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Rubber Production of Salt-Stressed Guayule at Various Plant Populations

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Summary. The hypothesis that increasing the plant population of guayule (*Parthenium argentatum*) to compensate for the reduced plant canopy size caused by soil salinity coupled with an anticipated enchancement of rubber production under the moderate environmental stress imposed by salinity was tested in a field plot experiment in the Imperial Valley of California. Irrigation waters having electrical conductivities (EC_i) of 1.2, 3.2, 6.5, and 9.4 dS/m were applied for 4 years to plots having plant populations of 28,000, 56,000, and 84,000 plants per hectare. The influence of salinity on rubber and resin production was independent of plant population. The salt tolerance threshold, maximum average salinity level of the root zone measured as the electrical conductivity of saturated soil extracts ($\overline{EC_e}$) without yield reduction, was 7.5 dS/m; beyond this threshold, rubber production was reduced 6.1% per unit increase of soil salinity. The salinity values were averaged through the root zone from planting to harvest. The average rubber content – 7.9% – was altered little by treatment or harvest age for 2- to 4-year-old plants. Resin content averaged 8.4% but increased salinity and increased plant population increased the resin content slightly in some cases. Dry matter production of shoots for the nonsaline treatment was 259 kg/ha/month for pollarded (clipped) shoots after 31 months, 203 kg/ha/month for shoots harvested after 43 months, and 401 kg/ha/month for the 24-month period after pollarding. Combining the shoot mass after 31 and 55 months gave an average growth rate of 321 kg/ha, supporting the recommendation for pollarding. Monthly growth rates for the lowest salt treatment (3.2 dS/m) were about 10% less than for the nonsaline treatment (1.2 dS/m). The hypothesis tested was proven to be false because neither increased salinity nor increased plant population increased rubber production.

Guayule (*Parthenium argentatum* Gray), a perennial shrub native to the Chihuahuan Desert of northern Mexico and the Big Bend area of Texas, accumulates rubber comparable in quality to that produced by the rubber tree (*Hevea brasiliensis*). Guayule also produces various hydrocarbons, particularly resins, that are comparable to rubber in amount and have potential economic value (Cornforth et al. 1980). Rubber accumulates in single, thin-walled cells contained primarily in the vascular rays of the phloem and xylem of plants older than one year. About two-thirds of the rubber is accumulated in the branches of the shoot; the remaining third in the large roots. Rubber content in nonirrigated plants is as high as 10% of the total dry weight of the plant while the content for irrigated plants can be as low as 5% (Tingey 1952).

Highest rubber production has been thought to occur when the plants are under a moderate environmental stress; with best production occurring when agronomic management minimizes stress during stand establishment and plant development, followed by limited watering to retard vegetative growth and enhance rubber production. Several environmental factors, such as low temperature, limited water availability, and excess soil salinity, may induce the desired stress to increase rubber production (Benedict et al. 1947). Benedict and colleagues reported that 4-month cycles of wet and dry conditions produced more rubber than 2-month cycles or than a 10-month dry cycle. Unfortunately, their experiment was terminated after 14 months, well before the age when harvesting normally occurs. Tingey (1952) reported that in the Salinas Valley of California water stress caused by withholding irrigation and close plant spacings increased rubber production of 3-year-old shrubs. Retzer and Mogen (1947) found that the highest rubber concentrations were from plants under frequent to moderate periods of stress, but higher rubber yields were present with the larger sized plants of lower rubber concentrations. The results of Wadleigh et al. (1946) indicated that plants grown under saline-irrigated conditions may have higher rubber contents than plants with a plentiful nonsaline water supply. Thus, moderate salinity levels may increase rubber production even though total growth is reduced. Very high soil salinity concentrations, however, were reported to decrease rubber content as well as growth.

In some crops, reduced yields caused by excess salinity can be offset by increasing plant population. Cotton yield, for example, can be increased at moderate salinity levels that reduce total plant mass by increasing plant populations from 60,000 to 90,000 plants per hectare (Francois 1982). Guayule is normally grown at plant populations of about 28,000 plants per hectare (Tingey 1952); but at high levels of soil salinity smaller plant stature may permit higher plant populations.

