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1982 SILVICULTURE RESEARCH AND BIOMASS PRODUCTION USING SALINE WATER

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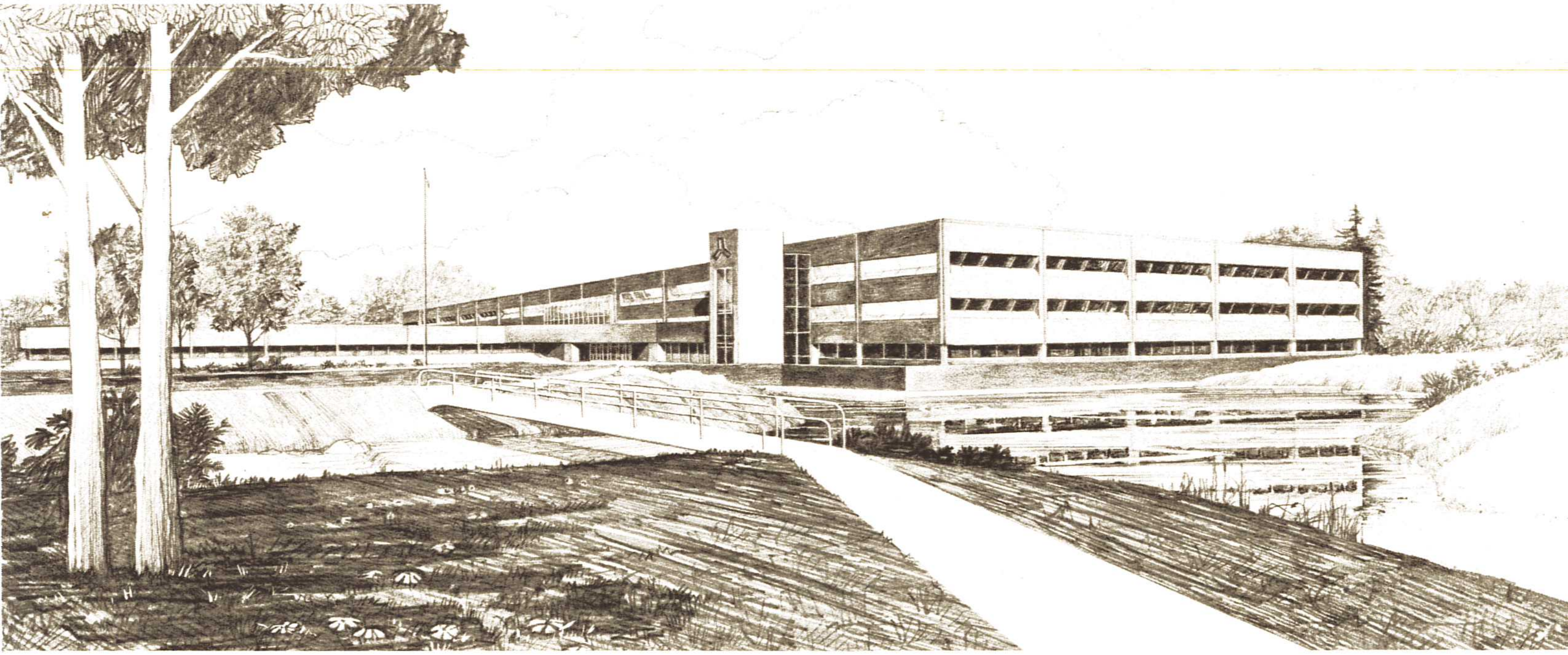

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ABSTRACT

The objective of this research was to determine the biomass production potential of tree species planted on land of marginal agricultural value and irrigated with saline water. By determining which tree species are tolerant of such conditions while still offering high biomass production potential, a crop could be grown with resources not suitable for agricultural crop production. This type of research is important because tree biomass is a renewable resource that produces a product, cellulose, which can be converted to petroleum substitutes for use as energy or as a feedstock from which many organic chemicals can be obtained. Data from this research will identify salt tolerant tree species and determine their production potential. These data will be a key factor in determining the technical and economic feasibility of such a program.

Data collected after the first year of field tests indicate that several species offer high potential for biomass production. Boxelder, russian olive, hybrid poplars and sumac, with first year biomass increases ranging from 272% to 409%, were the most promising of the 16 species tested. These dramatic increases suggest a great biomass production potential for these species.

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1. INTRODUCTION

Biomass has the potential for displacing substantial quantities of fossil fuel. According to the Congressional Office of Technology Assessment, bioenergy could supply as much as 20% of the current U.S. energy consumption by the year 2000. This would amount to anywhere from 4-17 quads of energy per year as compared to the 1.5 quads currently being produced. Of this, an estimated ten quads could come from wood. Economic considerations and the quality and quantity of land available for growing woody biomass will dictate whether or not these high production estimates will become a reality. If large silviculture farms could be established on tracts of marginal land, and if irrigation water could be obtained from marginal water supplies, competition with the agricultural industry for land and water of good quality could be minimized. This report describes an initial study of tree biomass production potential using marginal lands irrigated with saline water. It gives a projection of the applicability of this technique for the Intermountain West and for similar regions in other countries.

