Techniques for improving tree survival and growth in semiarid areas

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ABSTRACT—We tested seven methods for supplying additional water or altering the microclimate of eastern redcedar (Juniperus virginiana) *and Scotch pine* (Pinus sylvestris) *planting sites to increase survival and growth. Water-harvesting treatments (50 × 100 feet and 50 × 50 feet) produced 40 and 32 percent more redcedar growth than the control. Drip irrigation and snowfence protection produced 35 and 33 percent more redcedar growth, respectively. Shade treatment did not increase redcedar growth, but all test plantings survived, compared with 70 percent for the control. Although Scotch pines responded less than redcedars to the treatments, they survived and grew best when protected by snowfence and drip-irrigated.*

SHELTERBELTS and windbreaks again and again have proved to be valuable assets to American agriculture (*2, 4, 7, 31, 33, 35, 38*). But trees planted as barriers in areas of low annual rainfall and poor soil-physical characteristics grow slowly and erratically (*9, 11, 29*). For this reason we initiated a study in an area of limited rainfall to find simple, productive methods for increasing tree survival and growth.

Several publications are available on techniques for harvesting water in low rainfall areas (*8, 15, 23, 26, 27, 28, 30, 36*). Among the techniques are the use of gravel mulches to reduce evaporation and enhance infiltration (*1, 14*); use of wind barriers to modify microclimates and trap snow (*4, 5, 12, 13, 20, 31, 35, 37*); use of solar stills to obtain water in desert areas *(16, 17, 21,);* use of profile modification to improve soil-physical *(10, 18, 19, 34,)*; and manipulating the effects of solar radiation and shading on evapotranspiration, crops, and animals *(3, 6, 25, 32)*.

Study Methods

To test some of these techniques we planted trees under seven management systems and a control system in April 1971 at the Colby Agricultural Experiment Station in northwestern Kansas. Soil at the station is a Keith silty clay loam (15% sand, 54% silt, and 31% clay) with an infiltration rate of 0.04 inch per hour. Mean annual precipitation is 19 inches, 65 percent of which occurs between May 1 and September 30.

The seven treatments and a control (Figure 1), each replicated twice, included: (a) water-harvest area (50 × 100 feet), (b) water-harvest area (50 × 50 feet), (c) partial shading, (d) snowfence protection, (e) solar still (drip irrigation), (f) profile modification, and (g) gravel mulch (straw mulch).

We planted the trees in a 3-acre plot in 50-foot rows with 5 feet between trees. Half of each row was planted to eastern redcedar (*Juniperus virginiana*) (*24*), the other half to Scotch pine (*Pinus sylvestris*). We measured tree growth at the beginning and end of four growing seasons. Trees that did not survive were replanted at the beginning of each season.

We applied granular simazine (2 pounds per 1,000 square feet in a 20-foot wide area, centered on each tree row) each spring to control weeds.

Each month we determined soil moisture gravimetrically to a depth of 36 inches in each plot and calculated available water.

During the last two growing seasons we installed thermographs, wind anemometers, and a rain gage. Wind velocity and air temperatures were measured at a point 2 feet above the soil surface.

For the water-harvest treatment we cleared and smoothed the areas, then constructed berms around the edges to pond runoff on the tree rows. We used (a) 6-mil polyethylene, (b) asphalt emulsion, and (c) silicone and latex-in-water to cover the areas, one in each successive year. Because of its durability, the silicone-latex covering was used in both the third and fourth years.

We modified the soil profile in that treatment by digging a trench (2 feet wide by 4 feet deep) along the length of the row, mixing the soil from the trench, refilling the trench, and then planting the trees in the mixed soil.

For the solar-still treatment, we constructed similar trenches adjacent to the tree row and covered them

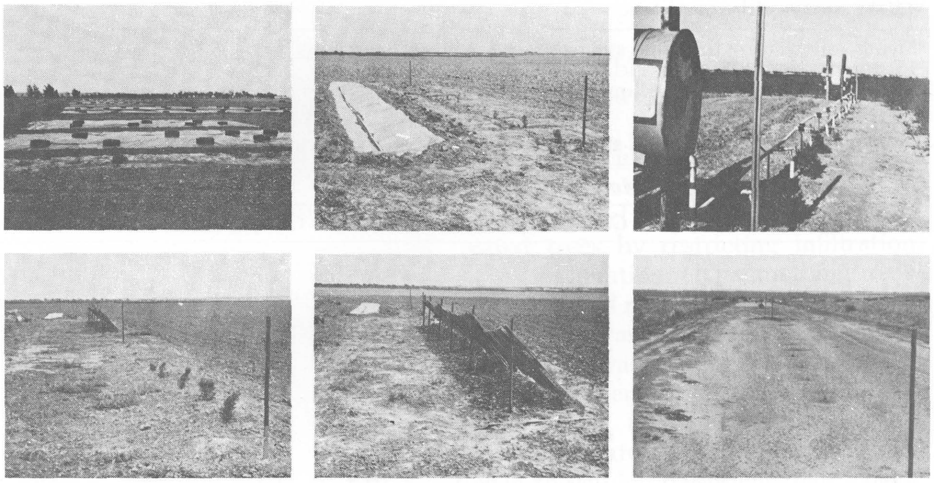

Figure 1. Six of the treatments used included: top (left to right): water-harvest, solar-still, drip-irrigation; bottom (left to right): profile-modification, shade, gravel-mulch.

