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SELECTION OF HIGH PRODUCING SHRUBS OF THE WESTERN UNITED STATES FOR ENERGY BIOMASS

Final Report

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SUMMARY

This project investigated the selection and preliminary study of the most productive native shrubs that are commonly found growing on millions of acres of arid and semiarid lands of the Western United States for their potential use as energy fuel from biomass. Many uncertainties exist in producing biomass for energy fuels. However, arid land shrub biomass production offers several advantages that may be more favorable than other biomass types. Shrubs could utilize available marginal croplands and rangelands; there would be little or no competition for scarce water resources, and within the wide diversity of native shrubs, a number of species have a potential for relatively large biomass production. Species chosen for study were fourwing saltbush (*Atriplex canescens*), big saltbush (*A. lentiformis*), big sagebrush (*Artemisia tridentata*), spreading rabbitbrush (*Chrysothamnus linifolis*), rubber rabbitbrush (*C. nauseosus*), and greasewood (*Sarcobatus vermiculatus*).

The study was divided into three phases. Phase one dealt with the selection, measurement, and burning quality of large growing shrubs in native populations. The main objective of phase two was to measure the biomass production of the selected large growing shrubs at a dryland field research station for three years. In addition the influence of planting space was ascertained. In phase three the genetic differences of large and small sagebrush (*A. tridentata*) were evaluated.

The results of phase one, the field study showed that shrub size and biomass production varied among the species. Big sagebrush was consistently the tallest while spreading rabbitbrush was the shortest. Fourwing saltbush produced the greatest ground cover. Greasewood provided the most biomass while sagebrush yielded the least. There were also difference in size within each species. These differences may be a result of genetic and/or ecological variation.

The burning quality of the shrubs varied among the species and plant part. Percent ash, sulfur and moisture was consistently lower for woody material than for current year's growth. Greasewood had the lowest percent ash in woody material but the highest in current year's growth. Percent sulfur was lowest in big sagebrush and highest in greasewood. Big sagebrush also had the lowest percent moisture while spreading rabbitbrush had the highest. Heat produced from the combustion of woody and current year's growth was about the same. Generally, heat of combustion varied from 4500 to 4700 Kcal/kg.

Shrub growth in the uniform garden study at Nephi, Utah, phase two, did not vary between the planting distances for the first two years. Apparently, the 1-meter spacing (within-row distance) between plants, plant competition was not great enough to influence shrub growth. Subsequently, plants with abundant growth began to compete for space. Plant survival among the shrubs was variable. Big sagebrush had the highest percent survival while big saltbush had the lowest. Plant growth was the greatest for fourwing saltbush and the poorest for greasewood. As expected, there were differences in growth among species from the various collection sites. The difference may result because of genetic and/or ecological reasons.

In phase three, the genetic and ecological differences between large and small growing big sagebrush plants were evaluated. Seedlings from large parent plants outgrew seedlings from small plants in both the greenhouse and uniform garden. A cytological study revealed that large sagebrush plants were diploid while small plants were tetraploid. In addition, a chromotographic study showed that the large and small plants could be separated based on their chromatograms. Large plants grew mainly in mesic habitats. The small plants were found in xeric habitats. Chemical analyses of the soil showed that large plants grew in more fertile soil than the small plants.

PHASE ONE: BIOMASS PRODUCTION AT SELECTED FIELD SITES

Introduction

As alternative energy sources are examined for their feasibility, it is logical to ask if highly productive native shrubs growing on millions of acres of arid and semi-arid rangelands of the Western United States have any potential use as energy fuel from their biomass. Although uncertainties exist in producing woody biomass for energy fuels, arid land shrubs offer several advantages that may be very favorable. Shrubs could be grown on marginal crop lands and multiple-use rangelands; there would be little or no competition for irrigation water; generally no need for fertilizer application; and within the wide diversity of native shrubs a number of species have a potential for relatively large biomass production on various soil conditions.

The main objective of this phase was to identify large-growing shrubs within a given species from native populations, measure their height, cover, basal circumference, burning quality and density. A secondary objective was to measure the regrowth of the shrubs two years after harvesting. In addition, the soil surface was sampled with each population to describe the physical and chemical properties supporting these large-growing shrubs.

Methods

Individual plants were selected for this study on the assumption that they would express a genetic ability to grow large and at a faster rate than the norm for the species. Such large biotypes would be valuable if they would be capable of superior growth under arid

conditions with but a minimum of management on various soil types. Personal observations have shown that some ecotypes within a species do not have the ability to grow large regardless of the environmental conditions.

Shrub species chosen for study were fourwing saltbush (Atriplex canescens), big saltbush (A. lentiformis), big sagebrush (Artemisia tridentata), spreading rabbitbrush (Chrysothamnus linifolius), rubber rabbitbrush (C. nauseosus), and greasewood (Sarcobatus vermiculatus). All are common to the cold deserts of the Intermountain states. Over 34 sites in Utah and the adjacent states were visited in the spring and summer of 1978 (Table 1). Possible study sites for large shrub biotypes were obtained from published records and from recommendations of range scientists.

At each site, three to five of the largest plants were measured and harvested. Plant height, plant cover, canopy thickness, stem basal circumference and plant biomass were measured for each plant harvested. Stem basal circumference is the total length around the stem or stems of the plant at ground level. Species such as greasewood, rabbitbrush and fourwing saltbush usually have multiple stems. Total plant biomass was separated into current year's growth and woody material. Also, individual plant mean area was determined by measuring its nearest neighbors. The height and ground cover of the nearest neighbors were also measured. However, only shrubs were considered as nearest neighbors. In addition, qualitative factors such as phenology, growth habit and plant vigor were assessed.

Table 1. Locations where giant shrubs were reported growing. Areas were subsequently visited for measurements and observations.

Utah	Nevada
Nephi Canyon	Wells
Jericho Sand Dunes	New Pass
Callao Road	Fallon
Maeser	Quail Canyon
Davis Spring Road	Palmetto
Huntington	Willow Creek
Johnson Canyon	Pyramid Lake
Nephi Field Station	Horse and Cattle Conservation
Antimony	Range
Monticello	Cold Spring
San Rafael Swell	Colorado
St. George	Little Dolores Canyon
Island Park	Dove Creek
Colo-Utah Border, Hwy. 650	Rangely
Henrieville	Meeker
Wyoming	Idaho
Buffalo Bill Reservoir	Fourth of July Canyon
Rock Springs	Bruno
Black Rock Butte	
Upper Slide Lake	

Samples of current year's growth and woody tissues were obtained from each shrub collected. These were oven dried, weighed and laboratory tested for heat of combustion, percent moisture, ash and sulfur.

At each site, a composite sample of surface soil (15 cm deep) was collected. Five to eight samples were put into a paper sack and thoroughly mixed with a portion of the soil being kept for laboratory analyses. Soil texture, pH, salinity and several fertility parameters were measured at the Utah State University Soil Testing Laboratory using standard procedures.

In order to measure regrowth of harvested shrubs, each site was revisited during September 1980. All species studied, except big sagebrush, have the potential for vegetal regrowth from the root crown after harvesting. At each site, plants that were harvested were located and the regrowth was again removed and weighed.

Results and Discussion

Plant size and density

Characteristically, within a given shrub community, larger than average shrubs can be found growing on favorable sites (Figures 1 and 2). Favorable sites represent areas which for some edaphic and/or topographical reason receive more moisture and have deep soils to promote plant growth. Such areas include swales, gullies, deep alluvial soils, etc.

The size and biomass of the large shrubs varied among sites (Table 2). In addition, there were obvious differences among species in size and biomass production. Big sagebrush was consistently the tallest

Figure 1. A population of large sagebrush in a valley bottom site north of Maeser, Utah. Note the small size of plants in the foreground.

Figure 2. A large sagebrush plant being measured for biomass characteristics.

Table 2. Mean size, biomass and density for 6 shrubs at various locations in the Intermountain area. Each mean is the average of three plants.

Species Site	Height m	Cover m^2	Stem Basal Circumference cm	Total Biomass (ovendry) kg	Plant Density No./$10m^2$
Big sagebrush					
Little Dolores Canyon	2.7	1.2	39.7	5.5	9.1
Maeser	3.2	3.5	53.0	13.6	2.4
Buffalo Bill Reservoir	2.3	3.8	62.7	15.9	1.3
Black Rock Butte	2.0	2.8	51.3	13.8	7.7
Big saltbush					
Cold Springs	1.9	5.6	--	17.5	--
St. George	2.2	7.8	160.0	30.5	1.5
Quail Canyon	2.0	7.5	148.0	17.5	5.2
Fourwing saltbush					
Jericho Sand Dunes	2.2	16.5	465.0	38.7	--
Utah-Colo Border	1.6	9.7	--	16.7	1.3
Kanab	1.5	5.2	147.7	12.0	2.8
St. George	1.7	11.7	209.3	33.6	1.4
Greasewood					
Davis Spring Road	2.4	9.1	186.7	44.8	2.1
Monticello	2.9	8.0	150.3	34.7	2.3
Palmetto	2.4	7.0	235.3	38.6	3.2

Table 2. Continued

Species Site	Height m	Cover m^2	Stem Basal Circumference cm	Total Biomass (ovendry) kg	Plant Density No./10m^2
Rubber rabbitbrush					
Huntington	1.8	5.7	--	3.1	2.2
Palmetto	2.4	7.5	164.7	16.7	2.8
Antimony	1.9	3.1	73.3	12.0	2.6
Monticello	1.7	8.3	80.0	33.6	2.9
Spreading rabbitbrush					
Henrieville	1.7	2.3	58.7	9.3	20.4
Nephi Field Station	1.6	4.8	110.7	25.6	1.2

among the species sampled and spreading rabbitbrush was the shortest. However, fourwing and big saltbush had the greatest ground cover and stem basal circunference whereas big sagebrush had the least. Greasewood provided the most biomass while sagebrush yielded the least. Differences among the biotypes relative to size within a species appeared to be associated with site favorability.

Big sagebrush and greasewood plant density was greater for the smaller sized shrubs than the larger shrubs (Table 2). Plants may compensate for a smaller size with a greater density to obtain an optimum biomass per unit area. Further research is needed to clarify the relationship of shrub biomass production to density. These data can be used only as a comparison at this time and for the conditions described.

Soil characteristics

Soil characteristics at the native sites were more uniform than expected (Table 3). Surface soil pH was basic at all sites. Values varied from 7.0 to 9.5. As expected, greasewood was found growing on the most alkaline soils. The electrical conductivity values varied from 0.3 to 5.9 mmhos/cm. The higher electrical conductivity values under which greasewood and big saltbush were growing was lower than expected as these species are normally found growing on highly alkaline soils. Values of electrical conductivity at these levels would be inhibitory to the growth of most crop plants. Soils on which greasewood plants were growing had the greatest variation while soils under spreading rabbitbrush had the smallest variation. The soil cation exchange capacity (CEC) of shrub study sites was highly variable.

Table 3. Soil analysis summary showing the range of values from 32 natural shrub growing sites in the Intermountain West.

Species	Number of sites	pH	ECe mmhos/cm	CEC meq/100g	Soil Class
Big sagebrush	11	7.2-7.7	0.3-1.5	2.8-21.5	Sand - silt loam
Fourwing saltbush	7	7.0-8.2	0.4-1.1	3.7-20.2	Sand - silt loam
Greasewood	3	7.9-9.5	0.7-5.9	7.2-17.1	Sandy loam - clay loam
Rubber rabbitbrush	6	7.5-7.9	0.4-1.7	1.6-19.6	Sand - clay loam
Spreading rabbitbrush	2	7.3-7.7	0.4-0.8	6.1-21.5	Loamy sand - silt loam
Big saltbush	3	7.5-8.3	0.8-3.1	3.7-14.7	Sandy loam

Values ranged from 2.8 to 21.5 mez/100g. The soil textural classes where big sagebrush was studied showed the greatest variation, whereas greasewood soil was the least. The surface soil texture was generally a sandy loam at all sites. Field observations indicate that spreading rabbitbrush may require more soil moisture than the other species.

Burning quality

The burning quality of arid land shrubs did not vary within species but did so among species (Table 4). Regardless of species, percent ash, sulfur and moisture was consistently lower for the woody material than for the current year's growth. Greasewood had the lowest percent ash in woody material but the highest in current year's growth compared with the other species. The high percent ash in current year's growth may influence the burning quality of this type of material. Among the six species, big sagebrush was the lowest in percent ash. Percent sulfur was lowest in big sagebrush and highest in greasewood. Big sagebrush also had the lowest percent moisture while spreading rabbitbrush had the highest. Heat produced from the combustion of woody and annual material was about the same for each species except greasewood. Combustion of greasewood annual growth produced less heat than the woody material.

Based on field data and laboratory results, approximate biomass and energy potentials for four rangeland shrubs can be calculated (Table 5). Rubber rabbitbrush and greasewood have the greatest potential for high energy production because of their ability to grow in dense stands and still have relatively high individual plant biomass yield. Fourwing saltbush does not grow in dense stands under natural

Table 4. Burning quality of the woody portion and the annual portion (leaves, young twigs) of five cold-desert shrubs from various locations through the Intermountain West. Each value is the average of three or more plants except the grand mean for each species.