Silvicultural biomass production research at the Idaho National Engineering Laboratory (INEL) was initiated as part of a Technical Development Program designed to assess the potential of producing biomass as a feedstock for energy production. The study took place in the cold desert of southcentral Idaho.

1.1 Background

Silviculture is the cultivation of trees. When practicing silviculture in the traditional sense, long growing periods or rotations are required. These rotations generally range anywhere from 30-80 years.[2] Such an extensive growing period allows trees to achieve sizes needed for lumber production. Recently, however, silviculture plantations are being viewed in a different light. The idea that such plantations could represent a viable source for production of woody biomass has been investigated. Research has shown that optimum rotations of 3 to 15 years are possible when sheer biomass production is the objective.[3,4] Additionally, advancements in conversion technology and the concern over world energy needs have led to several evaluations of short-rotation silviculture as a source of biomass for energy production.[5,6,7,8,10]

Management practices for conventional silviculture vary from those for short-rotation plantations. The objective of short-rotation systems is to take advantage of the rapid growth rates during the first five to ten years of tree growth. This early rapid growth rate is inherent in a number of promising tree species. Short-rotation systems often require extensive site preparation (destroying competing vegetation and aerating soils where necessary). Additionally, surface irrigation may be required for arid sites. Thus, short-rotation systems not only require more intensive management, but are also more costly than conventional tree farms. The major justification for the additional expenditure is not only the increased yield, but a faster return on the capital investment. Average annual biomass yields reported from several conventional forest management systems ranged from one to three dry metric ton equivalents (DMTE) per hectare. Initial results from short-rotation research indicate that biomass yields of 5 to 13 DMTE per hectare are currently possible and greater yields are expected as the practice becomes more refined.[2]

In order for short-rotation biomass systems to be successful, growth capacity of the site must be optimized. This can be accomplished by planting selected species at higher densities than those used for conventional systems. Most experimental work with short-rotation systems has utilized stand densities of up to about 3,000 small trees per hectare. Stems have been planted in densities of 190,000 per hectare. In contrast, conventional forest crops are generally planted at densities ranging from 494 to 1,729 trees per hectare.[2]

Harvesting biomass crops is another important consideration. The methods used for harvesting a short-rotation biomass crop could differ from conventional harvesting techniques, depending on the end use of the crop. The use of forest slash as a feedstock for energy conversion has been investigated.[9,8,10] Much of the technology presently considered for harvesting slash could be applied to short-rotational systems as well. Important considerations when selecting harvesting methods are economics, environmental constraints, efficiency of collection, and end use. An example of a practical system currently being tested is a self propelled harvester which would continuously shear a swath of small trees, chip them, and blow the chips into a wagon. Short-rotation silviculture operations could be managed in a manner quite similar to the way in which such agricultural crops as corn and grain are managed; the only difference would be the longer rotation period.

2. IMPETUS OF THE STUDY

The cold desert of southcentral Idaho and many areas similar to it are acceptable climates for agricultural crop production. Numerous sunny days provide the solar radiation necessary for good crop production. Often, the limiting factor to agricultural production is having access to water of good enough quality for irrigation. In fact, intensive cropping practices and water use have led to severe water shortages and, in many cases, misuse of the land. In many areas, salinization of the soil surface and subsurface water supplies is limiting development. Therefore, the present direction of this research involving a short rotational system is to evaluate the potential of using marginal water (i.e., geothermal effluent or brackish aquifers) to irrigate the plantation. Such a system would not only produce biomass, but could also provide an acceptable method for wastewater reuse and/or disposal. Also, soils or natural water sources not conducive to agricultural crop production could be used to produce trees. Many tree species are more salt tolerant than agricultural crops. Salt tolerant tree species that exhibit high biomass production rates could, therefore, represent a successful crop on an area otherwise unsuited for agricultural production.

The water that was used for irrigation in this study was heat-expended geothermal fluid produced at the Raft River facility.[15] Table 1 shows the average chemical content of the geothermal water. By using such fluid, the intent of this study was to demonstrate that silviculture plantations may provide a practical/beneficial alternative to injection of geothermal effluent. If it is feasible to irrigate silvicultural crops with geothermal water, there is great potential to apply this practice elsewhere because the water being used has a salinity similar to many cold aquifers of the world. The total concentration of soluble salts of the Raft River geothermal water ranges from 1500 mg/ℓ to 3000 mg/ℓ. A quarter-million square miles of the United States (one-twelfth of the continental land area) overlie aquifers with a salinity near 3000 mg/ℓ that could be economically developed. This represents a land area fifteen times the size of California. Two-thirds of the U.S. has what is considered slightly saline water, containing from 1000 mg/ℓ to 3000 mg/ℓ of salt. Every year, another half-million acres become too salty for conventional agriculture because of salt accretions resulting from irrigation with saline water. Since irrigation became a practice about 25 percent of the earth's irrigated cropland has become too salty to produce crops economically. Thus, there is a lack of vegetative cover and the land is subject to accelerated wind and water erosion. The development of tree plantations on such areas could help to reduce erosion and desertification, provide a feedstock for fuel or conversion processes and enhance land use.