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with 1-mil Tedlar.[1] Water collected on the Tedlar cover dripped into a partitioned trough where it was piped to individual trees. We fabricated a check valve with a funnel, table-tennis ball, and wire mesh to allow rainwater to flow into the trench and not collect on the Tedlar cover.

Because of wind and rodent damage to the Tedlar cover we switched the solar-still treatment to drip irrigation after the first season. The irrigation supplied each tree with 10 gallons of supplemental water a month, fed directly to the root zone, 12 inches below the soil surface.

For the partial-shade treatment, we covered the tree row with a 50-foot length of snowfence, supported by steel posts and raised each spring to allow for tree growth.

In the snowfence-protection trial, we surrounded the rows with 60-percent-open snowfencing, 48 inches tall and 25 feet from the row in all directions.

The last treatment used gravel as a mulch around the trees. Because of low survival rates we switched to a straw mulch during the last two growing seasons. We spread 4 tons of straw per acre and anchored it with a jute netting.

Two control plots, one oriented north-south and the other east-west, were planted in the usual manner with no special treatment other than the herbicide application.

[1]Trade names are used for clarity and do not constitute an endorsement by the U. S. Department of Agriculture.

Table 1. Yearly and total average growth and survival of eastern redcedar trees by treatment.

Treatment	*First Year*	*Second Year*	*Third Year*	*Fourth Year*	*Total*	*Survival*
			inches			%
Water-harvest (50′ × 50′)	4.2	16.4	17.8	11.2	49.6*[a]	80
Drip-irrigation[b]	1.7	18.3	16.3	11.4	47.7*	80
Snowfence	1.2	15.2	17.3	13.3	47.0*	90
Water-harvest (50′ × 100′)	3.5	17.9	15.1	10.3	46.8*	100
Control	0.8	10.4	14.3	9.9	35.4†	70
Shade	3.3	11.6	10.2	8.1	33.2†	100
Profile-modification	0.9	9.0	11.1	11.8	32.8†	70
Mulch[c]	2.0	1.5	4.0	7.5	15.0‡	20

[a]Means followed by the same symbol do not differ significantly ($P < 0.05$).
[b]First year solar-still.
[c]First and second year gravel-mulch; third and fourth year straw-mulch.

Table 2. Yearly and total average growth and survival of Scotch pine trees by treatment.

Treatment	*First Year*	*Second Year*	*Third Year*	*Fourth Year*	*Total*	*Survival*
			inches			%
Snowfence	0.8	2.1	1.8	5.8	10.5*[a]	90
Drip-irrigation[b]	0.5	1.3	1.4	4.9	8.1*	90
Water-harvest (50′ × 50′)	1.4	0.8	1.3	3.7	7.2*	60
Shade	0.9	1.1	1.0	2.5	5.5*	70
Water-harvest (50′ × 100′)	0.2	0.2	1.4	1.6	3.4*	50
Control	1.2	0	—	—	—	0
Profile-modification	0	0.4	0	—	—	0
Mulch[c]	—	—	—	—	—	0

[a]Means followed by the same symbol do not differ significantly ($P < 0.05$).
[b]First year solar-still.
[c]First and second year gravel-mulch; third and fourth year straw-mulch.

Table 3. Climatic data, field site of eastern redcedar and Scotch pine, Colby, Kansas.

Date	*Rainfall (in)*	*Monthly Mean Temperature (°F)*			*Wind (mph)*		
		Control	*Snowfence*	*Shade*	*Control*	*Snowfence*	*Shade*
1973							
May	5.18	—	—	—	—	—	—
June	0.71	77.4	77.9	79.5	6.2	4.4	6.1
July	4.55	74.5	75.3	75.9	5.6	4.1	5.9
August	0.75	78.2	78.9	79.9	7.0	4.8	6.8
September	5.91	57.4	58.1	59.1	7.0	4.6	6.9
1974							
May	1.85	63.7	64.0	—	5.1	5.1	3.6
June	5.20	69.0	72.6	72.6	5.2	4.7	4.0
July	0.90	79.0	82.3	84.4	6.7	5.4	5.8
August	3.55	70.0	71.4	72.4	5.6	4.7	4.7
September	0.85	61.4	62.3	63.8	6.1	5.0	5.3

Data and Observations

Tables 1 and 2 summarize the average survival and growth of the redcedar and Scotch pine trees for the four years. The survival percentages are for the initial plantings only and do not include the trees that were replanted each spring.