Site	Ash		Sulfur		Moisture		Heat of Combustion	
	Woody %	Annual %	Woody %	Annual %	Woody %	Annual %	Woody Kcal/Kg	Annual Kcal/Kg
Big sagebrush								
Little Dolores	3.1	6.8	0.04	0.18	28.6	55.9	4567	4729
Maeser	3.0	6.5	0.04	0.19	22.0	55.4	4723	4735
Buffalo Bill	3.2	6.8	0.02	0.14	26.6	55.9	4683	4640
Black Rock	3.2	6.8	0.01	0.17	22.8	56.8	4586	4688
Mean	3.1	6.7	0.03	0.17	25.0	56.0	4639	4698
Fourwing saltbush								
Jericho	2.5	9.9	0.05	0.03	24.9	64.2	4542	4358
Utah-Colo.	3.5	9.9	0.10	0.51	43.3	52.3	4487	4292
Callao Road	3.5	9.9	0.10	0.51	20.4	55.5	4486	4292
Mean	3.5	9.9	0.08	0.35	29.5	57.3	4505	4314
Greasewood								
Davis Spring	1.6	19.8	0.18	0.42	27.7	71.9	4708	3680
Palmetto	--	--	--	--	48.1	62.1	4699	3837
Monticello	1.8	20.6	0.30	0.50	26.2	67.3	4772	3481
Mean	1.7	20.2	0.24	0.46	34.0	67.1	4726	3666
Rubber rabbitbrush								
Huntington	2.8	7.6	0.04	0.18	53.0	62.5	4623	4837
Monticello	2.5	7.2	0.03	0.21	50.0	53.8	4535	4767
Palmetto	--	--	--	--	27.2	45.0	4808	4878
Antimony	--	--	--	--	48.6	58.7	4745	4815
Mean	2.7	7.4	0.04	0.20	44.7	55.0	4678	4832
Spreading rabbitbrush								
Nephi F.S.	--	--	--	--	56.1	59.9	4505	4421
Henrieville	--	--	--	--	49.2	58.4	4613	4537
Mean					52.7	59.2	4559	4479

Table 5. Estimated yield and energy potential for big sagebrush, fourwing saltbush, greasewood, and rabbitbrush. Calculations are based on the highest yielding site as reported in Table 2.

Species	Average plant biomass (dryweight) kg	Plant density in nature[1/] No./ha	Estimated energy potential Kcal/ha
Big sagebrush	15.9	1316	97,900,000
Fourwing saltbush	33.6	292	44,400,000
Greasewood	44.8	2174	458,500,000
Rubber rabbitbrush	29.0	2632	366,900,000

[1/] Data from space plantings at field station or production fields could markedly increase plant density.

conditions. However, with minimal management, fourwing saltbush plant densities could be greatly increased in spaced plantings. Big sagebrush could also be grown in dense stands but in the locations studied its individual plant biomass was not as great as the other species. Being a root and stem sprouter, spreading rabbitbrush could develop a dense ground cover in a few years.

Shrub regrowth of harvested field plants

The regrowth potential after harvesting should be considered when selecting shrub species as a source of energy fuel. Species such as fourwing and big saltbush, greasewood, and rabbitbrush have the potential for vegetal regrowth from the root crown after being harvested. However, big sagebrush does not resprout after harvesting. However, this species can readily reseed itself if several parent plants are left in the harvested area.

One year after the initial collection of field biomass data sites were revisited to observe the nature of the regrowth response and to determine the amount where possible. Regrowth from all species was poor (Table 6). In many cases plants did not regrow at all. The lack of regrowth can be a result of many factors such as time of harvesting, age or size of plant, plant competition and vigor of plant when harvested. Studies need to be conducted to evaluate such possibilities.

Table 6. Regrowth of fourwing saltbush, greasewood, rubber rabbitbrush, spreading rabbitbrush and big saltbush 2 years after harvesting.

Species Location	Mean field weight, kg	Number of plants no growth	 new growth
Fourwing saltbush			
Jericho Sand Dunes, Ut.	---*		
Callao Rd., Ut.	4.1	2	1
Kanab, Ut.	--- 1/	3	0
Monticello, Ut.	---	3	0
Ut.-Co. border	---	3	0
St. George	---	3	0
Greasewood			
Palmetto, Nev.	---	3	0
Monticello, Ut.	1.0	2	1
Davis Spring Rd., Ut.	---	3	0
Rubber Rabbitbrush			
New Pass, Nev.	1.7	1	2
Johnson Canyon, Ut.	1.1	2	2
Antimony, Ut.	---	3	0
Palmetto, Nev.	---	3	0
Huntington, Ut.	---	3	0
Monticello	---	3	0
Cold Spring, Nev.	---	3	0
Spreading Rabbitbrush			
Henrieville, Ut.	.25	2	1
Big Saltbush			
Cold Spring, Nev.	---	3	0
Quail Canyon, Nev.	---	3	0
St. George, Ut.	---	3	0

* Could not relocate the plant

1/ --- indicates no field weights were determined

UNIFORM GARDEN STUDY

The objective of phase two was to compare the biomass production of selected large-growing shrubs at a dryland field research station for three years. The uniform garden was treated as a plantation for shrub biomass production in that only minimal management was used to maintain the plants.

Methods

At the time the shrubs were being measured at each study site during phase one, wildings (seedlings growing in native populations) and stem cuttings were collected to propagate plants of the large growing shrubs. Seeds were also collected from the large shrubs as they matured during late summer and fall, 1978.

Wildings, rooted-stem cuttings and seedlings of fourwinq saltbush, big saltbush, big sagebrush, rubber rabbitbrush and greasewood were grown in containers (Figure 3) at the Snow Field Station (Ephraim, Utah) and Utah State University (Logan, Utah). Standard greenhouse procedures as to watering and fertilizing were followed. Before outplanting at the Nephi Field Station (Nephi, Utah) plants were placed out-of-doors for hardening. Outplanting occurred in late spring 1979.

A field plot design was developed to test biomass production under plantation conditions and the influence of row space competition. The field design consisted of 60 rows; with a between-row distance of 3 m. The within-row spacing was 1.0 and 2.0 m. Shrubs from 40 different sites consisted of 51 big shrub biotypes; 27 sagebrush, 8 rabbitbrush, 3 greasewood, 10 fourwing saltbush and 3 big saltbush.

Figure 3. Seedlings growing in containers in preparation for field planting.

Six plants of each biotype constituted the basic field study unit, thus a total of 2488 plants were set out in the experiment (51 accessions, 2 row spacings, 4 replications, 6 plants). Extra plants of some accessions were planted at another study site on the Snow Field Station located at Snow College, Ephraim, Utah. Minimal weed control was accomplished by cultivation two times per year. Plants were not irrigated except for approximately 1 liter at the time of outplanting.

During September 1979, 1980 and 1981, plant survival, height and canopy cover were measured. Using height and canopy cover, plant volume was determined by the following formula:

$$V = \frac{\Pi}{6} abc$$

V = volume

a = diameter of widest part of canopy

b = diameter of narrowest part of the canopy perpendicular to "a"

c = height

Plant volume was used to compare plant growth among the species and between the two within-row spacings.

On August 5, 1981, three of the six plants of each basic planting unit were cut at ground level and weighed. A representative sample of each species accession was run through brush chipper and an aliquot of the resulting chopped up wood stems and leaves was taken for moisture determination.

Results and Discussion

First year of growth 1979

Apparently, spacing distance did not influence plant growth during the first growing season (Table 7). Overall, plant survival was 82 percent and plant volume was 0.004 M^3 for both of the spacing treatments. In addition, survival and plant volume were essentially the same between the 1 and 2 m spacings for each species.

However plant survival and growth did vary among the species (Table 7). Fourwing saltbush and big sagebrush had the highest percent survival. Plant survival was the poorest for Greasewood. Plant volume was the greatest for fourwing saltbush and the least for big saltbush.

Second year of growth 1980

Plant competition after the second season of growth was not intense enough to influence plant survival and growth between the two spacing treatments (Table 8). Plant survival was 58 and 60 percent between the 1 and 2 m spacing respectively on September 23, 1980. Plant volume was 0.3 and 0.2 m^3 for shrubs growing within the 1 and 2 m spacing, respectively. Likewise, plant survival and growth was essentially the same between the 2 spacings for each species.

There were differences in plant survival and growth among the species (Table 8). Big sagebrush had the highest percent survival while big saltbush had the lowest (all plants died). Plant growth (volume) was the greatest for fourwing saltbush and the poorest for greasewood.

Table 7. Mean plant volume and percent survival on October 10, 1979 for fourwing saltbush, rubber rabbitbrush, greasewood, big sagebrush, and big saltbush after the first season of growth in a dryland biomass plantation at the Nephi Field Station. Shrubs were planted at two within row distances.

	Plant Spacing			
	1m		2m	
Species Location	% survival	Plant volume M^3	% survival	Plant volume M^3
Fourwing saltbush				
Jericho Sand Dunes	90	0.03	85	0.04
Callao Road	100	0.008	95	0.009
Little Delores River	95	0.009	100	0.02
Huntington	100	0.02	100	0.01
Johnson Canyon	100	0.03	100	0.02
Monticello	100	0.01	100	0.01
Willow Creek	100	0.02	100	0.02
St. George	100	0.03	90	0.02
Nephi Field Station	100	0.02	90	0.02
Mean	98	0.02	96	0.02
Rubber rabbitbrush				
Huntington	65	0.0001	75	0.0002
Johnson Canyon	75	0.0002	90	0.0004
Antimony	65	0.0004	90	0.0003
Monticello	85	0.0003	90	0.0004
New Pass	65	0.002	80	0.001
Pyramid Lake	65	0.0008	80	0.0007
Antimony	50	0.0005	45	0.0004
Mean	67	0.0006	79	0.0005
Greasewood				
Davis Spring Road	70	0.0002	50	0.0002
Monticello	60	0.0004	35	0.0003
Rangely	35	0.0001	50	0.0002
Fallon	100	0.002	95	0.003
Mean	66	0.0007	58	0.0008

Table 7. Continued

Species Location	Plant Spacing 1m % survival	1m Plant volume M^3	2m % survival	2m Plant volume M^3
Big sagebrush				
Nephi Canyon	100	0.003	100	0.001
Maeser	100	0.002	100	0.003
Little Dolores River	80	0.002	100	0.002
Cody	100	0.001	95	0.0006
Rock Spring	100	0.0004	100	0.0007
Antimony	100	0.002	100	0.001
Dove Creek	100	0.003	100	0.003
North Wells	100	0.0006	100	0.0005
Palmetto	100	0.001	100	0.002
San Rafael Swell	100	0.001	95	0.001
Meeker	100	0.002	100	0.002
Johnson Canyon	100	0.003	100	0.003
Mean	98	0.002	99	0.002
Big saltbush				
Quail Canyon	85	0.0001	85	0.002
Fallow	75	0.0003	75	0.0001
Mean	80	0.0002	80	0.0008
Grand Mean	82	0.004	82	0.005

Table 8. Mean plant volume and percent survival on September 23, 1980 for fourwing saltbush, rubber rabbitbrush, greasewood, big sagebrush, and big saltbush after the second season of growth in a dryland biomass plantation at the Nephi Field Station. Shrubs were planted at two within row distances.

	Plant Spacing			
	1m		2m	
Species Location	% survival	Plant volume M^3	% survival	Plant volume M^3
Fourwing saltbush				
Jericho Sand Dunes	90	1.6	85	1.9
Callao Road	100	0.6	95	0.7
Little Delores River	95	0.7	95	0.8
Huntington	100	0.9	95	1.0
Johnson Canyon	100	1.0	100	0.8
Monticello	100	0.7	100	0.8
St. George	30	0.1	25	0.5
Nephi Field Station	100	1.0	90	1.1
Willow Creek	95	0.5	90	0.5
Mean	90	0.8	86	0.9
Rubber rabbitbrush				
Huntington	100	0.07	100	0.07
Johnson Canyon	70	0.06	90	0.09
Antimony	60	0.04	95	0.05
Monticello	90	0.08	80	0.1
New Pass	100	0.04	100	0.04
Pyramid Lake	70	0.03	85	0.04
Mean	82	0.05	92	0.07
Greasewood				
Davis Spring Road	20	0.01	25	0.06
Monticello	30	0.10	10	0.01
Rangely	10	0.03	20	0.05
Mean	20	0.05	18	0.04

Table 8. Continued

Species Location	Plant Spacing 1m % survival	1m Plant volume M^3	2m survival	2m Plant volume M^3
Big sagebrush				
Nephi Canyon	100	0.07	100	0.08
Maeser	100	0.1	90	0.2
Little Dolores River	95	0.2	100	0.2
Cody	95	0.05	95	0.05
Rock Springs	100	0.05	95	0.05
Antimony	95	0.09	100	0.07
Dove Creek	100	0.2	100	0.1
North Wells	100	0.04	100	0.04
Palmetto	100	0.09	100	0.1
San Rafael Swell	95	0.2	100	0.1
Meeker	100	0.1	95	0.1
Johnson Canyon	100	0.1	100	0.2
Mean	98	0.1	98	0.1
Big saltbush				
Quail Canyon	0	--	5	0.001
Fallon	0	--	5	0.003
Mean	0	--	5	0.002
Grand Mean	58	0.3	60	0.2

Third year of growth 1981

By the end of the third growing season plant spacing began to show its effects on plant volume as indicated by the volume index values (Table 8). Variability among the biotypes was high and indicates that some were not well adapted to environmental conditions at the Nephi Dryland Station. Further, the outstanding performance of some biotypes suggests that they would be good candidates for use in biomass plantations in sites similar to the Nephi Station (Table 9).

A comparison of the four species that grew at the Nephi Station indicates that sagebrush and fourwing saltbush were much better adapted to site conditions than the rabbitbrush or greasewood accessions (Figure 4). Average plant volume for sagebrush in the 1-meter spacing was .712 as compared with .798 m^3 in the 2-meter spacing. Fourwing saltbush showed a volume of 1.62 m^3 at the 1 meter spacing as compared with 1.99 m^3 at 2 meters. Rabbitbrush volume was also less at the 1-meter spacing (.235 m^3) as compared with the 2-meter spacing (.299 m^3). Because of low survival for greasewood the numerous gaps in the rows precluded spacing from showing an adverse influence in plant volume even though the data show a positive effect. Average biomass yield of shrubs harvested in early August 1981 indicated that row spacing was not a major influence during the three year period of growth (Table 10). However, the data suggest a trend for heavier plants in the 2-meter row spacing which is in agreement with the larger volume measurements in the wider spacing.

Generally, fourwing saltbush plants were larger than sagebrush which in turn were larger than greasewood. Rabbitbrush plants were the smallest. Obviously, this was in contrast to the size of these

Table 9. Mean plant volume of big sagebrush, fourwing saltbush, rabbitbrush and greasewood in a biomass plantation at the Nephi Field Station, Nephi, Utah, August 5, 1981.