TABLE 1. CHEMICAL CONTENT OF THE ENERGY EXPENDED GEOTHERMAL FLUID USED FOR IRRIGATION AT RAFT RIVER. RESULTS ARE IN mg/l. CONDUCTIVITY RECORDED IN μmhos/cm.

Cl-	920
F-	8.7
Total N	0.8
PO_4	0.2
Si	90
Na	580
K	40
B	0.3
Ca	55
Mg	0.4
pH	7.3
Conductivity	2867
TDS	1452
Temperature (°C)	28

Based on research and results from the literature, short-rotational tree farm systems offer several advantages when compared to conventional forest management throughout the United States including:

- Higher yields per unit land area (5 to 15 dry metric tons/ha/yr)
- Lower land requirements for a given biomass output
- Shorter time span from initial investment to obtaining a positive cash flow from the harvestable crop

- Increased labor efficiency through potential mechanization of most operations

- Increased harvesting efficiency through the use of methods similar to those used in agriculture.

There are some disadvantages, however, which should not be overlooked.

- Irrigation with saline water must be carefully managed to ensure maintenance of the longterm productivity of the site.[11]

- Costs per unit area to establish and manage short-rotation plantations are generally higher than for conventional forest crops. Site preparation and stand establishment/regeneration are commonly the most expensive silvicultural operations during a rotation. Hardwoods, however, are particularly advantageous for biomass production since stands can usually be established with cuttings. Also, regeneration costs of most hardwood plantations would be low due to coppicing (regeneration from cut stumps) ability of these species.

- There are site limitations since only sites amenable to mechanized operations may be used for cost effective operation.

- Insect and fungal outbreaks may threaten the plantation. Genetic diversity can be exploited to build resistance to attack. Pests can also adapt, however, and the threat of epidemic pest outbreak in monoculture plantations is very real. Thus, selection for resistance while, at the same time, maintaining genetic diversity in plantations is the optimum goal.

2.1 Previous Research

Studies on tree biomass production have, in most cases, been small-scale research projects; however, the results are very promising. Studies performed as early as the 1950's investigated growth potential of hybrid poplars.[12] Numerous summary reports are available evaluating the potential of using short-rotational systems to provide feedstock for conversion into energy and/or chemical by-products.[8,10,6,5,1,2] However, essentially all previous tree biomass production research in the United States has been conducted in the East and Midwest. These sites are usually on arable land; thus, results from this research do not accurately reflect production potential in the arid Intermountain West.

Most of the research that has been conducted in the western region has been concerned with the latex producing shrubs and salt tolerant plants of the Southwest.[13,14] However, most of these species cannot grow throughout the Great Basin because of the cold winters.

In 1976, the University of Idaho received a DOE grant to test the potential of using geothermal water to grow trees at Raft River.[23] The site chosen for the study is characterized by high alkaline, low permeability soils. Bare rooted nursery seedlings were planted at this location. The resulting transplant shock and a late frost combined to kill many of the seedlings. The surviving trees were then watered via sprinkler irrigation. Sprinkling is poorly suited to saline water use in an arid climate because the water droplets that land on the foliage evaporate causing salt crystalization on the leaves. The salt desiccates the leaves, interferes with normal respiration, and results in eventual death of the plant. Consequently, the result of that study was that essentially all the trees died.

As part of a concurrent agricultural study performed by EG&G Idaho and Utah State University, four species of trees were planted in a cultivated field that was watered with geothermal fluid via flood irrigation. The species tested were green ash (Fraxinus pennsylvanica), golden willow (Salix babylonica), siberian elm (Ulmus pumila), and energy mix poplar (Populus diversifolia). One hundred-fifty individuals of each species were planted. Although no quantitative data are available, the survival rate was high and the trees grew very rapidly.[22]

In June of 1981, EG&G Idaho initiated a screening study to evaluate the survivability of ten species of trees. These trees were flood irrigated with heat-expended geothermal fluid produced at the Raft River Geothermal Area. The criteria used to select the trees were high production potential, known tolerance to the climate of the region, and the ability to coppice, an important attribute for obtaining multiple harvests. Because of late funding and, therefore, late planting, the objectives of the 1981 study were limited to screening the trees for survivability and obtaining a qualitative estimate of growth rate. Four species--honey locust (Gledetsia tricanthos), hybrid locust (Robinia sp.),tamarisk (Tamarix parviflora) and russian olive (Elaeagnus angustifolia)--all readily adapted to irrigation with the geothermal fluid and grew very rapidly. Four other species--golden willow (Salix babylonica), hybrid willow (Salix sp.), narrow leaf cottonwood (Populus angustifolia) and freemont cottonwood (Populus fremontii)--survived, but did not demonstrate much new growth. This might have been a result of slow root establishment after transplanting. Two species, european sycamore (Platinus occidentalis) and siberian pea (Caragana arborescens), died within 8 weeks of planting.[16] External symptoms preceding death indicated salt intolerance. This was confirmed by plant tissue analysis which showed high concentrations of chloride. The 1982 research was guided by results from the screening study.

