will be improved considerably if some type of protective barrier is provided to prevent animal damage. In fact, on some sites junipers apparently can remain less than 0.5 m indefinitely without protection. On sites where animal pressure is particularly severe, protection can benefit early survival greatly. Because

TABLE 11. Competing vegetation response to planting date × fertilizer treatment interaction (data shown are mean values from experiment 3, McKinley site)

Planting date	% canopy cover					
	Grass		Shrub		Combined	
	No fert.	Fert.	No fert.	Fert.	No fert.	Fert.
Aug.	17.9	47.4	14.8	6.4	32.7	53.8
Sept.	42.5	38.2	15.9	8.8	58.4	47.0
Nov.	50.3	52.3	11.1	7.9	61.4	60.2

NOTE: The interaction affecting grass cover was significant at the 0.005 level. The interaction affecting combined cover was significant at the 0.03 level. The interaction affecting shrub cover was not significant at the 0.05 level.

the rigid tubes are difficult to install and maintain, the netting used in experiment 2 is recommended. Mulch will improve survival on at least some sites. More specifically, the wood chips greater than 2.5 cm^2 applied in these studies resisted removal by wind; therefore, wood particles probably should be at least this large. Fertilization with the rates and formulations tested is not recommended because no benefits were obtained and adverse effects on survival and grass cover were sometimes observed. More specifically, trees can respond positively to fertilization initially as reported by Fisher et al. (1986) but negatively years later when grass stimulation becomes more obvious. Results of these studies reported here and elsewhere (Fisher et al. 1986) support the view that planting date does effect survival and growth, with adverse results occurring after either early fall or May to June planting. May to June planting failure is related to a seasonal drought period commonly occurring in the southwest during these months (Fisher et al. 1986).

Vegetation management before and after juniper planting on mined sites clearly deserves attention. Although weed competition accounted for less than 50% of the variation in survival, the relationships detected could be useful in formulating hypotheses for additional testing. The long-term effects of fertilization should be considered, as should the postponement of reseeding in areas to be planted in juniper. Also, the adverse effects associated with shrub cover suggest that junipers and other tree and shrub species must be given adequate space to minimize competition effects. At present, the optimal spacing for juniper or mixed species planting is not known. Another issue requiring attention is the length of time junipers will require weed management to eliminate competition effects. Clearly, species such as broom snakeweed pose a serious threat because they invade cleared sites rapidly.

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