Collection	Location	Row spacing	Volume index cu m 1980	1981
Sagebrush				
1	Nephi Canyon	1 meter	.078	.648
		2 meter	.074	.753
4	North Maeser	1 meter	.117	.820
		2 meter	.154	.982
6	Little Delores	1 meter	.154	1.002
		2 meter	.207	1.209
10	Cody	1 meter	.048	.525
		2 meter	.044	.459
11	Rock Springs	1 meter	.049	.436
		2 meter	.049	.432
13	Johnson Canyon	1 meter	.149	1.010
		2 meter	.171	1.134
16	Antimony	1 meter	.091	.636
		2 meter	.072	.588
22	Dove Creek	1 meter	.150	.977
		2 meter	.133	.991
24	North Wells	1 meter	.033	.378
		2 meter	.040	.669
28	Palmetto	1 meter	.088	.720
		2 meter	.128	.745
29	San Rafael	1 meter	.081	.548
		2 meter	.094	.641
33	Rangely	1 meter	.123	.753
		2 meter	.141	.928
34	Meeker	1 meter	.094	.714
		2 meter	.112	.904
35	San Rafael	1 meter	.154	.850
		2 meter	.112	.748
37	Meeker	1 meter	.113	.764
		2 meter	.116	.939
38	Little Delores	1 meter	.116	.743
		2 meter	.159	.761
40	Antimony	1 meter	.111	.588
		2 meter	.114	.682
	Species Means:	1 meter	.106	.712
		2 meter	.113	.798

Table 9. Continued

Collection	Location	Row spacing	Volume index cu m 1980	1981
Fourwing saltbush				
2	Jericho #1	1 meter	1.517	2.839
		2 meter	1.911	3.739
3	Callao Road	1 meter	.545	1.081
		2 meter	.678	1.373
7	Little Delores	1 meter	.657	1.341
		2 meter	.810	1.782
8	Huntington	1 meter	1.038	1.934
		2 meter	1.026	1.996
12	Johnson Canyon	1 meter	1.038	1.379
		2 meter	.842	1.258
15	Nephi Field St.	1 meter	1.027	1.834
		2 meter	1.063	2.125
21	Monticello	1 meter	.684	1.322
		2 meter	.780	1.916
23	Jericho #2	1 meter	1.420	3.081
		2 meter	1.821	3.657
30	St. George	1 meter	.127	.457
		2 meter	1.117	3.60
39	Willow Creek	1 meter	.496	.877
			.486	1.031
	Species Means:	1 meter	.855	1.62
		2 meter	.987	1.99
Rabbitbrush				
9	Huntington	1 meter	.070	.242
		2 meter	.065	.299
14	Johnson Canyon	1 meter	.058	.271
		2 meter	.090	.387
17 Chna	Antimony	1 meter	.033	.247
		2 meter	.049	.277
18 Chli	Antimony	1 meter	.055	.318
		2 meter	.059	.442
20 Chna	Monticello	1 meter	.081	.337
		2 meter	.102	.422
25	New Pass	1 meter	.024	.163
		2 meter	.047	.176
31	Pyramid	1 meter	.031	.132
		2 meter	.377	.142
36	Johnson Canyon	1 meter	.033	.166
		2 meter	.054	.249
	Species Means:	1 meter	.048	.235
		2 meter	.063	.299

Table 9. Continued

Collection	Location	Row spacing	Volume index cu m 1980	1981
Greasewood				
5	Davis Springs	1 meter	.105	.353
		2 meter	.059	.323
19	Monticello	1 meter	.100	.802
		2 meter	.012	.230
32	Rangely	1 meter	.028	.321
		2 meter	.049	.257
	Species Means:	1 meter	.078	.492
		2 meter	.040	.270

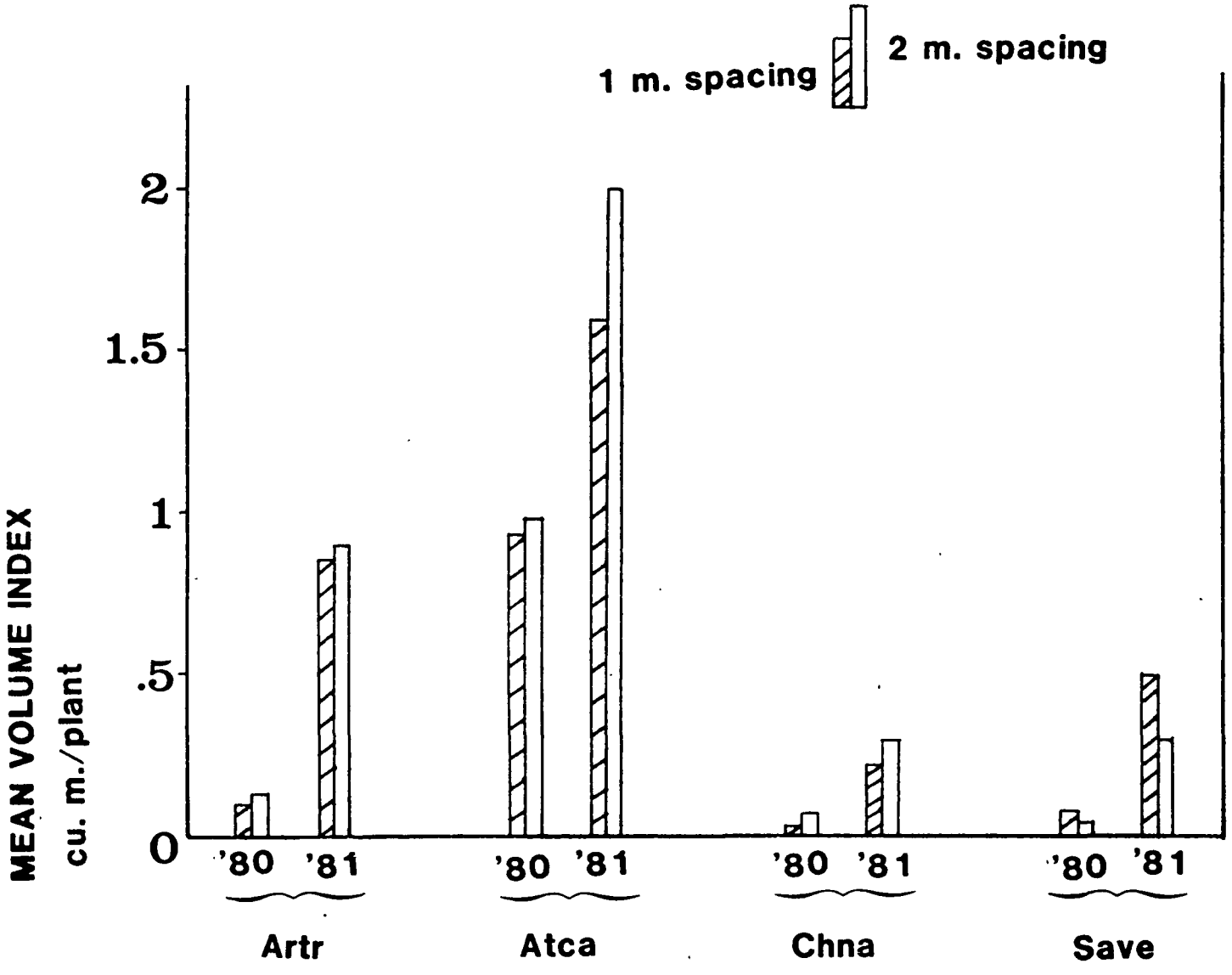

Figure 4. Comparison of shrub volume increase from the second to third growing season as influenced by row spacing.

Table 10. Mean green weight of large biotypes of big sagebrush, fourwing saltbush, rabbitbrush and greasewood grown for 3 years in a biomass plantation at the Nephi Dryland Station, Nephi, Utah. Figures are the average of 4 replications of 2 plants/ replications.

Collection location	Green wt (Kg/plant) 1 meter spacing	2 meter spacing
Sagebrush		
Nephi Canyon, Ut.	2.20	2.35
North Maeser, Ut.	2.91	3.74
Little Delores #1, Co.	3.44	4.20
Cody, Wyoming	2.16	1.81
Rock Springs, Wyo.	1.62	2.21
Johnson Canyon, Ut.	3.15	3.67
Antimony, Ut.	3.02	3.14
Dove Creek, Co.	3.89	3.75
North Wells, Nev.	1.41	1.94
Palmetto, Nev.	2.77	3.04
San Rafael, Ut.	2.24	2.89
Rangely	2.99	3.47
Meeker, Co.	2.47	3.31
San Rafel, Ut.	3.11	2.85
Maeser, Ut.	2.59	3.34
Little Delores #2 Co.	2.71	3.04
Antimony, Ut.	2.20	2.84
Means	2.64	3.04
Fourwing saltbush		
Jericho, Ut.	5.54	8.86
Callao Rd., Nev.	3.68	5.34
Little Delores Co.	3.99	6.11
Huntington, Ut.	6.41	6.03
Johnson Canyon, Ut.	4.94	5.00
Nephi Field Stn., Ut.	5.01	7.52
Monticello, Ut.	4.85	6.74
Jericho #2, Ut.	7.41	9.47
St. George, Ut.	1.05	3.60
Willow Creek, Ut.	4.51	5.00
Means	4.74	5.36

Table 10. Continued

Collection location	Green wt (Kg/plant) 1 meter spacing	2 meter spacing
Rabbitbrush		
Huntington, Ut.	.81	.95
Johnson Canyon, Ut.	.33	.64
Antimony #1, Ut.	.97	.86
Antimony #2, Ut.	.60	1.22
Monticello, Ut.	.64	.94
New Pass, Nev.	.38	.69
Pyramid Lake, Nev.	.45	.56
Johnson Canyon #2, Ut.	.62	.52
Means	.60	.80
Greasewood		
Davis Springs	1.10	1.00
Monticello	3.30	1.30
Rangely	1.35	1.50
Means	1.92	1.27

plants in their original collection sites as reported in phase I. Rabbitbrush plants did not appear to be adapted to the Nephi Field Station environment and the greasewood transplants were severely grazed back by rabbits during the first season of the study.

There was considerable variability among the biotypes of each species, thus indicating a high variability and opportunity to select for large plants within the populations of these four shrub species.

The highest yielding sagebrush biotypes were from little Delores Canyon near the Utah-Colorado stateline (Figure 5). Other large biotypes were from Dove Creek, Colorado, Johnson Canyon in Southern Utah and Maeser Utah. The lightest plants were from Wells, Nevada, Rock Springs and Cody, Wyoming.

The largest fourwing saltbush plants were from the Jericho sand dunes of central western Utah (Figure 6). These plants are known to be diploid (2n) according to Professor Howard Stutz of the Brigham Young University and consistantly show a much larger size than polyploid species found in other locations. Another high yielding biotype was taken from the Nephi Field Station but was originally collected in New Mexico. Because of their larger size the fourwing saltbush plants demonstrated a marked increase in weight when grown in the 2 meter spacing.

Rabbitbrush plants produced considerably less biomass at the Nephi Field Station than sagebrush or fourwing saltbush and none of the biotypes were outstanding in yield (Figure 7). Of the three surviving greasewood biotypes only the Monticello accession showed any indication of yield potential for sites similar to the Nephi station (Figure 8).

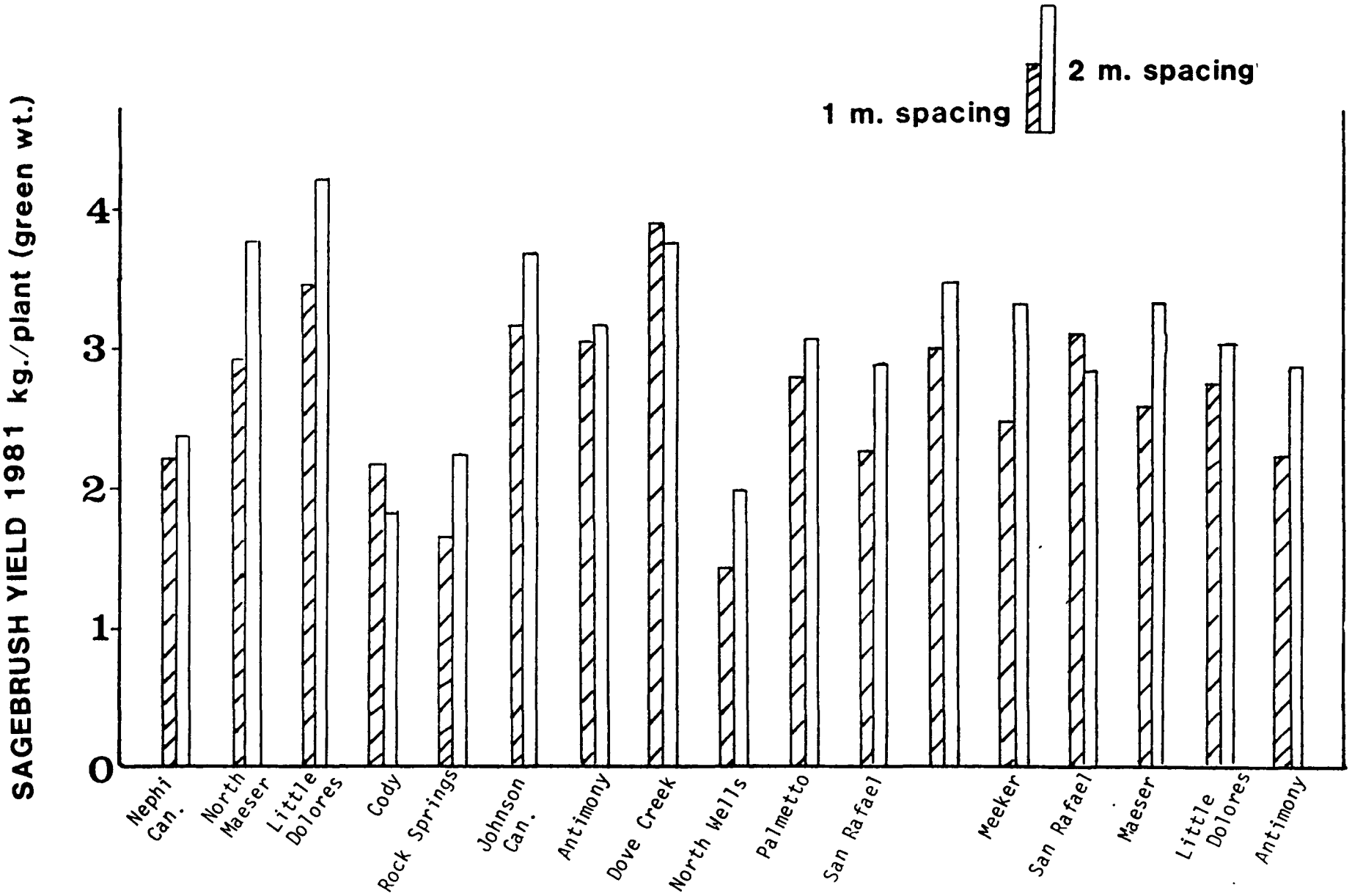

Figure 5. Variability in biomass yield of large biotypes of sagebrush grown at the Nephi Dryland Field Station for years.