Table 3 shows the climatic data from the field site for the last two years of the study. Rainfall from May 1 to September 30 was 17.10 inches in 1973 and 12.35 inches in 1974 (the 60-year average was 12.51, figure 2).

Average daytime temperature was lower in the control than in either the snowfence or shade treatment, and the average nighttime temperature was higher in the shade treatment than in either the control or snowfence treatment. We expected this because shade restricts long-wave reradiation, absorbs short-wave radiation, and reduces energy transfer and evaporative cooling from plant transpiration, thus increasing ambient temperatures.

Total wind averaged 30 percent less in the snowfence treatment than in the control in 1973, but only 12.6 percent less in 1974. Total wind in the control treatment for 1974 averaged about 11 percent less than for 1973, partially because the field surrounding the plot was in a fallow-wheat-fallow rotation, and 1973 was a fallow year. The wheat was harvested on June 30, 1974, leaving a 12-inch stubble the remainder of the season.

Table 4 shows the available-water averages during the 2 years of record. Monthly averages for all eight treatments varied little throughout 1973 but declined steadily during the 1974 growing season, averaging about 50 percent less than in 1973. Rainfall amount and distribution greatly influenced the averages.

Both water-harvesting treatments and the drip-irrigation treatments resulted in no more water available in the soil than the control either season. Because the trees on the two water-

Table 4. Average available water (inches)[a] during indicated months in 1973 and 1974 in the top 36 inches of the soil profile.

Month	*Water-harvest 50′ × 100′* 1973	1974	*Water-harvest 50′ × 50′* 1973	1974	*Drip-irrigation* 1973	1974	*Snowfence-protection* 1973	1974	*Control* 1973	1974	*Shade* 1973	1974	*Profile-modification* 1973	1974	*Straw mulch* 1973	1974
May		4.00		4.48		3.78		4.43		4.49		4.50		3.95		5.90
June	4.14	3.57	4.44	4.11	4.51	3.49	4.68	3.58	4.80	4.07	5.10	4.06	4.56	3.36	5.49	5.54
July	4.17	2.06	4.17	2.25	3.93	2.04	4.00	2.18	4.45	2.57	4.64	2.61	3.46	1.95	5.44	4.23
Aug.	4.36	0.81	4.36	1.24	3.65	0.84	3.81	1.06	4.26	1.65	4.40	1.55	2.46	1.22	5.42	4.10
Sept.	3.89	1.51	4.31	2.16	4.01	0.99	3.86	1.02	4.91	1.76	4.27	1.24	3.21	1.03	5.81	3.82
Avg.	4.25	2.39	4.50	2.85	4.22	2.23	4.24	2.45	4.61	2.91	4.70	2.79	3.73	2.30	5.69	4.72

[a]Available water in inches equals (BD) (%H_2O) depth ÷ D_w, where BD is soil bulk density, %H_2O is %H_2O as measured minus %H_2O at wilting point, depth is depth in inches that %H_2O represents, and D_w is density of water.

harvesting treatments were considerably larger, transpiration demand was greater and available water was depleted faster. We no doubt missed some peaks in available water because of the monthly soil moisture determinations.

The snowfence-protection treatment recorded less average available water than the control but produced more tree growth. Transpiration and evaporation demand obviously were less in the protected environment.

Analysis of variance indicated that treatment was significant ($P < 0.05$) in the growth of redcedars and Scotch pines. Tables 1 and 2 give results of the Duncan multiple range test of significance for the treatments.

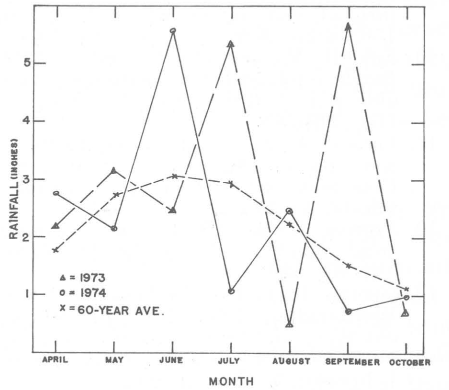

Figure 2. Rainfall distribution, April through October 1973 and 1974, and 60-year average.

Interpretations and Discussion

The water-harvest, drip-irrigation, and snowfence-protection treatments improved redcedar survival and growth (Figure 3). Shade improved redcedar survival. Survival and growth of Scotch pine improved under the water-harvesting, snowfence-protection, drip-irrigation, and shade treatments. Profile modification and mulch treatments did not improve survival or growth of either species.