The objective of this experiment was to determine if rubber production per unit land area can be improved by increasing the plant population of guayule at moderate soil salinity levels. While fulfilling this primary objective, the response of guayule to salinity and plant population individually was evaluated.

Experimental Procedure

Guayule cv. N565-II was tested in field plots on a 0.5 ha parcel of land at the Irrigated Desert Research Station of the USDA, Agricultural Research Service, in Brawley, California. The soil was Holtville silty clay (Typic Torrifluvents, clay over loamy, montmorillonitic (calcareous), hyperthermic) and the inital electrical conductivity of saturated soil extracts (EC_e) averaged 2.5 dS/m before planting (February, 1982). Three-month-old seedlings, purchased from a commercial nursery, were transplanted into 48 plots on October 20, 1981. Each plot, consisting of four raised beds spaced on 1 m centers, was 15 m long. The middle two rows of each plot were harvested for yield determinations. All plots were irrigated with Colorado River water (EC_i $= 1.2$ dS/m) subsequent to planting and on October 26, November 9, December 15, and January 18 following transplanting. Salinized irrigation treatments began on February 17, 1982.

Table 1. Mean values of electrical conductivity and constitutents of irrigation water treatments

Electrical conductivity dS/m	(mol/m^3)							pH
	Ca	Mg	Na	K	HCO_3	Cl	SO_4	
1.2	2.0	1.2	5.8	0.1	2.1	3.3	3.4	7.4
3.2	3.4	2.7	20	0.1	4.6	14	6.5	7.2
6.5	7.8	4.2	40	1.1	6.5	41	9.1	7.1
9.4	22	4.2	40	1.1	6.5	69	9.1	7.1

The experimental design was a complete randomized block design consisting of 12 treatments, each with four replicates. The treatments were three plant population (28,000, 56,000, and 84,000 plants per hectare) each irrigated with four levels of irrigation water salinity ($EC_i = 1.2$, 3.2, 6.5, and 9.4 dS/m). Colorado River water was applied as the lowest salt treatment (control) throughout the experiment. Saline water, taken from an adjacent subsurface drainage system (EC varied from 5 to 8 dS/m) was blended with river water to achieve an irrigation water with an EC of 3.2 dS/m. The two highest saline irrigation waters (6.5 and 9.4 dS/m) were obtained by injecting a concentrated solution of calcium chloride into the drain water as needed. Average concentrations of the constituents of the four irrigation waters are given in Table 1. Two replicates of each treatment were irrigated simultaneously from gated pipe and the irrigation volume delivered to each plot was measured with water meters. Equivalent depths of each irrigation computed on the basis of the total plot area ranged from 50 to 100 mm depending on the irrigation requirement. All treatments were irrigated on the same schedule but the depth of irrigation was adjusted based upon soil water depletion calculated from neutron probe readings taken in the plant bed and in the furrow to a depth of 1 m prior to an following each irrigation.

The plant population treatments varied from the low end of the recommended range of 25,000 to 50,000 plants per hectare (Fangmeier et al. 1984) to 50% above the high end of the range. The lowest plant population (28,000 plants/ha) was achieved by planting one row at the center of each raised bed at a plant spacing of 36 cm. The middle population level, two rows of plants on each bed staggered at plant spacings of 36 cm, has been tested in several recent experiments (Bucks et al. 1984; Fangmeier et al. 1985). The highest population consisted of two rows of plants on each bed with the plants staggered at a spacing of 24 cm.

Soil salinity was monitored throughout the experiment by a combination of soil sampling for laboratory determination of electrical conductivity and measurements with a Wenner array of the four-electrode salinity probe (Rhoades and Ingvalson 1971). Soil samples were taken at 15 cm increments to a depth of 90 cm in both the center of the furrow and plant bed during February, July, and December 1982, December 1983, September 1984, and October and December 1985. The average root zone salinity with soil depth ($\overline{EC}_e$) was the average value of the 15 cm depth increments from beneath the furrow and the center of the bed, excluding the salinity value within the bed itself. Wenner array measurements gave an average electrical conductivity value for the soil profile to a depth of 90 cm. Wenner array readings were taken at three locations in the center furrow of each plot during June and December 1983 and April, September, and October 1984. Measurements from soil samples taken in December 1983 were used to calibrate the Wenner array measurements taken at the same time. Chloride and water content were also determined on the soil samples, but the data are not reported except to calculate leaching fraction.