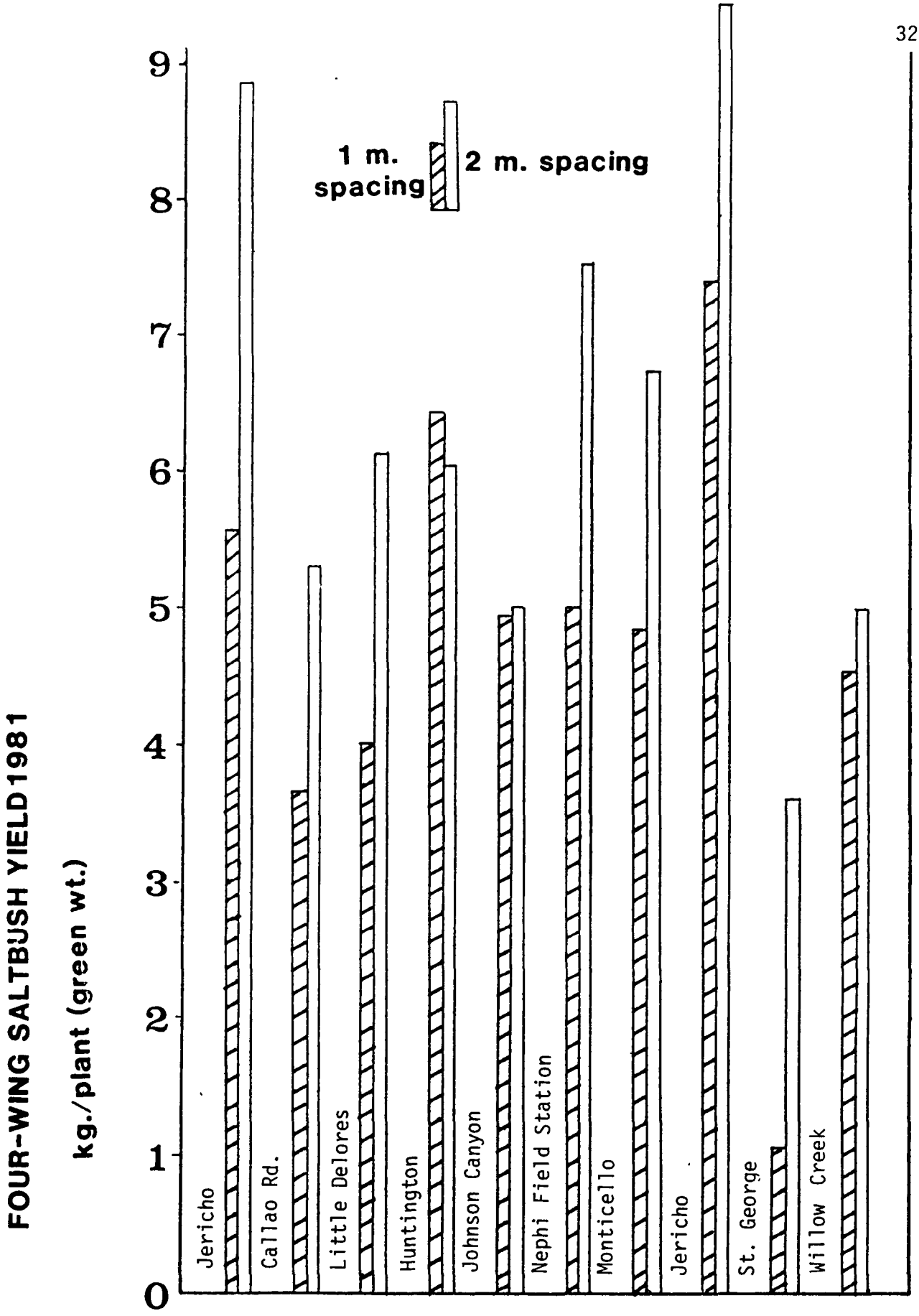

Figure 6. Variability in biomass yield of large fourwing saltbush biotypes grown at the Nephi Dryland Field Station for three years.

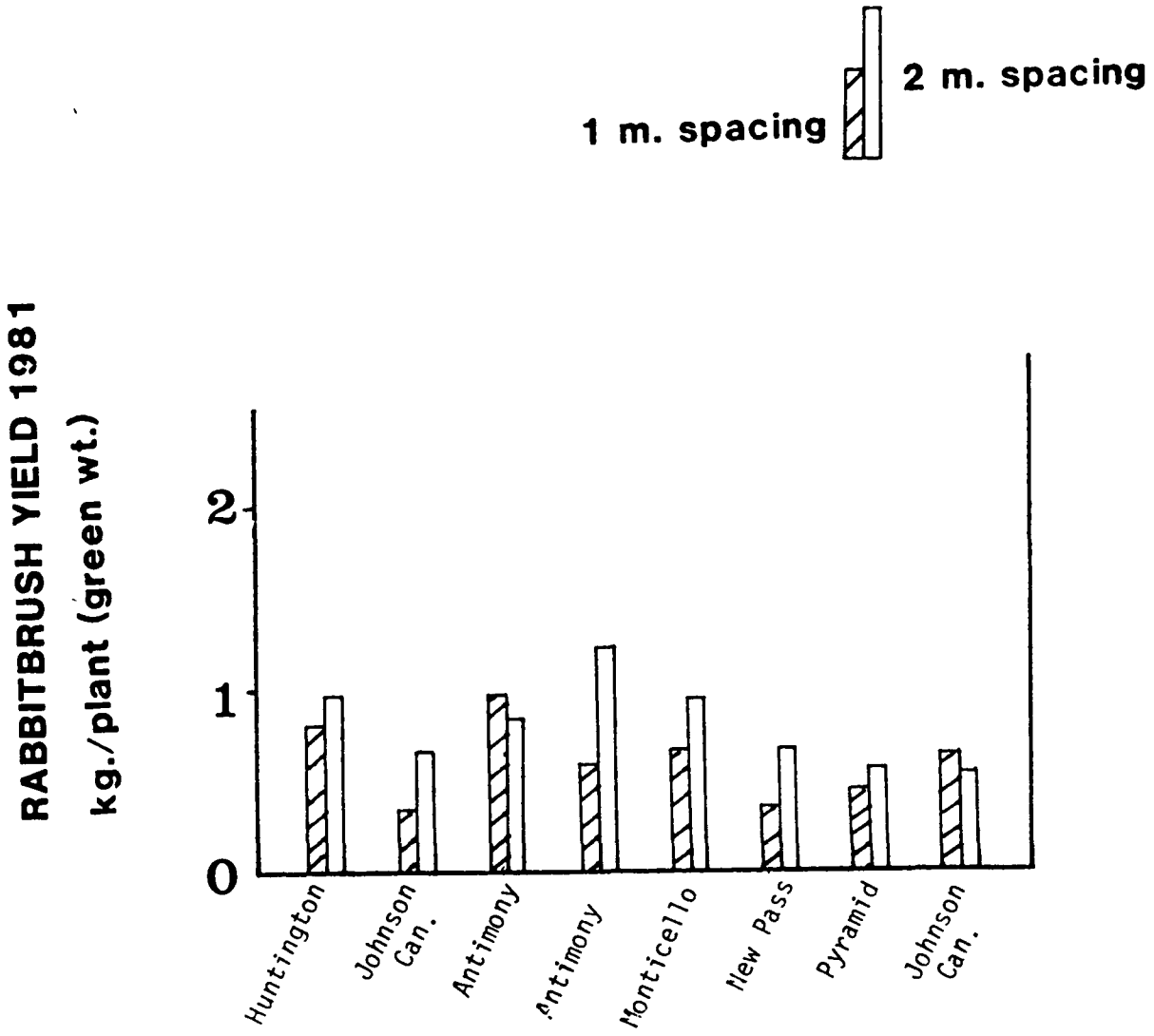

Figure 7. Variability in biomass yield of large rabbitbrush biotypes grown at the Nephi Dryland Field Station for three years.

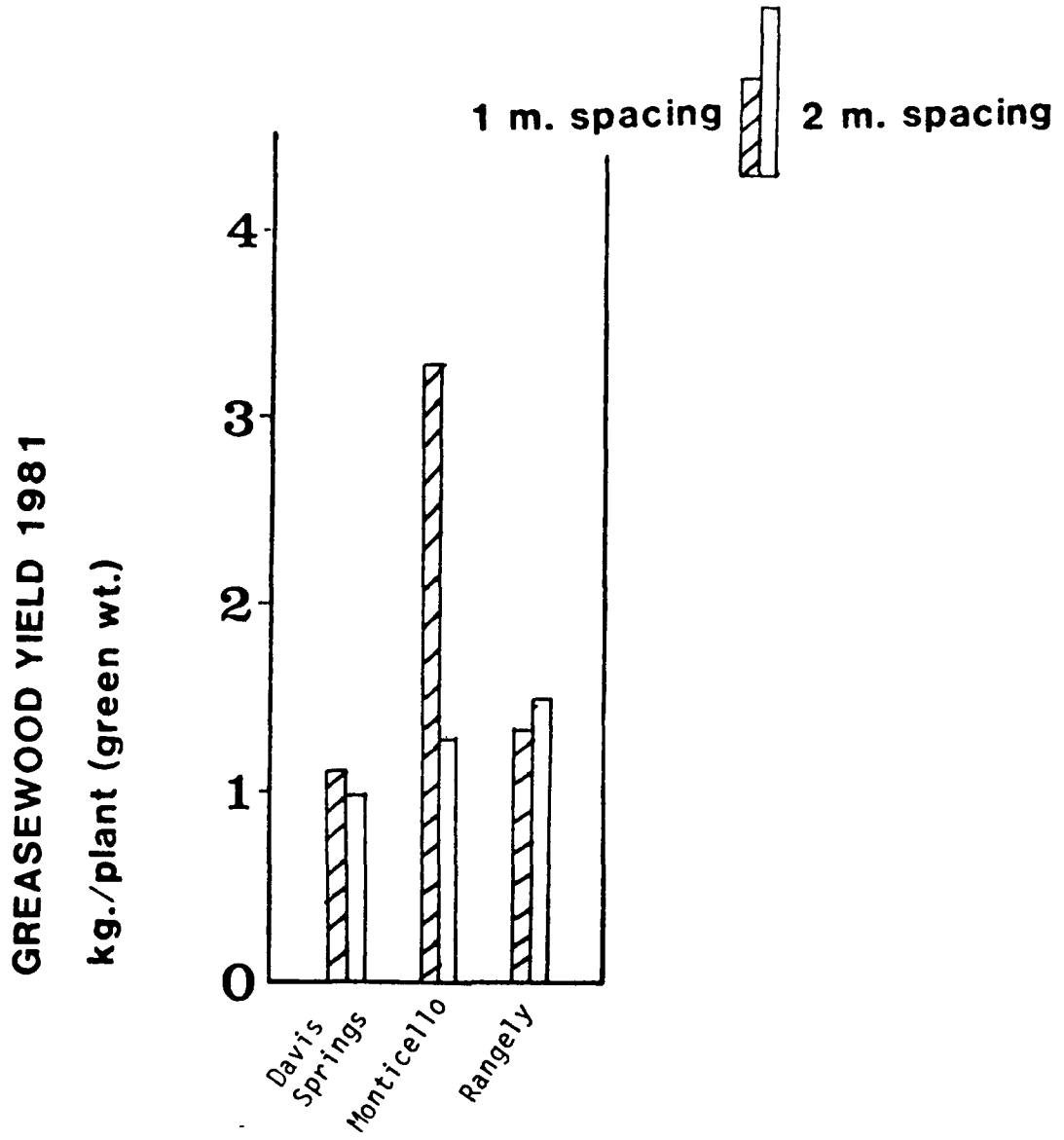

Figure 8. Variability in biomass yield of large greasewood biotypes grown at the Nephi Dryland Field Station for 3 years.

In addition to the data generated from the biomass plantation at the Nephi Dryland Experiment Station, harvest yields were obtained from a smaller plantation at the Snow Field Station at Ephraim, Utah. Some comparisons of biomass yields for selected biotypes of sagebrush (Table 11) and fourwing saltbush (Table 12) indicate that the Snow Field Station was a more favorable location for shrub biomass than the Nephi Station. Biomass yields on a per plant basis was more than double at the Snow Field Station.

Extrapolating the data obtained on an individual plant basis to an area basis provides some interesting and exciting yield possibilities. If sagebrush were to be grown on a 1-meter spacing, yields of green material as high as 10 tons per hectare could be obtained at the Nephi Station using the biotype from Little Delores Canyon (Table 13). At the Snow Station 27 tons per acre could be grown at a location similar to the Snow Field Station. Assuming that fourwing saltbush would grow larger at a 2-meter spacing than at 1 meter, biomass yields as high as 17.4 tons per hectare could be grown at the Nephi Station using the Jericho No. 2 biotype. Even greater yields might be expected by using the Jericho No. 1 biotype at environments similar to the Snow Field Station where 38.9 tons per hectare were calculated (Table 14).