3. METHODOLOGY

3.1 Location, Climate and Soil Type

The site chosen for the 1982 silviculture study was located on the Raft River Known Geothermal Resource Area (KGRA) near the Idaho-Utah border in southcentral Idaho. The mean annual temperature in the Raft River Valley is 8°C. In the coldest months, December and January, the mean temperature is -3.1°C, and in the warmest months, July and August, the mean temperature is 20°C. During the period of geothermal development at the Raft River KGRA, the yearly precipitation averaged 255 mm.

The soil at the chosen site is an Aysees-Hiko Peak Complex. This is a mixture of soils formed in alluvium from different sources and influenced by volcanic tuff. In a typical undisturbed profile, the ∿15 cm surface layer is loam and silt loam. The substratum is very gravelly sandy loam and sand. This is underlain by about 140 cm of interstratified layers of very gravelly loam, very gravelly sandy loam, sand, and gravelly sand. The soil is calcareous with a zone of lime accumulation at a depth of 15 cm to 65 cm. It is moderately and strongly alkaline and strongly saline. Permeability is moderately rapid. Effective rooting depth is 150 cm or more. Available water capacity is 6.1 to 9.1 cm. In general, big sagebrush (Artemisia tridentata) is the dominant natural plant species associated with this broad soil classification.

3.2 Tree Selection

The trees chosen for the FY-82 silviculture study were selected in accordance with the following criteria:

- High production potential
- Ability to coppice
- Known tolerance to the climate of the region
- Known performance from previous research.

A total of sixteen species was selected (Table 2) and seventy individuals of each species were planted.

3.3 Site Preparation and Design

The topography of the chosen site was moderately level (6% slope), even before being bulldozed to design specification; thus, it was readily suited to a flood irrigation system and was partitioned into six basins.

The six basins were paired and identified as plots one, two, and three. The area of each basin was 353 square meters. Much of the thin layer of topsoil was removed during basin construction. This did not hinder the study, however, as the plot became more representative of marginal lands. Prior to planting the trees, each plot received fertilizer equivalent to 100 units of nitrogen and 80 units of phosphate per acre from a 20-16-0 commercial fertilizer. Following fertilization, a series of parallel trenches were dug with a backhoe for the entire length of the plots. These trenches were 1.25 m apart and were 0.6 m deep. This method not only created the trenches in which the trees were planted, but it incorporated the fertilizer and loosened the soil to enable better water infiltration.

TABLE 2. TREE SPECIES SELECTED FOR THE 1982 RAFT RIVER TREE PLANTATION PROJECT

Common Name	Scientific Name
Russian Olive	*Elaeagnus angustifolia*
Smooth Sumac	*Rhus glabra*
Silver Maple	*Acer saccharinum*
Russian Mulberry	*Morus rubra*
Globe Willow	*Salix spp.* hybrid
Tamarisk	*Tamarix gallica*
Green Ash	*Fraxinus pennsylvanica*
Boxelder	*Acer negundo*
Honey Locust	*Gleditsia tricanthos*
Black Locust	*Robinia pseudoacacia*
Black Willow	*Salix nigra*
Norway Poplar	*Populus spp*. hybrid
Theves Poplar	*Populus spp*. hybrid
Siberian Elm	*Ulmus pumila*
Hybrid Elm	*Ulmus spp*. hybrid
Energy Mix Poplar	*Populus diversifolia*

3.4 Planting

Trees were planted in rows of ten across the width of each basin. The trees were planted in groups of five such that there were two species per row. The order in which species were planted in each basin was determined by random selection. Ten representatives of each species were planted per basin. Where possible, identical groups of trees were not planted next to each other in order to obtain results which would be well representative of the basins. The saplings were placed in the trenches 1.25 meters apart. Then, the trenches were backfilled with a combination of subsoil, some topsoil and about 0.5 kg of a soil conditioner.

3.5 Water Supply and Watering Schedule

Irrigation water was applied to the test plots via basin flooding. This method was chosen because previous research has shown that sprinkler irrigation would likely have resulted in salt crystallization on the leaves, thus causing severe foliar damage. Furrow irrigation was not chosen because of the tendency for salt to accumulate on the ridges between the furrows. Also, since soils receiving saline water are subject to increasing salinity and decreasing permeability, a flood irrigation system left open the option to flush with excess water to leach salts from the soil in order to maintain a favorable Na^+ ion balance. This, however, did not become necessary during the one year study.