In February 1984, plants in one-half of each plot were clipped about 10 cm above the surface of the bed (pollarded). Yield was determined from the center two beds for a length of 4.5 m beginning 3 m from the end of the row (harvest area of 9.3 m^2). Plants in the remaining half of each plot were harvested in February 1985 (43 months after the seeds were planted in the greenhouse or 40 months after transplanting into the field) by cutting off shoots at the soil surface and removing the roots to a depth of about 15 cm and harvesting the root crown. The center two beds were harvested for yield for a length of 6.8 m beginning 0.7 m from the end of the row (harvested area of 14.1 m^2). In February 1986, the half of each plot that had been pollarded in 1984 was harvested using the same procedures as in 1985. Fresh weights were obtained of the shoots and root crowns. Samples taken of both shoots and roots were dried and the calculated water contents were used to determine dry weights. Following drying, the samples were chipped and subsampled for rubber and resin analyses by near infrared reflectance spectroscopy (Black and Hamerstrand 1985).

Following the harvest by pollarding in February 1984, regrowth was evaluated in July 1984 by counting the number of plants that appeared to be regrowing normally, those where regrowth was slow, and those without any signs of regrowth. The condition of the plants was again checked visually in April 1985 and February 1986. As the experiment progressed into the final year of the study, Ridomil 2E was applied at a rate of 32 l/ha in the irrigation water on March 14, 1985 to prevent phytophora.

The guayule was fertilized annually in the spring with 55 kg of nitrogen per hectare. Plant samples were taken in May 1983 and analyzed for nitrate, phosphorous, potassium, sodium, calcium, and magnesium.

Results and Discussion

Water Management

When the experiment began the appropriate irrigation requirement was unclear. Polhamus (1962) indicated guayule grew in unirrigated areas having an annual rainfall from 380 to 1000 mm. Various water management schemes evaluated during the Emergency Rubber Program from 1942 to 1946 suggested that plant stress caused by a soil water deficit could increase rubber concentrations; however most irrigation tests were conducted for less than two years (Hammond and Polhamus 1965). Reports published since this experiment began have shown that under high plant populations (44,000 to 54,000 plants/ha) shrub and rubber yields increased almost linearly with increased irrigations up to 3,000 mm for the first 2 year of growth (Bucks et al. 1984, 1985; Miyamoto et al. 1984). Continuing their experiment for an additional 2 years, Bucks and Nakayama (1986) reported average annual evapotranspiration rates ranging from 810 to 1,760 mm from the dry to wet treatments.

Irrigation applications for this experiment averaged from 1,180 mm for the low salt treatment ($EC_i = 1.2$ dS/m) to 910 mm for the high salt treatment (Table 2). As soil salinity increased, less water was required in response to reduced plant stature and a subsequent reduction in evapotranspiration. The low salt treatment received about the same amount of water as the middle treatment of Bucks and Nakayama (1986) which gave significantly less yield than their highest irrigation treatment.

Soil Salinity

The average salinity level ($\overline{EC}_e$) of the soil profile (0–90 cm deep for both methods of measurement) for each salinity treatment throughout the experiment is presented in Fig. 1. Note that soil salinity increased rapidly during 1982 for the saline treatments but following 1982 the salinity levels increased gradually, essentially in parallel with the gradual increase in salinity of the 1.2 dS/m treatment. This gradual increase in salinity indicates that not enough water was applied to create a leaching fraction high enough to permit the soil profiles to reach a steady condition that is typical of salt tolerance experiments. The soil salinity profiles presented in Fig. 2 represent the initial conditions (February 1982), values at the end of the rapid increase in salinity (December 1982), and conditions midway through the gradual rise in salinity (September