The amount of moisture contained in the leaves and stems of the harvested shrubs is important to the total perspecitve using shrubs for their biomass fuel potential. The moisture content of the four shrub species and selected individuals varied according to the amount of woody tissue present, such as in fourwing saltbush (Table 15) and the succulence of leaves such as in greasewood.

Table 11. Biomass yields of selected biotypes of big sagebrush grown in 1-meter spacings at the Nephi and the Snow Field Stations for three years.

Sagebrush

Weight comparison - Two locations
1 meter spacing - Kg (green wt.)

Location	Nephi	Snow
Little Delores	2.71	7.60
Maeser	2.91	6.40
Johnson Canyon	3.15	5.90
Dove Creek	3.89	5.40
Meeker	2.47	5.30
Nephi Canyon	2.20	4.85

Table 12. Biomass yields of selected biotypes of fourwing saltbush grown at 2-meter spacing at the Nephi and the Snow Field Stations for three years.

Fourwing saltbush

Weight comparison - Two locations
2 meter spacing - Kg (green wt.)

Location	Nephi	Snow
Jericho	8.86	21.20
Jericho	9.47	15.20
Huntington	6.03	14.05
Little Delores	6.11	9.50
Callao	5.34	8.70
Monticello	6.74	8.00

Table 13. Weight comparison of sagebrush grown at two locations at a 1-meter spacing. (Tons/ha green wt).

Location	Nephi	Snow
Little Delores	10.00	27.90
Maeser	10.70	23.50
Johnson Canyon	11.60	21.70
Dove Creek	14.30	19.80
Meeker	9.10	19.50
Nephi Canyon	8.10	17.80

Table 14. Weight comparison of fourwing saltbush grown at two locations at a 2-meter spacing. (Tons/ha green wt).

Location	Nephi	Snow
Jericho	16.30	38.90
Jericho	17.40	27.90
Huntington	11.10	25.80
Little Delores	11.20	17.50
Callao	9.80	16.00
Monticello	12.40	14.70

Table 15. Moisture content of large shrub biotypes grown at the Nephi Dryland Field Station. Samples for moisture analyses were obtained from branches run through a clipper.

Species	Location	Percent Moisture %
Sagebrush		
Plot # 1	Nephi Canyon, Utah	60
4	North Maeser, Utah	58
6	Little Delores Creek Col.	59
10	Cody, Wyo.	61
11	Rock Springs, Wyo.	63
13	Johnson Canyon, Utah	60
16	Antimony, Utah	61
22	Dove Creek, Col.	62
29	San Rafael Swell, Utah	64
33	Rangely	61
37	San Rafael Swell, Utah	60
38	Little Delores Creek, Col.	63
40	Antimony, Utah	62
	Mean moisture percent	61.09
Fourwing saltbush		
2	Jericho Sand Dunes, Utah	57
3	Callao Road, Utah	62
8	Huntington, Utah	58
12	Johnson Canyon, Utah	57
15	Nephi Field Station, Utah	61
21	Monticello, Utah	57
23	Jericho Sand Dunes, Utah	59
39	Willow Creek, Nevada	66
	Mean moisture percent	59.6
Rabbirbrush		
9	Huntington, Utah	65
14	Johnson Canyon, Utah	69
17	Antimony, Utah	66
18	Antimony, Utah	64
20	Monticello, Utah	67
25	New Pass, Nevada	62
31	Pyramid Lake, Nevada	62
36	Johnson Canyon, Utah	68
	Mean moisture percent	65.38

Table 15. Continued

Species	Location	Percent Moisture %
Greasewood		
Plot # 5	Davis Spring, Utah	61
19	Monticello, Utah	67
32	Rangely, Col.	64
	Mean moisture percent	64.0

Costs for field maintenance

No cost data are available for the container grown plants or planting operations. However, current prices for container grown species equal to those outplanted in 1978 would be approximately 60¢/plant.

Plants were set out in an experimental field that had been kept relatively weed free and fallowed 2 years prior to planting. Yearly cultivation for weeds required 1 hr. of a 40 hp tractor with a cultivator. In addition twice yearly 2 hours of hand/hoe weeding was required. In fields of heavy weed populations more cultivation would be required to reduce weeds, to obtain the benefits of space-planting in terms of soil moisture available for use by the biomass shrub weed control is essential.

PHASE TWO: GENETIC DIFFERENCES BETWEEN LARGE AND SMALL *ARTEMISIA TRIDENTATA* PLANTS IN CONTIGUOUS POPULATIONS

Characteristically, within a given shrub community, larger than average shrubs can be found growing on favorable sites. Favorable sites represent areas which for some edaphic and/or topographical reason receives more moisture and have deep, fertile soils to sustain large plant growth. Such areas include swales, gullies, alluvial soils, etc. The question is: are these shrubs larger than the surrounding shrubs because of genetic or environmental reasons. To find an answer to this question big sagebrush was selected for intensive study.

The objective of phase three was to investigate the genetic and environmental relationships of large and small big sagebrush plants as they are found growing in contiguous populations.

Study Sites

Three study sites were selected for study because of the discrete differences in plant size which occurred within relatively short distances. At each site, large big sagebrush plants were growing within and adjacent to a gully, plant height decreased with distance from the gully.

The Sage Creek study site (T.12 N.,R.7 C., Sec. 20 NW 1/4 SE 1/4) was located about 4.8 km west of Sage Creek Junction on Highway 30 in northeastern Utah. Average annual precipitation varied from 25-30 cm. The frost free period ranges between 55-65 days (personal communication,

Soil Conservation Service Personnel, Logan, Utah). Elevation is 1950 m. Slope associated with the small plants varies around 15-20 percent. The slope associated with the large plants is 3-4 percent. The exposure is northerly.

The Greasewood Wash study site (T. 23 N., R. 101 W., Sec. 32 SW 1/4 SW 1/4) was located about 19.2 km north of the Jim Bridger Coal Mine along Sweetwater County Road 4-17 in southwestern Wyoming. Average annual precipitation varies from 17 to 22 cm. The frost free period ranges from 80-110 days (personal communication with Soil Conservation Service personnel, Rock Springs, Wyoming). The slope of the site is 2 to 4% with a western exposure.

The Maeser study site (T. 35, R. 25 E., Sec. 17 NE 1/4 NW 1/4) was located 11.2 km north of Maeser, Utah along Taylor Mountain Road. Average annual precipitation is 25 to 30 cm. The frost free period ranges between 110-140 days. Slope of the area is 3-4 percent with a southern exposure. Elevation is 2296 m.

Methods

Plant-height measurements, a plant-water relationship study, and soil and plant tissue chemical analyses were conducted to characterize each study site. Six individual experiments tested the hypotheses of genetic differences between large and small statured A. tridentata plants in contiguous populations. Greenhouse and uniform garden studies compared seedling growth. Morphological, phenological, cytological, and chromatographic studies also examined potential genetic differences. A chromatographic study tested for the

possibility that large and small statured shrubs intermix between contiguous populations.

Plant-height measurements, a plant-water relationship study, and soil and plant tissue chemical analyses were conducted to characterize each study site. Greenhouse and uniform garden studies compared seedling growth. Morphological, phenological, cytological, and chromatographic studies also examined potential genetic differences. A chromatographic study tested for the possibility that large and small statured shrubs intermix between contiguous populations.

Plant height

A. tridentata plant height was measured to quantify its decrease with distance from the gullies. The length of the transects were 60, 40, and 100 m at Sage Creek, Greasewood Wash, and Maeser, respectively. The transects terminated at each site when plant height ceased to decrease with distance from the gully.

These transects per site were randomly selected along a 50 m baseline. The baseline was placed parallel and adjacent to each gully. The transects were situated at right angles to the baseline which ran parallel to the bottom of the gully or drainage. At equal intervals (2, 3, and 5 m at Greasewood Wash, Sage Creek, and Maeser, respectively) height of the closest plant to the transect was measured in meters. Sampling began at the edge of the gullies and proceeded outward with 20 plants per transect being measured.

Plant-water relationships

At each site, soil-water potential, leaf-water potential, and transpiration resistance were measured to compare the various water relations

of the large and small plants. Five randomly selected plants per population per site were studied. Under each plant at all three sites, on April 28 and 29, 1980, thermocouple psychrometers were placed at 30 and 60 cm to measure soil-water potentials. These depths were selected because they characterize the area where the majority of lateral roots less than 3 mm in diameter occur. Soil water potential readings were taken about every two weeks starting in mid-May, 1980.

Leaf-water potentials were read immediately after the soil-water potentials were determined. The meristematic portion of three to four stems per plant were inserted into a sample chamber containing a Peltier psychrometer. To reduce variation, the meristems were selected from the southern, topmost portion of the plant. Sample chambers were then placed in an ice chest and shaded from the sun for a minimum of 60 minutes to reduce temperature gradients and allow vapor equilibration before readings were made. Meristems were collected about noon-time each sampling day.

Transpiration-resistance measurements were made on three to four leaves per plant. Leaves were selected from the southern, topmost portion of the plant to reduce variation. Readings were made at noon-time of each day. The sensor was placed on the upper surface of the leaves and shaded while the reading was conducted to minimize temperature gradients.

Soil and plant tissue analyses

To identify edaphic differences which may influence plant growth, soils associated with each population were described and classified according to Soil Conservation Service methods. Soil samples were

collected from each horizon of the pedons for laboratory analyses. Standard analyses for soil classification were performed by the Soils Testing Laboratory, Utah State University.

Vegetal current year's growth was collected September 21, 1979 to determine if mineral content was a factor in the differing plant statures. Plant material was collected from six plants per population per site. Percent nitrogen, calcium, magnesium, phosphorus, potassium, and chloride were measured. Also, copper, iron, manganese, zinc, sodium, and boron ppm were determined. These elements were measured to ascertain differences in chemical content between large and small plants. Chemical analyses were performed by the Soils Testing Laboratory, Utah State University.

Greenhouse study

The objective of this study was to compare the growth of seedlings from the large and small statured plants under three soil moisture regimes. Seeds were collected November 3 and 4, 1979 from the large and small plant populations at each site. At the same time, the surface soil was also collected from each population to use as the growth medium.

In the greenhouse, the amount of water at field capacity (F.C.), field capacity minus 5% (F.C.-5%) and field capacity minus 10% (F.D.-10%) water content was estimated for each soil. To accomplish this, one kilogram of soil was placed in a one-quart, paper milk carton. Water was then slowly added to wet the top portion of the soil. The container was then covered with a plastic bag. After 48 hours, a portion of wet soil was oven-dried for 24 hours.

Plastic-lined, one-quart, paper milk cartons were used as plant containers. One kilogram of air-dried soil was placed in each container. Enough water was then added to bring the soil to F.C., F.C.-5% or F.D.-10%. A plastic bag was placed over the container to prevent evaporation. After 24 hours, seeds were sown into the soil on January 26, 1980. The plastic bags were maintained over the containers until the seedlings were about 1 cm tall. Then, to reduce evaporation, the plastic bags were cut and laid directly on the soil with a small hole to allow seedling growth. At this time, seedlings were thinned to one per container.

To maintain the proper water content, containers were weighed every two to three days and then brought up to original weight with water. After April 5, 1980, a syringe was used to distribute water around the roots. Seedling height was measured every two weeks until June 13, 1980 at which time the seedlings were harvested. Seedlings were then oven-dried at 80 C and weighed.

A completely randomized statistical design was used for the greenhouse study. The main factors were plant populations, soil, and soil water. The study included eight replications.

Uniform garden study

The purpose of the uniform garden study was to compare seedling growth from the large and small parent plants when grown under similar conditions for at least one growing season. The location of the garden was at the Green Canyon Research Area, maintained by the Ecology Center, Utah State University.

Seeds were collected on November 3 and 4, 1979 from ten randomly selected plants per population at each site. Twelve seedlings per plant per population per site were planted into containers on February 4, 1980. The planting medium was peat moss, vermiculite, and native soil (2/5: 2/5: 1/5 by volume). On May 5, 1980, seedlings were placed out-of-doors for hardening. Six seedlings per plant were outplanted on June 5, 1980. Seedlings were planted 1 m apart to reduce competition. A completely randomized field-plot design was used.

Leader-growth measurements

The purpose of this study was to determine if differences existed between the large and small plants with regard to leader growth (length of current year's growth). On October 30 and 31, 1980, twenty plants were randomly selected from each population at each site for leader length. The five longest stems growing on the top portion of a plant were measured.

Cytology

Mitotic chromosome analyses were made of five plants per genotype at each site to ascertain if ploidy differences existed between the large and small plant genotypes using methods described by McArthur and others in 1981. Mitotic spreads were prepared by squashing root tips of two- to three-day old seedlings. Seeds were germinated on moistened filter paper in plastic petri dishes. Seedlings were treated with a 2.5×10^{-3} M (0.1%) colchicine solution for one hour at room temperature and overnight at 4 C. Seedlings were then fixed in an acetic-ethanol solution (1:3) for 24 hours. One N hydrochloric acid was used for seedling hydrolysis for six to eight hours. Seedlings

were stored in 70% alcohol. Ther meristem of root tips was excised and squashed in a drop of acetocarmine on a microscope slide under a cover slip in Hoyer's medium. To avoid the problem of endoploidy, somatic chromosomes were counted in three root tips per parent plant and three to four cells per root tip.

Chromatography

The purpose of the chromotographic study was to help confirm the taxonomic status of the large and small plants and discover whether the two populations significanly intermix. Current year's vegetal growth was harvested from the same plants that were measured for plant height. A total of 180 plants were chromatographically analyzed.