Because it was necessary to determine if tree survivability and production rates were affected by saline water or by some other environmental factor, one of the test plots served as a control. The control plot was irrigated with water (800 mg/ℓ salinity) from a domestic well on the site at an application rate of three acre feet/growing season. This rate corresponded to the application rate of geothermal fluid (adjusted to 2000 mg/ℓ salinity) to plot two. This enabled determination of whether or not water salinity had any impact on growth response of the species being tested.

Two water application rates were used on the three test plots. As previously mentioned, plot one, or the control plot, received 3.0 acre ft/yr (370,970 liters/yr) of domestic well water. Plot two was irrigated with the same amount of water; however, it received heat expended geothermal fluid (application temperature 25°C). Plot three received 4.5 acre ft/yr (554,941 liters/yr) of water with the same salinity concentration as that applied to plot two. The salinity concentration of 2000 mg/ℓ was maintained for plots two and three by adding NaCl to the 1500 mg/ℓ geothermal water prior to irrigation. Each basin was irrigated once per week throughout the growing season.

3.6 Sampling Collection and Handling

Five trees from each species were randomly selected at the beginning of the study and were dried and weighed to determine initial biomass content. After the growing season, six individuals of each species were randomly selected for harvesting from each study plot. This random selection occurred following a ranking of the trees. Once trees had been ranked according to physical growth condition, the selection was made in the group that encompassed 90% of the population. Sample selection was conducted such that three trees from each species were removed from each basin. Only above-ground biomass was collected. The trees were cut 10 cm above the soil surface in order to allow for coppice growth.

Once selected trees had been harvested, foliage was separated from the woody portion. This was done for all species with the exception of tamarisk which has a growth form not conducive to this type of treatment. The woody portion of the trees was ground to woodchips. The foliar and woody biomass samples were then oven dried at 90°C until the sample reached a constant weight. Each sample was then weighed.

3.7 Data Evaluation

The data were analyzed using an analysis of variance (ANOVA) procedure and the Duncan's Multiple Range Procedures.[17] The following model was used during the statistical evaluation:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

$i = 1, 2, 3$

$j = 1, 2, \ldots, 16$

$k = 1, 2, 3$

where

Y_{ijk} = percent change in biomass for species j in plot i replicate k.

μ = general effect common to all experimental units

α_i = effect of plot i

β_j = effect of species j

$(\alpha\beta)_{ij}$ = interaction effect of plot i by species j

ε_{ijk} = component of random error associated with observation ijk.

4. RESULTS AND DISCUSSION

4.1 Results from the ANOVA Tests

Results of the analysis of variance tests (ANOVA) on percent change in total (leafy and woody combined) biomass indicate that a significant species effect exists (99% confidence level: $p < 0.01$). There is no indication of a significant plot effect ($p = 0.994$) or a significant plot by species interaction ($p = 0.236$) (Table 3). In other words, although there was a significant biomass production difference among the various

TABLE 3. ANOVA BIOMASS PRODUCTION RESULTS:

Source	Degrees of Freedom	F Value	Probability
Plot	2	0.006	0.994
Species	15	20.56	0.001
Plot X Species	30	1.22	0.236
Error	96		
Total	143		

tree species tested, there was no significant difference in biomass production among the three test plots. These data indicate that the differences in salinity and in water application rates did not cause a significant difference in production. This information indicates that the concentration at which salinity begins to affect production of the species that grew well is higher than 2000 mg/ℓ. Likewise, an irrigation rate of 3 acre-ft/growing season met the water needs of most species. A summary of the production data is shown in Table 4, with descriptive statistics in Table 5.

4.2 Results from the Duncan's Multiple Range Procedure

Further investigation into the species effect was accomplished using Duncan's Multiple Range Procedure ($\alpha = 0.05$) with plots combined. This test further separated the significant differences in biomass production determined by the ANOVA. These differences are somewhat dampened by large standard deviations of the data sets. These deviations were primarily due to natural variation and the small sample size (the sample size was dictated to a large extent by the scope of the study). The rate of individual tree recovery after transplant was another important contributing factor to the data variation. Dieback and the length of dormancy following transplant was highly variable among individuals of each species. Such variation would not be present once the plantation became established. Nevertheless, even with the high standard deviation, several distinct tree growth performance classes do exist.