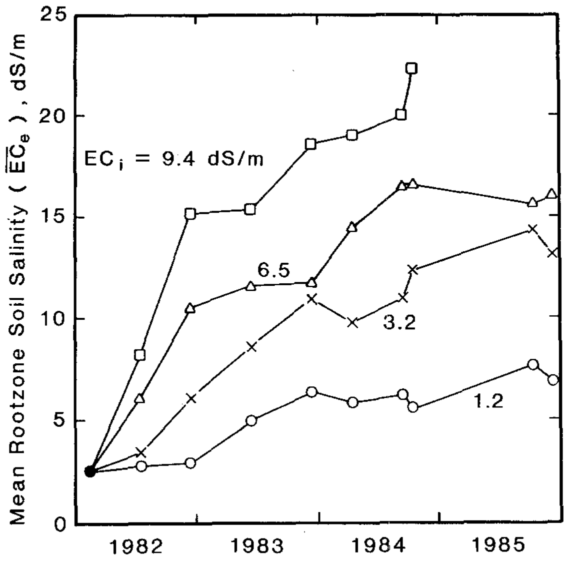

Fig. 1. Salinity trends with time for the guayule experiment for the four salinity treatment noted as the electrical conductivity of the irrigation water (EC_i)

Table 2. The number of irrigations and equivalent depth of application for each saline water treatment and rainfall on an annual basis

Year	Number of irrigations	Irrigation (mm)				Rain (mm)
		Irrigation water salinity (dS/m)				
		1.2	3.2	6.5	9.4	
1982	16	1,310	1,290	1,260	1,180	93
1983	13	1,320	1,210	1,000	880	190
1984[a]	12	1,030	950	750	660	83
1985	11	1,080	990	740	0	78
Mean	13	1,180	1,110	940	910	111

[a] Plots received less water in 1984 because half of each plot was pollarded and required less water

1984). For brevity, only salinity profiles for the low and high salt treatments are presented.

An estimate of the leaching fraction can be made by dividing the chloride concentration of the irrigation water by the chloride concentration of the soil water determined from soil samples taken at the 75 to 90 cm soil depth. The leaching fractions calculated were 0.17 (69 mol/m^3/408 mol/m^3) for the 9.4 dS/m treatment and 0.03 (3.3 mol/m^3/95 mol/m^3) for the 1.2 dS/m treatment based upon chloride measurements from soil samples taken in September 1984. The leaching fractions calculated from soil samples taken in December 1985 were 0.02 (3.3/142), 0.06 (14/222) and 0.20 (41/202) for the 1.2, 3.2, and 6.5 dS/m treatments, respectively. Soil salinity values did not continue to increase below a depth of 60 cm (Fig. 2), thus, the major water uptake region was above a depth of 60 cm. These results are substantiated by salinity values