The 50- × 50-foot water-harvesting treatment produced 40 percent more growth among redcedars than did the control, and the 50- × 100-foot treatment produced 32 percent more redcedar growth. Redcedar survival was 80 and 100 percent in the 50- × 50-foot and 50- × 100-foot harvest areas, respectively. Scotch pine survival was 60 and 50 percent under the two water-harvesting treatments.

Based on the precipitation data, the 50- × 100-foot water-harvesting treatment had an additional 60 inches of water available for trees in 1973 and an additional 24 inches in 1974. The 50- × 50-foot areas had 30 inches and 12 inches more, respectively. Because of the low soil infiltration rate, water collected from the harvest areas was ponded a long time and evaporation losses were considerable. The 50- × 100-foot water-harvesting areas may have been detrimental to small trees by inundating them for a considerable time after heavy rains.

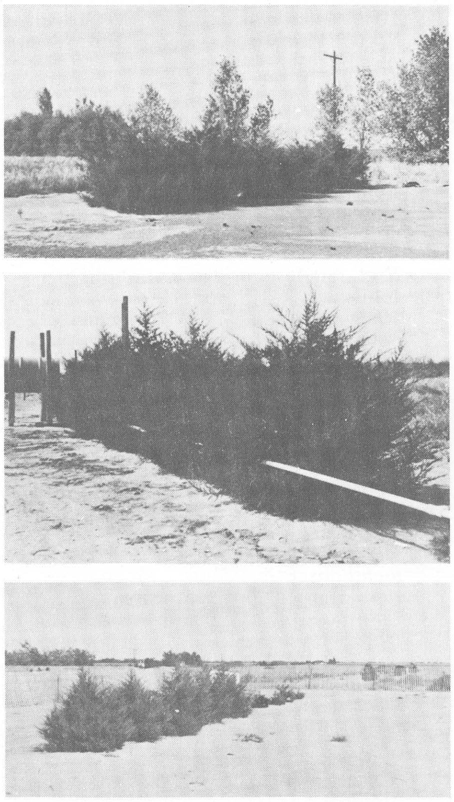

Figure 3. Redcedars in the fall of 1974. Top, water-harvest; middle, drip-irrigation; bottom, snowfence-protection.

The drip-irrigation and snowfence-protection treatments produced 35 and 33 percent more redcedar growth than the control. Survival was 80 and 90 percent, respectively. Scotch pine survival was 90 percent for both treatments.

Survival under the shade treatments was 100 percent for redcedar and 70 percent for Scotch pine, but shade did not improve redcedar growth over the control. The shade may have been so close that it actually suppressed growth.

The profile-modification treatment resulted in 70 percent survival among redcedars but 10 percent less growth than the control. Scotch pine survival was zero under the treatment. Average available water was consistently less in the profile-modification plots than in the control. This lack of water probably was the factor limiting tree growth.

The poor survival on the mulch plots is difficult to explain. Three possible explanations include: (a) fines in the gravel sealed over and suffocated trees by restricting infiltration and soil aeration, (b) something toxic in the gravel remained in the soil after the gravel was removed, (c) too much herbicide was applied to the plots. Excessive herbicide seems to be the most likely explanation. Average available water was consistently higher in the mulch treatment than in any other treatment.

Many tree species initiate growth between April 15 and May 1 and complete more than 90 percent of their annual growth in 60 to 90 days (22). But our growth measurements in early August and October 1973 showed that redcedar trees obtained about 30 percent of their 1973 growth after August.

Climatic data varied little between the 2 years. The most rainfall in 1973 was recorded in July and September, while June 1974 was above average and July 1974 was below average. This accounts for differences in available soil water between fall 1973 and fall 1974. The 60-year average indicated declining precipitation in August, September, and October, so available soil water normally would be depleted by the fall in most years.

Summary and Conclusions

Four of the eight techniques tested improved redcedar growth. Five improved redcedar survival. The two water-harvesting treatments produced 40 and 32 percent more growth in redcedars and also improved their survival. Drip-irrigation and snow-fence-protection treatments produced 35 and 33 percent more growth in redcedars, respectively, and increased their survival. The shade treatment increased redcedar survival but not redcedar growth.

Scotch pines grew less than redcedars, but protected Scotch pines tended to respond better than unprotected ones. The snowfence-protection treatment produced the most growth; with drip-irrigation, the 50- × 50-foot water-harvest, shade, and 50- × 100-foot water-harvest treatments next in order. No Scotch pines survived under the control, profile modification, or mulch treatments.

Our results indicate that it may very well be possible to shorten the time it takes trees in semiarid regions to reach effective wind-barrier heights.

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