Two-dimensional, ascending, paper chromatography was the method used. Plant material was slowly air dried until the leaves would crumble. A mortar and pestle were used to pulverize 0.5 g of leaf material. Samples were then placed into 30 ml beakers containing 7.0 ml absolute methanol. Extraction of phenolic substances occurred at room temperature for 24 hours. The extractant was then decanted and evaporated to 2.0 ml. Twenty-five μℓ of concentrated extract were added to duplicate 22.5 cm squares of Whatman No. 3 mm chromatographic grade filter paper. The first dimension solvent was n/butanol:acetone: water (4:1:3). The second dimension solvent was acetic acid:water (15:85). Spots of the chromatograms were first observed under longwave ultraviolet light. The chromatograms were then exposed to ammonia fumes and ultraviolet light to note the changes in spot color and appearance of new spots. Each spot was given an identification number (different than Hanks et al. 1973) with the R_F value being computed for

each dimension. The R_F value for each spot was computed as:

$$R_F = \frac{\text{Distance of spot from starting point}}{\text{Distance of solvent from starting point}}$$

To group the chromatograms into meaningful results, unweighted pair-group method using arithmetic averages (UPGMA) cluster analysis was used. Percent similarity was determined using the Jaccard primary resemblance coefficient.

Results

Plant height along the gradients

At each study site, plant height decreased with distance from the gully (Figure 9). The decrease in plant height is positively correlated with distance (4 = 0.97, 0.98, and 0.97 for Sage Creek, Greasewood, and Maeser, respectively) and can be substantiated by a second-degree polynomial equation.

Plant-water relationship

Soil-water potential, leaf-water potential, and leaf-transpiration resistance were measured during the summer of 1980. These important attributes of plant-water relationship showed similar trends at each of the three study sites. Therefore, data were grouped together.

Soil-water potential for large and small plants at depths of 30 and 60 cm averaged around -1 bar for the first and second measurement dates. After the first two weeks of June, soil-water potential decreased rapidly. The soil-water potential for small plants at 30 cm deep decreased the fastest. For the last three measurement dates, soil-water potential under small plants was significantly lower than under large plants. The soil-water potentials

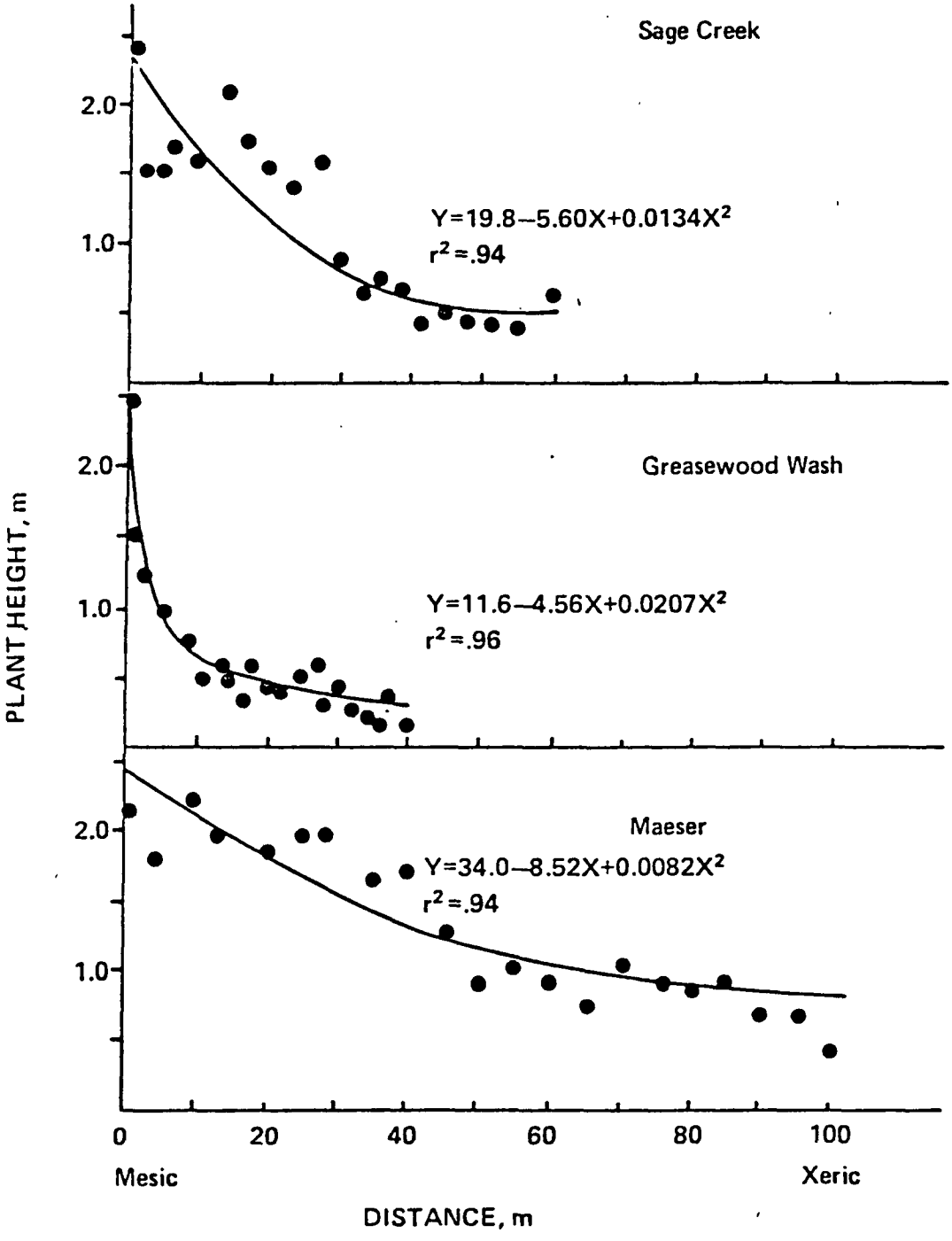

Figure 9. The decrease in A. tridentata plant height with distance from the gullies at Sage Creek, Greasewood Wash, and Maeser study sites. Data points were the average of three plants.

were -23.7, -29.2, and -34.6 bars for small plants; and -13.6, -15.4, and -16.5 bars for large plants. Also, for the last two dates, soil-water potential at 30 cm was significantly lower than at 60 cm. The genotype by depth interaction was not significant.

Leaf-water potential for large and small plants was -24.2 and -21.1 bars respectively on June 6 (Figure 10). For large plants the leaf-water potential decreased to -45.8 bars on July 8, after which it increased. The leaf-water potential for small plants decreased to -55.8 bars on July 25 and then increased. Only on July 25, August 10, and September 5 was the leaf-water potential for small plants significantly lower than for large plants.

Transpiration resistance on June 6 was 8.46 and 7.85 $s \cdot cm^{-1}$ for large and small plants (Figure 10). The transpiration resistance for both subspecies increased to 33.14 and 40.56 $s \cdot cm^{-1}$ for large and small plants on July 25. Transpiration resistance on August 10 was 15.86 and 25.64 $s \cdot cm^{-1}$ for large and small plants. Even though transpiration resistance values were numerically greater for small plants than large, these differences were not significant.

Soil and plant tissue analyses

The chemical and physical analyses showed that there were differences between soils of large and small plants (Table 16 and 17). Soils associated with the large plants were Torrifluvents at each site. Soils associated with the small plants were Haplargid, Camborthid, and Torrifluvent at Sage Creek, Greasewood Wash, and Maeser, repectively. Soils associated with large plants had a slightly higher organic carbon, nitrogen, water holding capacity,

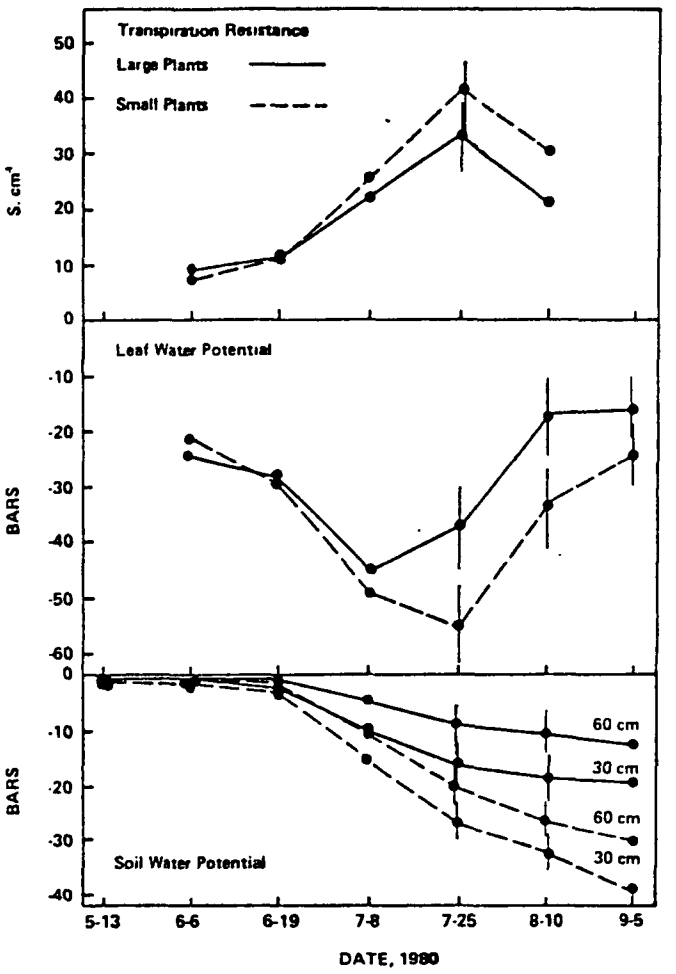

Figure 10. Transpiration resistance, leaf-water potential, and soil-water potential at a depth of 30 and 60 cm for large (——) and small (---) plants from June to September 1980. Data points were the average of 15 plants. Confidence intervals were formed at the 95% level.

Table 16. Soil classification at the Sage Creek, Greasewood Wash, and Maeser study sites.

Site Genotype	Soil family
Sage Creek	
Large plants	fine-silty, mixed, frigid Xeric Torrifluvent
Small plants	fine-silty, mixed (calcareous), frigid Typic Haplargid
Greasewood Wash	
Large plants	fine-loamy, mixed (calcareous), frigid Xerollic Torrifluvent
Small plants	fine-loamy, mixed (calcareous), frigid Typic Camborthid
Maeser	
Large plants	fine-loamy, mixed (calcareous), frigid Ustic Torrifluvent
Small plants	fine-silty, mixed (calcareous), frigid Ustic Torrifluvent

Table 17. Fertility and moisture characteristics of the "A" horizon for soils associated with large and small *A. tridentata* plants at Sage Creek, Greasewood Wash, and Maeser.

Site soil	Plant size	Fertility[1] OC	N	P	K	CEC	Moisture 1/3 atmos (%)	15 atmos. (%)
Sage Creek								
Torrifluvent	Large	2.3	0.25	20.2	2.5	20.8	27.2	12.2
Haplargid	Small	1.7	0.19	6.8	1.3	16.5	20.1	10.2
Greasewood Wash								
Torrifluvent	Large	2.8	0.25	54	1.5	17.7	30.5	11.7
Camborthid	Small	1.2	0.11	22	0.5	12.8	22.2	8.6
Maeser								
Torrifluvent	Large	1.8	0.19	64	1.7	10.7	19.8	7.6
Torrifluvent	Small	1.1	0.12	21	1.0	7.2	17.6	6.0

[1] OC = Organic carbon %
N = Nitrogen %
P = Phosphorus ppm
K = Potassium me/100 g
CEC = Cation Exchange Capacity me/100 g

cation exchange capacity, potassium, and phosphorus than the soils associated with the small plants.

There were no physical barriers to root growth in the soils with the exception of the Haplargid soil at Sage Creek. At this site, a calcic horizon was discovered at 30-40 cm which at times restricted root penetration. However, when the soil profile was described, a few roots were observed which had penetrated this horizon.

Mineral content of annual vegetal growth varied between large and small plants for several nutrients (Table 18). The large plants had a significantly greater content of nitrogen, magnesium, phosphorus, potassium, and zinc. On the other hand, the iron content of small plants' vegetal growth was significantly greater than the large plants.

Greenhouse study

Under uniform growing conditions seedlings from large parent plants grew taller than seedlings from the small parent plants. Seedling growth during the study period showed the typical S-shaped growth curve. From February 6 to April 15, growth was essentially the same for both large and small seedlings. After that time, seedlings from the large plants grew faster than seedlings from the small plants. On the last three measurement dates, seedlings from large plants were significantly taller than seedlings from small plants.

Seedlings responded differently to the three water treatments (Figure 11). Seedling growth with the water content at field capacity was the tallest. With the water content at field capacity minus 10%, seedling growth was the poorest. The differences in plant response between the soil water treatments were significant. There was no

Table 18. Mineral content of vegetal annual growth for large and small plants*

Mineral	Large plants	Small plants
N **	1.98a	1.73b
Ca	0.41a	0.38a
Mg	0.18a	0.16b
P	0.33a	0.27b
K	1.62a	1.48b
Cl	0.25a	0.23a
Cu***	22.7a	19.6a
Fe	121.2a	171.4b
Mn	42.8a	44.2a
Zn	30.7a	20.0b
Na	52.6a	45.8a
B	10.1a	11.8a

* Each mean was the average of 18 plants. Those means for each mineral that are followed by the same letter were not significantly different (P <0.5).