TABLE 4. MEAN WEIGHTS BEFORE AND AFTER ONE SEASON OF GROWTH FOR THE 1982 TREE STUDY

Species	$\bar{x}$ wt before growth* (grams)	$\bar{x}$ wt (grams) After One Year of Growth*								
		Plot 1[a]			Plot 2[b]			Plot 3[c]		
		woody biomass	leafy biomass	total biomass	woody biomass	leafy biomass	total biomass	woody biomass	leafy biomass	total biomass
Russian Olive	290	565	357	922	703	532	1235	723	765	1488
Theves Poplar	198	539	245	784	551	310	861	473	163	636
Siberian Elm	344	575	129	704	706	201	907	639	239	878
Black Locust	328	491	179	670	513	342	855	556	314	870
Hybrid Elm	1202	1176	88	1264	1370	248	1618	1542	329	1871
Globe Willow	679	794	245	1039	937	196	1133	807	161	968
Tamarisk	230	489	--**	489	541	--**	541	546	--**	546
Boxelder	53	209	139	348	141	53	194	183	69	252
Green Ash	292	331	99	430	318	112	430	306	106	412
Energy Mix Poplar	64	153	73	226	115	54	169	111	54	165
Sumac	40	95	51	146	102	42	144	102	54	156
Norway Poplar	418	389	208	597	265	221	486	287	167	454
Black Willow	42	66	36	102	89	30	119	63	30	93
Honey Locust	386	289	117	406	357	72	429	377	98	475
Russian Mulberry	260	232	8	240	329	21	350	193	24	217
Silver Maple	1410	965	119	1084	1129	112	1241	1092	82	1174

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* Results are reported on an oven dried basis, rounded off to the nearest gram.

** Leafy biomass was not separated from woody biomass for this species.

a. irrigated at a rate of 3 acre-ft/yr with water averaging 800 ppm salinity.

b. irrigated at a rate of 3 acre-ft/yr with water averaging 2000 ppm salinity.

c. irrigated at a rate of 4.5 acre-ft/yr with water averaging 2000 ppm salinity.

TABLE 5. DESCRIPTIVE STATISTICS FOR INCREASE[a] IN TOTAL BIOMASS (GRAMS)

Species	Mean	Standard Deviation	95% Confidence Interval for Mean		
Black Willow	62.2	28	40.6	to	83.7
Black Locust	470.2	306.4	234.6	to	705.7
Globe Willow	368.7	205.9	210.3	to	526.9
Silver Maple	244.0	156.3	-364.1	to	-123.8
Sumac	108.7	49.5	70.5	to	146.7
Russian Olive	924.8	405.5	613.0	to	1236.4
Norway Poplar	94.4	150.5	-21.2	to	210.1
Theves Poplar	562.2	131.6	461.0	to	663.4
Tamarisk	295.2	93.2	223.5	to	366.9
Boxelder	212.6	88.2	144.7	to	280.3
Russian Mulberry	8.8	96.4	-65.3	to	82.9
Siberian Elm	485.6	304.1	251.7	to	719.3
Green Ash	131.8	73.0	75.6	to	187.8
Hybrid Elm	382.6	424.3	56.4	to	708.7
Energy Mix Poplar	122.2	95.2	48.9	to	195.4
Honey Locust	50.1	86.1	-15.5	to	116.9

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a. Increase = mean total biomass--mean wt. before growth (calculated with data from Table 4).

Table 6 shows the groupings and ranking for mean percent change in total biomass for the 1982 growing season. All species connected by a vertical line represent a group of species whose performance was not significantly different from any other species within that group. For example, the production rates of russian olive, theves poplar and sumac were not significantly different from each other. Boxelder, however, grew significantly better than any of those species in the aforementioned group. All species listed below sumac had a production rate significantly lower than species of that same group. At least half of the species tested displayed encouraging rates of increase. Boxelder, russian olive, theves poplar and sumac were especially impressive as they demonstrated growth rates ranging from 272% to 409% increase in biomass. The measured performance of russian olive confirms the visual observation of the earlier findings of the 1981 screening study.[7]

Analysis was conducted to determine the distribution of production in the leafy and woody portions of the tree. These data are important as the form of biomass determines potential uses of the tissue produced. Also, by evaluating these data separately, a more detailed analysis of how the species responded to changes in water quality and quantity could be made. Results from the ANOVA run on the woody portion of the trees for purposes of evaluating the interaction between plot and species showed no significant difference. Following this evaluation, a Duncan's test was run on the data to determine which species were significantly different from each other (Table 7). Comparing results of the percent change in woody biomass (Table 7) to the mean change in total biomass (Table 6), boxelder was again the best performer. Theves poplar, sumac and russian olive changed positions within the group, but did not move into another group.

Data from the leafy portion of the trees were also subjected to an ANOVA and Duncan's test. The ANOVA test showed that there was a significant "species by plot" interaction. Thus, a separate Duncan's test was run to evaluate how the leafy portion of the trees responded to the various applications of the three plots. Results show that as the salt concentration increased, the variability and number of species within the groups changed (Table 8). Results from plot three show that as the amount of salt applied was increased, the number of groups increased and the number of species within each group decreased. This helps to exhibit which species have more tolerance to the saline water. This response may provide some indication of species tolerance to saline water.