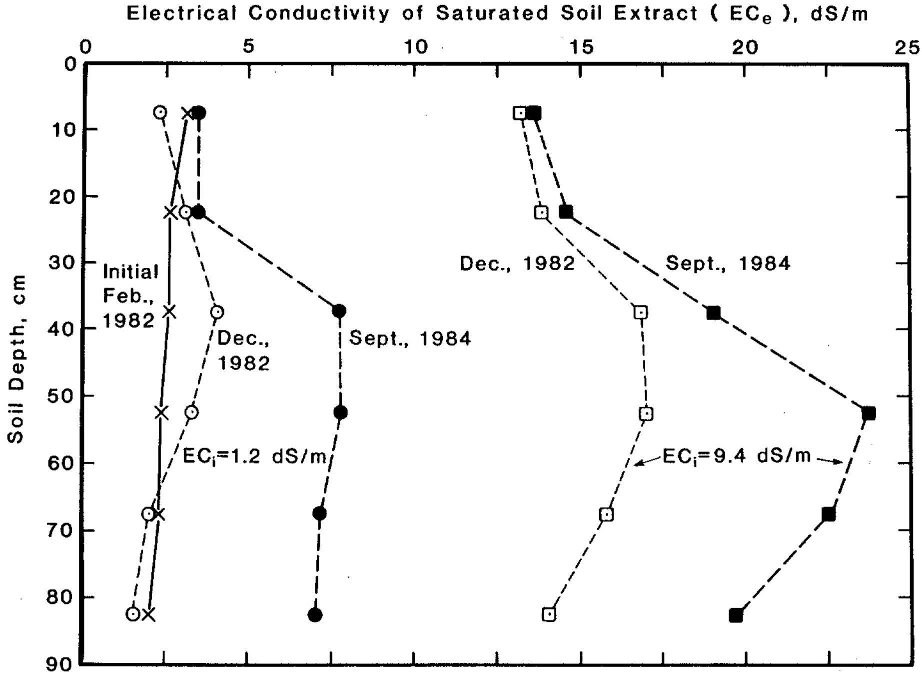

Fig. 2. Soil salinity profile at the initiation of the saline treatments (Feb 1982) and at the end of the rapid increase of salinity (Dec 1982) and midway through the gradual rise in salinity (Sept 1984) for the low ($EC_i = 1.2$ dS/m) and high ($EC_i = 9.4$ dS/m) treatments

Table 3. Average salinity values for the soil profile (0–90 cm) for each harvest as a function of the salinity of the irrigation water. Values are the electrical conductivity of saturated soil extracts averaged over time and with soil depth (EC_e), dS/m

Harvest date	Time period for average value	Irrigation water salinity (dS/m)			
		1.2	3.2	6.5	9.4
Feb 1984	Feb 82 to Feb 84	4.2	6.9	9.0	12.8
Feb 1985	Feb 82 to Feb 85	4.8	8.3	11.3	15.3
Feb 1986	Feb 84 to Feb 86	6.6	12.4	15.8	–[a]

[a] Plots abandoned in the spring of 1985 because more than 85% of the plants had died

taken in 1985 and by chloride concentrations determined from soil samples taken in both 1984 and 1985. If the root system of guayule extended below 60 cm, the roots at deeper depths extracted unmeasureable water volumes as inferred from insignificant increases in soil salinity. This root depth is comparable to that reported by Mills et al. (1987).

To determine yield-salinity relationships, the average soil salinity value was determined by integrating the data presented in Fig. 1 over time. These integrated values were essentially the same as the average of the values presented in Table 3 for each harvest period.

Table 4. Production of pollarded shoots of guayule (31-month-old plants) on a dry weight basis as a function of salinity and plant population

Irrigation water salinity (dS/m)	Plant population (#/ha)	Dry weight (Mg/ha)	Rubber content (%)	Rubber yield (kg/ha)	Resin content (%)	Resin yield (kg/ha)
1.2	27,000	9.0	7.5	680	8.1	730
	54,000	8.4	8.1	680	7.8	660
	81,000	6.7	7.6	510	8.0	540
3.2	27,000	9.8	7.8	760	9.0	880
	54,000	6.4	8.6	550	10.0	640
	81,000	5.5	8.6	470	10.1	560
6.5	27,000	7.3	8.4	610	9.1	660
	54,000	7.2	7.7	550	8.6	620
	81,000	5.4	8.4	450	9.4	510
9.4	27,000	8.3	8.2	680	8.5	710
	54,000	5.4	8.2	440	9.1	490
	81,000	5.3	7.8	410	8.2	430
Duncan's multiple range test (5% level)						
1.2		8.0a	7.7a	620a	7.9c	630ab
3.2		7.2b	8.3a	600ab	9.6a	690a
6.5		6.6bc	8.2a	540bc	9.1ab	600bc
9.4		6.3c	8.1a	510c	8.6bc	540c
	27,000	8.6a	8.0a	690a	8.7a	750a
	54,000	6.8b	8.1a	550b	8.8a	600b
	81,000	5.7c	8.1a	460c	8.9a	510c
Salinity × population interaction *		NS	0.01	NS	NS	NS

* Level of significance based upon analysis of variance. NS indicates not significant

Crop Production

Production from pollarding half of each plot in February 1984 is summarized in Table 4. Production results from harvesting the shoots and root crowns in the unpollarded half of each plot for 43-month-old plants are given in Table 5 while Table 6 presents the production of shoots and root crowns of guayule plants that had been pollarded 2 years earlier. For evaluating the effects of salinity and plant population on guayule production, summaries giving the results of the Duncan's multiple range test at the 5% level are given at the bottom of each table. Interactions between salinity and population were determined from an analysis of variance on each set of results. Interactions not discussed were not significant.