** Mineral content in percentage.

*** Mineral content in ppm.

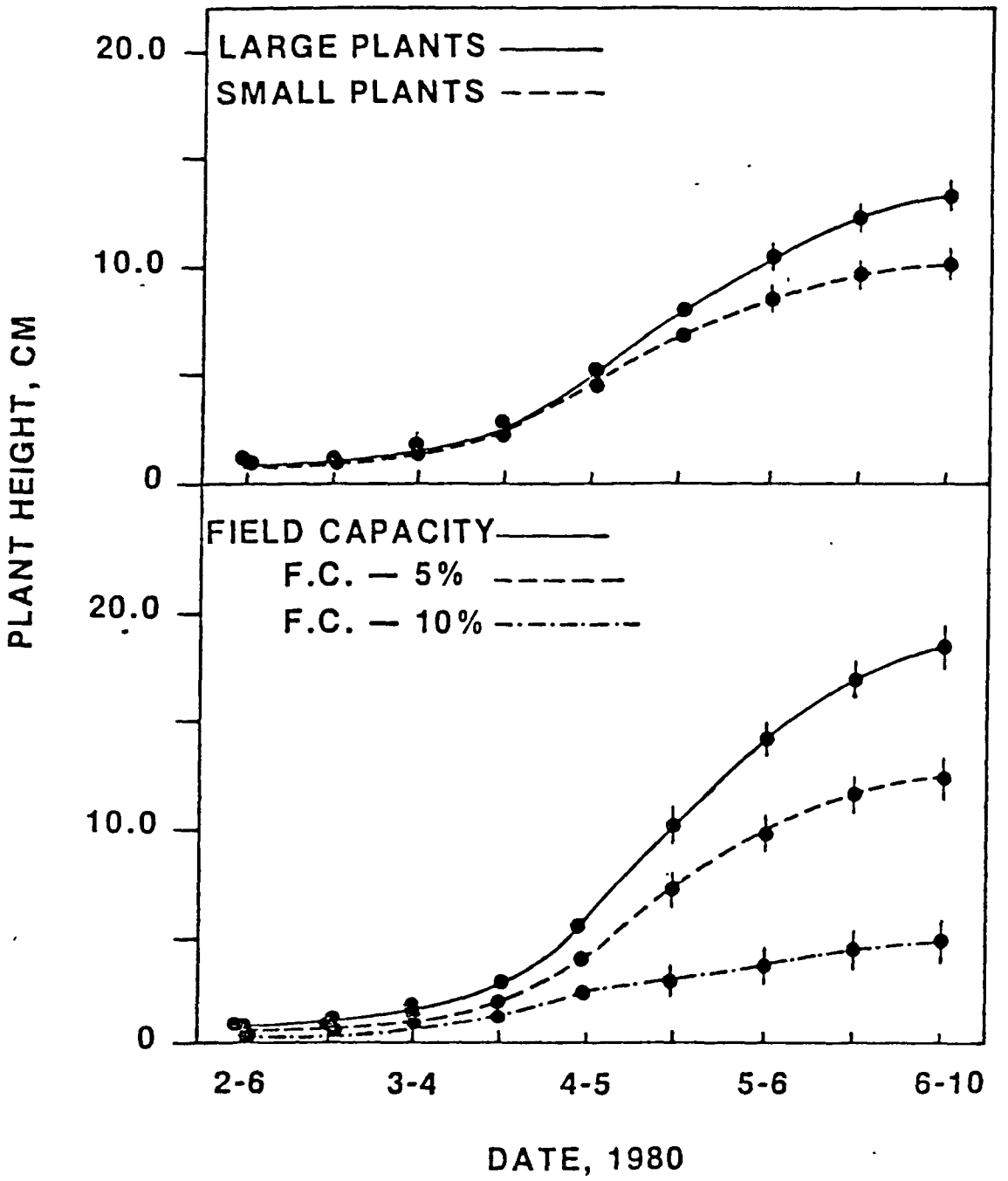

Figure 11. A. tridentata seedling growth of the large and small plant populations (top graph). Seedling growth on soils at field capacity, field capacity minus 5 and 10% water content (bottom graph). Data points were the average of 144 seedlings for the top graph and 96 seedlings for the bottom graph. Confidence intervals were formed at the 95% level.

same for both large and small seedlings. After that time, seedlings from the large plants gew faster than seedlings from the small plants. On the last three measurement dates, seedlings from large plants were significantly taller than seedlings from small plants.

Seedlings responded differently to the three water treatments (Figure 11). Seedling growth with the water content at field capacity was the tallest. With the water content at field capacity minus 10%, seedling growth was the poorest. The differences in plant response between the soil water treatments were significant. There was no significant difference within the genotype by water treatment interaction. However, seedlings from the large plants were generally taller than seedlings from the small plants on each water treatment.

Seedling shoot biomass production between populations and among soils and water treatments also varied significantly (Tables 19 and 20). Seedlings from large plants produced greater biomass than seedlings from small plants. Large seedling mean shoot production was 1.3 g while small seedling shoot production was 1.0 g. Seedlings grown on native soil associated with the large plants produced more biomass than seedlings growing on soils from the small plants at the Greasewood and Maeser sites. As expected, seedling shoot production was the greatest on soils at field capacity. Shoot production was poorest on soils at field capacity minus 10% water content.

The population by soil interaction for seedling shoot production was also significant (Table 21). Seedlings from the large parent plants at Sage Creek and Greasewood Wash produced greater shoot biomass on the Torrifluvent soils than on the Haplargid or Camborthid

Table 19. A. tridentata seedling shoot biomass production in the greenhouse on soils associated with large and small plants at each study site*

Site Source of soil for seedling production	Biomass (g)
Sage Creek	
Torrifluvent	0.9c
Haplargid	0.9c
Greasewood Wash	
Torrifluvent	1.9a
Camborthid	1.3b
Maeser	
Torrifluvent	0.9c
Torrifluvent	0.6d

* Each mean is the average of 48 seedlings. Those means that are followed by the same letter were not significantly different ($P < 0.05$).

Table 20. A. tridentata seedling shoot biomass production at three different soil water contents*

Water Content	Biomass (g)
Field capacity	1.9a
Field capacity - 5%	1.1b
Field capacity - 10%	0.4c

* Each mean was the average of 96 plants. Means followed by the same letter were not significantly different ($P < 0.05$).

Table 21. *A. tridentata* shoot production of seedlings from the large and small plant populations at Sage Creek, Greasewood Wash, and Maeser. Seedlings were grown for 18 weeks in a greenhouse in native soil associated with each population at each site*.

Site Native Soil	Population shoot production (g) Large	 Small
Sage Creek		
Torrifluvent	1.1d	0.6h
Haplargid	0.7fgh	0.6h
Greasewood Wash		
Torrifluvent	2.2a	1.6bc
Camborthid	1.6b	1.1de
Maeser		
Torrifluvent	1.0def	0.9defgh
Torrifluvent	1.0def	0.9defgh

* Each mean was the average of 24 seedlings. Those means that are followed by the same letter were not significantly different ($P < 0.05$).

soils. Only at Greasewood Wash was the small seedling shoot production greater on the Torrifluvent soil than on the Camborthid soil.

Uniform garden

Seedlings grown from seed of parent plants at each site showed differential growth during the first growing season when planted in a uniform garden. Overall, seedlings from large plants were significantly taller than seedlings from small plants. Average height was 22.8 cm and 18.0 cm, respectively.

There was also a significant differences in the genotype site interaction (Table 22). Seedlings from large plants were significantly taller than seedlings from small plants at Sage Creek and Maeser but not at Greasewood Wash.

Leader-growth measurements

Leader growth varied between the large and small plants. Mean leader length for the large and small plants was 14.2 and 8.5 cm, respectively. There differences were significant.

Cytology

At each site, the large plants were found to be diploid (2N=18) and the small plants were found to be tratrploid (2N-36 (Table 23).

Chromatography

Chromatographic differences between large and small plants based on spot occurrence were subtle (Table 24). In general, all spots were common to both subspecies except no. 3 which occurred at a low frequency of chromotograms in small plants (Figure 12). Even so,

Table 22. Mean seedling height after one growing season in a uniform garden. Parent plants of the seedlings were located at the Sage Creek, Greasewood Wash, and Maeser study sites*

Site Field origin of seeds and parent population	Height (cm)
Sage Creek	
Large plants	24.1ab
Small plants	18.9cd
Greasewood Wash	
Large plants	18.3cd
Small plants	15.4d
Maeser	
Large plants	26.0a
Small plants	19.7c

* Each mean was the average of at least 40 seedlings. Means followed by the same letter were not significantly different ($P < 0.05$).

Table 23. The occurrence of polyploidy between the large and small plants at Sage Creek, Greasewood Wash, and Maeser.

	Large plants		Small plants	
Site	Diploid	Tetraploid	Diploid	Tetraploid
Sage Creek	5	0	0	5
Greasewood Wash	5	0	1	4
Maeser	5	0	0	6

Table 24. Chromatographic spot frequencies, R_f values, colors and color intensities for the large and small plant populations

Spot No.	R_{f1}	R_{f2}	Color		Color* intensity		Spot frequency	
			Ultra-violet Light	Ultra-violet Light + Ammonia Vapor	Large Plants	Small Plants	Large Plants	Small Plants
1	.38	.10	yellow orange	yellow orange	1	3	.89	1.0
3	.46	.19	yellow orange	yellow orange	0	1	0	.26
5	.52	.10	yellow orange	yellow orange	1	3	.93	1.0
7	.68	.16	yellow	yellow	1	1	.27	.26
10	.90	.20	violet	violet brown	2	2	.96	.98
15	.95	.28	deep violet	deep violet brown	3	3	1.0	1.0
20	.89	.57	light blue	light blue	1	1	.22	.12
25	.89	.66	light blue	yellow green	1	1	.68	.60
30	.93	.74	blue violet	blue violet	1	1	.57	.70
33	.73	.75	--	violet	1	1	.07	.12
35	.63	.83	bright blue	bright blue	1	3	.68	.88
37	.61	.87	--	orange	1	3	.21	.46
38	.59	.91	--	violet	1	3	.49	.75
39	.52	.78	--	violet	1	1	.67	.64
40	.47	.80	blue	yellow green	2	3	1.0	1.0
45	.25	.67	blue violet	blue violet	1	1	.02	.09
47	.36	.73	--	violet blue	1	1	.44	.43

Table 24. Continued

Spot No.	R_{f1}	R_{f2}	Color		Color intensity		Spot frequency	
			Ultra-violet light	Ultra-violet light + ammonia vapor	large plants	small plants	large plants	small plants
50	.37	.65	pink	yellow pink	1	1	.02	.09
55	.45	.58	deep violet	violet brown	3	3	1.0	.98
58	.52	.57	dark blue	yellow green	1	1	.21	.23
65	.61	.50	blue	yellow green	2	2	1.0	1.0
70	.72	.50	light blue	yellow green	1	1	.07	.02
75	.12	.36	violet	violet brown	1	1	.92	.88
80	.29	.89	--	blue green	1	1	.77	.79

* 1 = light, 2 = average, 3 = intense.

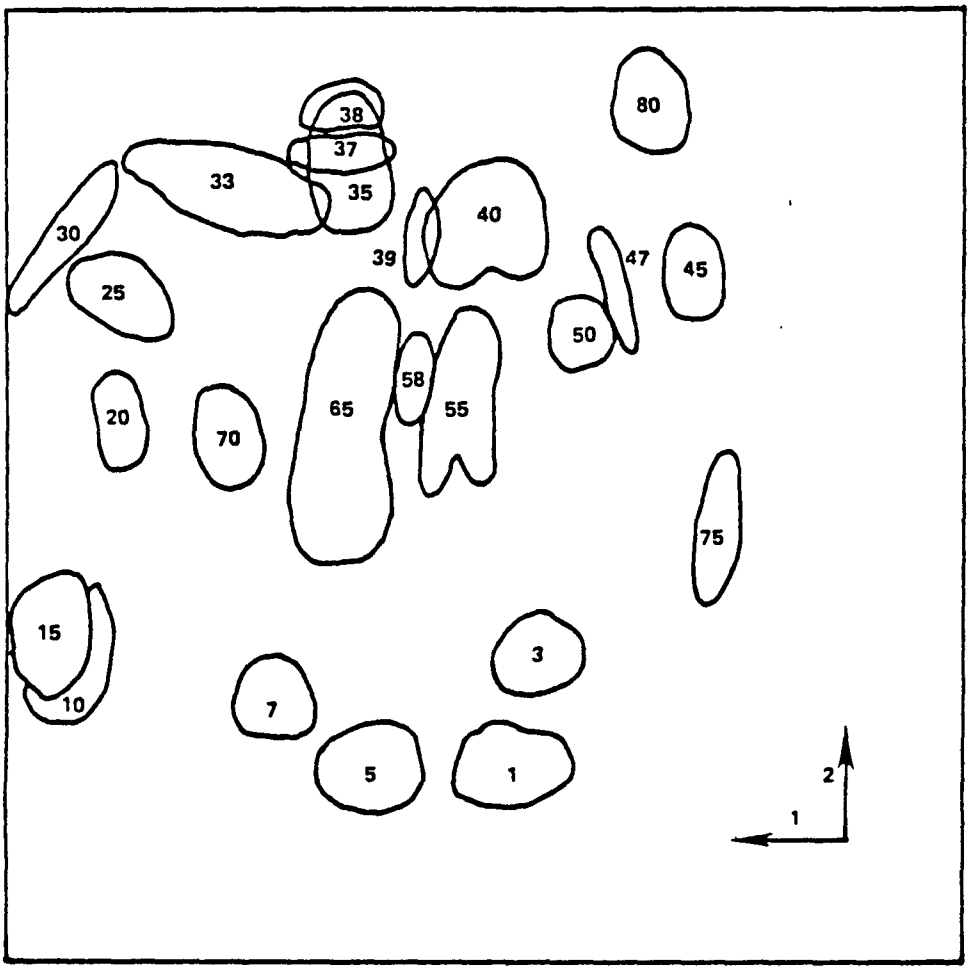

Figure 12. Composite two-dimensional chromatogram showing the relative location and size of spots. Variations in color intensity and spot frequency were the largest differences shown in chromatograms of individual plants

differences in spot frequencies were important. Spots nos. 30, 35, 37 and 38 were less frequent in large plant chromatograms than in small.

Spot color intensities apparently can be used to separate the populations. Spot nos. 1, 5, 35, 37, and 38 were light colored in large plant chromatograms but intense colored for the small plants. The differences in spot nos. 1 and 5 were the most consistent.