TABLE 6. RESULTS FROM DUNCAN'S MULTIPLE RANGE TEST FOR MEAN PERCENT CHANGE IN TOTAL BIOMASS OVER THE INITIAL GROWING SEASON

Species	Mean Percent Change in Biomass Over One Growing Season	Duncan's Multiple Range Lines[a]				
Boxelder	409	│				
Russian Olive	319		│			
Theves Poplar	284		│			
Sumac	272		│			
Energy Mix Poplar	191			│		
Black Willow	148			│		
Black Locust	143			│		
Siberian Elm	141			│		
Tamarisk	128				│	
Globe Willow	54				│	│
Green Ash	45				│	│
Hybrid Elm	32					│
Norway Poplar	23					│
Honey Locust	13					│
Russian Mulberry	3					│
Silver Maple	-17					│

a. Species connected by the same line are not significantly different.

4.3 Users and Management of Silviculture Projects

Much of the land of the Intermountain West is controlled by the federal government. The land receives the greatest amount of solar radiation in the country, but a lack of rainfall limits the cultivation of agricultural crops. In many areas, water is available but, because of poor quality, is not acceptable for crop production. However, based on the preliminary results presented in this report, there is a good indication that a benefical use could be realized from some of these waters. Well developed programs with technically competent management will play a major role in the success of these types of projects.

TABLE 7. RESULTS FROM DUNCAN'S MULTIPLE RANGE TEST FOR MEAN PERCENT CHANGE IN WOODY BIOMASS OVER THE INITIAL GROWING SEASON.

Species	Mean Percent Change in Woody Biomass Over One Growing Season	Duncan's Multiple Range Lines*
Boxelder	242	
Theves Poplar	163	
Sumac	149	
Russian Olive	129	
Tamarisk**	---	
Energy Mix Poplar	97	
Siberian Elm	86	
Black Willow	73	
Black Locust	59	
Globe Willow	25	
Hybrid Elm	13	
Green Ash	9	
Russian Mulberry	-3	
Silver Maple	-12	
Honey Locust	-25	
Norway Poplar	-25	

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*Species connected by the same line are not significantly different.

**Tamarisk was not included because it has a growth form not conducive to separation of woody and leafy biomass.

TABLE 8. DUCANS MULTIPLE RANGE TEST ON THE INTERACTION BETWEEN PLOTS FOR LEAFY BIOMASS FROM ONLY 15 SPECIES

	Plot One				
Species	Mean % Change in Leafy	Duncans Multiple Range Lines			
Boxelder	267	│			
Sumac	128		│		
Theves Poplar	124		│		
Russian Olive	123		│		
Energy Mix Poplar	114		│	│	
Black Willow	85		│	│	│
Black Locust	54		│	│	│
Norway Poplar	50		│	│	│
Siberian Elm	37			│	│
Globe Willow	36			│	│
Green Ash	34			│	│
Honey Locust	30			│	│
Silver Maple	8			│	│
Hybrid Elm	7				│
Russian Mulberry	3				│

	Plot Two			
Species	Mean % Change in Leafy	Duncans Multiple Range Lines		
Russian Olive	184	│		
Theves Poplar	157	│	│	
Sumac	105	│	│	│
Black Locust	104	│	│	│
Boxelder	101	│	│	│
Energy Mix Poplar	84		│	│
Black Willow	71		│	│
Siberian Elm	58			│
Norway Poplar	53			│
Green Ash	38			│
Globe Willow	29			│
Honey Locust	25			│
Hybrid Elm	21			│
Russian Mulberry	8			│
Silver Maple	8			│

	Plot Three						
Species	Mean % Change in Leafy	Duncans Multiple Range Lines					
Russian Olive	264	│					
Sumac	135		│				
Boxelder	132		│				
Black Locust	96		│	│			
Energy Mix Poplar	84		│	│	│		
Theves Poplar	83		│	│	│		
Siberian Elm	69			│	│	│	
Black Willow	69			│	│	│	
Norway Poplar	40				│	│	│
Green Ash	36				│	│	│
Hybrid Elm	27					│	│
Globe Willow	24					│	│
Honey Locust	19					│	│
Russian Mulberry	9						│
Silver Maple	6						│

If silviculture projects are to be successful in the Intermountain West, they may need to serve a dual function. In most cases, the most important of these functions would be as a biomass producer. The following are additional benefits these types of projects could offer:

- Wastewater disposal/treatment--numerous types of wastewaters are generated that could be used to grow trees. All large towns have municipal wastewater systems. These waters are rich in nutrients and have been used to produce trees in other parts of the country. Large volumes of water are often produced during drilling and mining operations. Depending on what materials were present in that water, it could be used as an integral component in silvicultural operations. Other sources of water include, but are not limited to: natural saline springs, shallow saline aquifers, cooling water from power production and industrial facilities, and excessive spring runoff. Since pumping and irrigation systems cost money, the only economical way to develop such a disposal system is to locate it in close proximity to the source of water.