Regrowth After Clipping. The influence of salinity and plant population on the regrowth and survival of guayule plants after clipping is summarized in Table 7. Plant population had no significant influence on plant recovery. As salinity increased, however, regrowth and survival diminished significantly. Five months after clipping (July 1984), all but 5% of the plants showed regrowth in the two lowest salt treatments. At a salt level of 6.5 dS/m, 85% of the plants had regrowth while at the highest salt

Table 5. Production of guayule (43-month-old plants) on a dry weight basis as a function of salinity and plant population

Irrigation water salinity (dS/m)	Plant population (#/ha)	Dry weight (Mg/ha)		Rubber content (%)		Rubber yield (kg/ha)		Resin content (%)		Resin yield (kg/ha)	
		Shoots	Roots	Shoots	Roots	Shoots	Roots	Shoots	Roots	Shoots	Roots
1.2	27,000	9,0	3.4	7.9	7.3	710	250	8.3	6.5	750	220
	54,000	8.9	3.8	7.8	8.3	690	320	8.4	6.8	750	260
	81,000	8.3	4.4	8.1	7.9	670	350	8.5	7.4	710	330
3.2	27,000	10.2	3.0	8.3	7.7	850	230	8.1	6.8	830	200
	54,000	7.4	3.6	7.6	7.8	560	280	9.0	7.4	670	270
	81,000	6.6	3.2	7.5	7.4	500	240	8.1	7.4	530	240
6.5	27,000	8.3	2.3	7.9	8.4	660	190	7.8	5.7	650	130
	54,000	7.5	3.4	7.6	8.2	570	280	8.8	6.4	660	220
	81,000	5.4	2.9	8.1	9.9	440	290	8.9	6.8	480	200
9.4	27,000	5.7	1.8	7.8	9.5	440	170	8.5	5.5	480	100
	54,000	4.5	2.1	7.7	10.0	350	210	9.9	6.6	450	140
	81,000	4.2	2.6	7.6	9.7	320	250	9.6	6.6	400	170
Duncan's multiple range test (5% level)											
1.2		8.7 a	3.9 a	7.9 a	7.8 c	690 a	300 a	8.4 b	6.9 ab	730 a	270 a
3.2		8.1 a	3.3 b	7.8 a	7.6 c	630 ab	250 b	8.4 b	7.2 a	670 b	240 a
6.5		7.1 b	2.9 b	7.9 a	8.8 b	560 b	250 b	8.5 b	6.3 bc	590 c	180 b
9.4		4.8 c	2.2 c	7.7 a	9.7 a	370 c	210 c	9.3 a	6.2 c	330 d	140 c
	27,000	8,3 a	2.6 b	8.0 a	8.2 a	660 a	210 b	8.2 b	6.1 b	670 a	160 b
	54,000	7.1 b	3.2 a	7.7 a	8.6 a	540 b	270 a	9.0 a	6.8 a	630 a	220 a
	81,000	6.1 c	3.3 a	7.8 a	8.7 a	480 c	280 a	8.8 ab	7.0 a	530 b	230 a
Salinity × population interaction*		0.04	0.05	NS	NS	0.004	NS	NS	NS	NS	NS

* Level of significance based upon analysis of variance. NS indicates not significant

Table 6. Production of guayule (55-month-old plants) on a dry weight basis after having been pollarded at an age of 31 months as a function of salinity and plant population