Based on spot frequency on the chromatograms, large plants appeared to differ from small plants. Cluster analysis used chromatogram spot frequencies to separate large and small plant populations (Figure 13, 14, and 15). At Sage Creek, Greasewood Wash, and Maeser, large and small plants were found to be about 60, 50 and 55% similar, respectively. In addition, the dendrograms showed that the subclusters nested within the large and small plants were somewhat ordered sequentailly with distance from the edge of the gully.

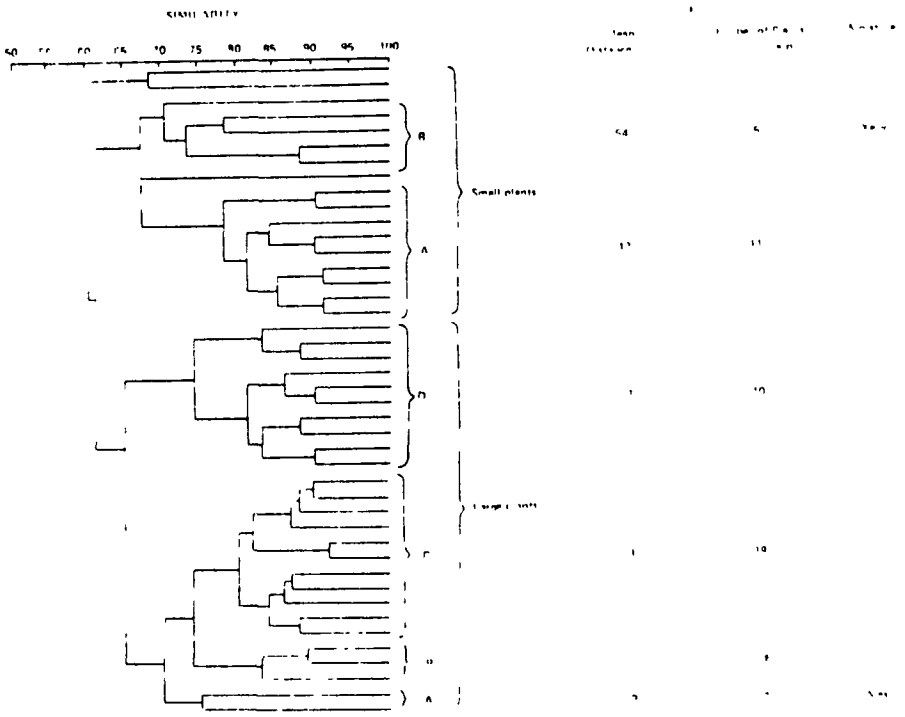

Figure 13. Dendrograms showing the relationship of large and small A. tridentata plants at Sage Creek based on two-dimensional chromatography. Ecotypes nested within plant population are represented by the letters. The number of plants and mean distance from the gully is given for each ecotype. Large and small plants were 60% similar. Ecotypes were formed at the 74% similarity level.

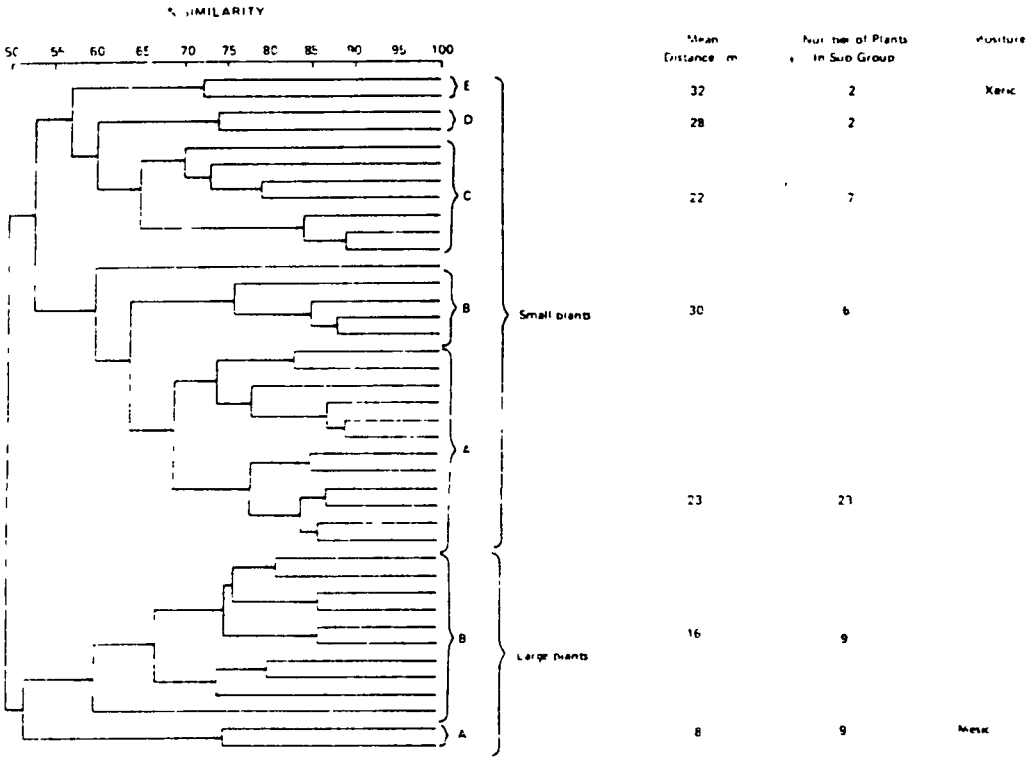

Figure 14. Dendrogram showing the relationship of large and small A. tridentata plants at Greasewood Wash based on two-dimensional chromatography. Ecotypes nested within plant population are represented by the letters. The number of plants and mean distance from the gully is given for each ecotype. Large and small plants were 50% similar. Ecotypes were formed at the 65% similarity level.

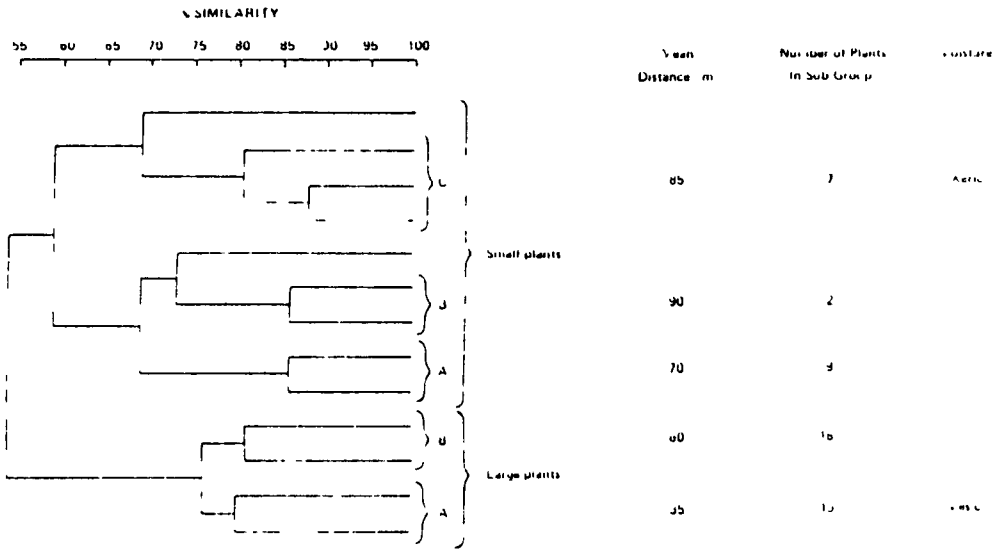

Figure 15. Dendrogram showing the relationship of large and small A. tridentata plants at Maeser based on two-dimensional chromatography. Ecotypes nested within plant population are represented by the letters. The number of plants and mean distance from the gully is given for each ecotype. Large and small plants were 55% similar. Edotypes were formed at the 77% similarity level.

DISCUSSION

For the purposes of discussion the large and small plant genotypes of *Artemisia tridentata* will be considered as subspecies *tridentata* and *wyomingensis*, respectively. This assumption will be validated later.

Characterization of study sites

Plant height near the gullies averaged about 2.5 m and decreased with distance along the moisture gradients to less than 1.0 m. The tallest plant found was at the Sage Creek site and measured about 3.2 m. *Tridentata* is the tallest of the *A. tridentata* subspecies, its height varies from 1 to 2 m with plants as tall as 4.5 m occurring. Subspecies *wyomingensis* maximum height is usually less than 1.0 m. In this study, several *wyomingensis* plants at each study site had a height around 1.5 m.

The taxonomy of the soils suggested the existence of long term differences in soil moisture along the gradients. Soils associated with *tridentata* were Torrifluvents. These are Entisols that were formed by water deposited sediments and flooded, but not frequently. On the other hand, the soils associated with *wyomingensis* at Sage Creek and Greasewood Wash were Haplargid and Camborthid, respectively. Both Haplargid and Camborthid are Aridisols which are characteristically dry as indicated by their aridic moisture regime.

According to the plant-water relationship study, a seasonal moisture gradient existed at each site. During 1980, subspecies *wyomingensis* experienced greater drought conditions than *tridentata*.

The difference in soil water potentials indicate that tridentata plants grow in a more mesic habitat than does wyomingensis. The gullies may have been responsible for concentrating water where tridentata plants grow. During July, 1979, after a thunderstorm, standing water remained in the gully at Greasewood Wash for about two weeks. Furthermore, the increased plant cover of the tridentata plants may reduce evaporation by reducing incident radiation striking the soil surface.

Both leaf water potential and transpiration resistance are influenced by the soil water status. As the soil water potential decreases, leaf water potential decreases and transpiration resistance increases. Leaves with lower than normal water potentials and higher than normal transpiration resistances indicate a plant suffering from water stress. Measurements of both of these parameters indicate that wyomingensis plants experienced a greater water stress than tridentata.

In addition to the soil moisture gradient, there also appeared to be a soil organic matter and fertility gradient at the study sites. Soils associated with tridentata plants have a slightly higher organic carbon, nitrogen, cation exchange capacity, potassium and phosphorous than for wyomingensis plants. However, these differences may have developed in relation to the soil moisture gradient. Plant productivity should be greater on the mesic portion of the gradients than on the xeric part.

No great differences were found among the three sites in soil fertility which would result in reduced plant growth. However, the fertility of soils associated with tridentata plants was somewhat

better than for wyomingensis. This increase in fertility may have resulted from periodic flooding. The flood waters could have concentrated additional organic matter and nutrients in alluvial deposits, swales and along the edges of gullies. In general, soils associated with A. tridentata plants are fertile and arable.

Genetic differences between the large and small plant genotypes

The greenhouse, uniform garden, morphological, phenological, cytological and chromatographic studies indicate that genetic differences between the large and small plants exist. These studies also support the classification of large and small plants as subspecies tridentata and wyomingensis.

The growth of plants under uniform conditions is a method whereby genotypic differences between plants can be detected because environmental influences have been minimized. Such was the purpose of the greenhouse and uniform garden studies. In both studies tridentata seedlings were significantly taller than wyomingensis. This suggests that tridentata has a greater potential for growth than wyomingensis.

Seedling shoot production in the greenhouse regardless of genotype was greater on the native soils associated with tridentata plants than on soils from wyomingensis. These growth differences show the more fertile nature of the tridentata soils.

The fact that seedling shoot production was different when grown under the influence of the three soil water treatments may be related to subspecies adaptation as pointed out before. Subspecies wyomingensis in wildland conditions usually grows on more exeric soils than

tridentata. Therefore, tridentata seedlings may have the genetic potential to outgrow wyomingensis on treatments consisting of field capacity and field capacity minus 5 percent water content because they are better adapted to the more mesic conditions.

It is well known that polyploidy and hybridization within plants increase their ecological amplitude. The development of the polyploidy nature in wyomingensis may have allowed it to exploid the dry, shallow soils not occupied by tridentata but also resulted in its shorter stature and more conservative growth characteristics.

This detailed study of genetic and environmental influences on sagebrush supports several generalizations useful to a shrub biomass development program. First seeds from populations of big shrubs may be expected to produce seedlings with vigorous growth habits. Second we may expect that large shrubs will maintain their more vigorous growth habits when transferred to sites within their ecological tolerance. Third, the best sites for finding shrub genotypes capable of precocious growth in western rangelands will be where favorable soil moisture and fertility conditions prevail.

CONCLUSIONS

1. Various ecotypes and biotypes of shrub species must be grown in areas where they are adapted.
2. Further study is needed to determine the time of harvesting shrub biomass so that regrowth may occur.
3. More than 3 years is needed to determine the full influence of competition for space on shrub growth.
4. Substantial production of biomass may be expected from shrubs grown under spaced plantings and minimal cultural conditions in dryland plantations. Yields as high as 38 tons/ha (green wt) were harvested at the end of 3 years at the Snow Field Station in Utah.
5. Genetic differences were found between large and small statured big sagebrush plants.

PUBLICATIONS

The following publications have resulted from the project up to this time:

Barker, J.R. and C.M. McKell. 1979. Shrub biomass for energy fuel. p. 34 in Abstract of Papers. 32nd Annual Meeting of the Society for Range Management. Casper, Wy.

Cox, L.M. 1969. Searching for energy in self-made monsters. Edge 2:26-27.

Van Epps, G.A., J.R. Barker and C.M. McKell. 1981. Energy biomass from large rangeland shrubs of the Intermountain United States. J. Range Manage. (in press).

Barker, J.R. 1981. Genetic differences between large and small *Artemisia tridentata* plants in contiguous populations. Ph.D. Dissertation, Utah State University, Logan, Ut.

Barker, J.R. 1981. Genetic variability of *Artemisia tridentata* along soil moisture gradients. p 5 in Abstracts of Papers, 34th Annual Meetings of the Society for Range Management. Tulsa, Ok.

Barker, J.R. and C.M. McKell. Habitat differences between basin and Wyoming big sagebrush. Submitted to the J. Range Manage.

Barker, J.R. and C.M. McKell. Genetic differences between large and small *Artemisia tridentata* plants in contiguous populations. Submitted to the Amer. J. Bot.

An additional manuscript will be prepared from the Phase II field plantation results.