- Land Management--much of the federally owned land in the west is of marginal quality for agriculture and is used for grazing. Silviculture projects could be implemented to help reduce soil erosion, serve as wind breaks to retard desertification or curb problems with drifting snow, provide wildlife habitat, and help enrich the soil. However, these types of projects require good management practices and a thorough understanding of tree growth requirements.

4.4 Biomass Production

Short rotation tree plantations have the potential to produce large amounts of biomass on a limited area of land. However, in order to obtain good yields, the proper mixture of solar radiation, water, arable land and crop management is needed. The key to success in these systems is to determine where and under what conditions selected species can be used to produce biomass in an economical and energy efficient manner.

Because of the limited study period on the silviculture project at Raft River, it is difficult and would be misleading to project concrete production values. However, based upon our preliminary results, it is possible to calculate mean growth potential on a per hectare basis using some of the species that performed best during this first year study.

Mean potential biomass production rates, Table 9, were calculated based on the following assumptions:

- Size of each plot would be one hectare (ha)
- Trees would be planted on 1.25 m centers
- Trees would be planted to within 0.6 m of the berm on all sides
- ∿6562 trees could be harvested per ha
- Production values would be reported in dry metric ton per hectare per year.

Preliminary results show promise as to the potential to generate above average amounts of biomass. Average production rates for short-rotation intensive cultured systems for the Intermountain West have been projected to be 0 - 5 Mg ha^{-1} $year^{-1}$.[18] It should be noted that the reported values in Table 9 are felt to be conservative values for the following reasons:

- The trees were purchased as nursery stock and thus, many of the species were pruned and were not able to fully branch out in only one growing season
- This was the initial year for the larger-scale study and thus, many of the trees were recovering from transplant shock

- Based on results from other researchers, a greater average annual yield appears to occur between the first and second year's growth as compared to subsequent years.[21] Thus, a much greater percent increase during the next growing season might be expected if the project can be continued.

TABLE 9. POTENTIAL BIOMASS PRODUCTION (MEANS AND STANDARD DEVIATIONS) FROM A ONE YEAR TREE PLANTATION FOR SOME OF THE MORE PROMISING SPECIES

Species	Potential Biomass Production dry Mg ha^{-1} First Growing $Season^{-1}$ Means	Standard Deviations
Russian Olive	6.1	1.9
Siberian Elm	3.2	0.7
Theves Poplar	3.0	0.7
Black Locust	3.1	0.8
Hybrid Elm	2.2	2.4
Boxelder	1.4	0.5
Energy Mix Poplar	0.8	0.2
Sumac	0.7	0.1

4.5 Economics of Silviculture

The biomass productivity of a short-rotation silviculture plantation of given species on a given site is a function of stand density and management intensity. These and additional factors must be considered when evaluating the economic feasibility of these systems. Sensitivity analyses and economic payback studies have identified the most critical factors in the economics of short-rotation intensive cultures as being:

- Selling price of feedstocks

- Productivity per unit area

- Costs of land, site preparation, management practices and harvesting techniques

- Scale of operation, number of coppicings and rotations

- Uncertainity and variability of the data used to evaluate short-rotation intensive culture.[18,19,20]

It must be noted that productivity is the pivotal item in an economic evaluation. In order to realize short-rotation biomass yields which have been obtained experimentally, intensive management techniques have been required. Such management is costly; therefore, while large biomass yields in short-rotation silviculture plantations are technically possible, they are not economically feasible in all cases. Thus, feasibility of these systems can only be determined through a careful case-by-case analysis which considers the best alternative uses of land and capital involved.

It would be difficult and misleading to develop an economic evaluation for the project at Raft River due to the short period of record at this time. Planting and management costs for the projects were in line with values reported in the literature.[6,8,20] Because of the close proximity of the tree plantation to the geothermal development at Raft River, irrigation pumping and road constuction costs were minimal. As stated earlier, this is an important consideration in location of the plantation.

5. SUMMARY AND CONCLUSIONS

A silviculture research project was conducted at the Raft River geothermal facility to evaluate the potential for producing woody biomass on marginal lands using saline water. The project was a result of a screening study conducted in 1980 which showed that several species of trees could thrive in moderately saline waters. This silviculture project involved planting 1200 saplings of 16 different species of trees. The trees were planted into three test plots which received varying amounts of water with different salinity concentrations.

Results indicate that several species--boxelder, russian olive, and sumac--can increase their biomass anywhere from 292 to 409% over one growing season. These results are encouraging and demonstrate that land of marginal quality could play a role in producing biomass for energy conversion.

Results reported here are from only a one year study and are not conclusive. Thus, it is recommended that this study and/or studies similar to it be continued to further investigate the production potential of marginal lands. If this type of project proves successful, it could be adopted as a viable land management and conservation technique in the United States or other countries.

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