Irrigation water salinity (dS/m)	Plant population (#/ha)	Dry weight (Mg/ha)		Rubber content (%)		Rubber yield (kg/ha)		Resin content (%)		Resin yield (kg/ha)	
		Shoots	Roots	Shoots	Roots	Shoots	Roots	Shoots	Roots	Shoots	Roots
1.2	27,000	9.6	2.6	7.9	5.1	760	130	7.3	4.7	700	120
	54,000	10,3	3.1	7.8	5.4	800	170	7.4	5.3	760	160
	81,000	9.0	3.1	8.8	5.9	790	180	8.2	6.0	740	190
3.2	27,000	8.9	2.0	7.4	4.7	660	90	6.9	5.4	610	110
	54,000	7.1	2.1	7.9	5.5	560	120	7.1	6.2	500	130
	81,000	7.4	2.2	8.0	5.4	590	120	7.5	6.4	560	140
6.5	27,000	4.0	0.9	6.5	4.8	260	40	6.7	5.8	270	50
	54,000	3.4	1.4	6.6	4.1	220	60	7.1	6.2	240	90
	81,000	3.6	1.4	7.9	5.0	280	70	8.0	6.1	200	90
Duncan's multiple range test (5% level)											
1.2		9.6a	2.9a	8.2a	5.4a	780a	160a	7.6a	5.3a	720a	160a
3.2		7.8b	2.1b	7.8ab	5.2a	610b	110b	7.2a	6.0a	560b	130a
6.5		3.7c	1.2c	7.0b	4.6a	250c	60c	7.3a	6.0a	260c	70b
	27,000	7.5a	1.8b	7.3b	4.9a	560a	90b	7.0a	5.3b	530a	90b
	54,000	6.9a	2.2a	7.4ab	5.0a	560a	110ab	7.2a	5.9ab	490a	130a
	81,000	6.6a	2.2a	8.2a	5.4a	530a	120a	7.9a	6.1a	520a	140a
Salinity × population interaction*		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Level of significance based upon analysis of variance. NS indicates not significant

Table 7. Condition of guayule plants following the harvest by pollarding in February 1984. Values reported are the percentage of the initial plant population

Irrigation water salinity (dS/m)	Plant population (#/ha)	July 1984			April 1985			February 1986		
		Normal re-growth	Poor re-growth	No re-growth	Live plants	Plants near death	Dead plants	Live plants	Plants near death	Dead plants
1.2	27,000	82	14	4	90	5	5	87	6	7
	54,000	81	16	3	88	6	6	86	2	12
	81,000	76	20	4	86	6	8	76	8	16
3.2	27,000	82	14	4	77	15	8	78	6	16
	54,000	79	16	5	77	14	9	63	6	31
	81,000	77	19	5	79	10	11	71	6	23
6.5	27,000	73	10	17	35	25	40	25	6	69
	54,000	71	13	16	19	22	59	11	3	86
	81,000	72	15	13	22	17	61	15	5	80
9.4	27,000	53	7	40	1	9	90	–	–	–
	54,000	56	12	32	2	12	86	–	–	–
	81,000	52	13	35	3	8	89	–	–	–
Duncan's multiple range test (5% level)										
1.2		79 a	17 a	4 c	88 a	6 c	6 c	83 a	6 a	12 c
3.2		80 a	16 a	5 c	78 b	13 b	9 c	71 b	6 a	23 b
6.5		72 b	13 b	15 b	25 c	22 a	53 b	17 c	5 a	78 a
9.4		50 c	10 b	36 a	2 d	10 ab	84 a	–	–	–
	27,000	72 a	11 b	16 a	51 a	14 a	36 a	47 a	5 a	48 b
	54,000	72 a	14 a	14 a	46 a	14 a	40 a	40 a	3 a	57 a
	81,000	67 a	16 a	14 a	48 a	11 a	39 a	41 a	5 a	55 ab

level only 65% showed regrowth. At the second evaluation of plant condition (April, 1985, 14 months after pollarding), almost 90% of the plants in the lowest salt treatment had recovered and only about 5% of the population had died (Table 7). Slightly more than 75% of the plants recovered in the 3.2 dS/m treatment. As salinity increased, survival was reduced significantly and for the 9.4 dS/m treatment more than 80% of the plants had died at all three plant populations. The high salt treatment was, therefore, discontinued in the spring of 1985. From the spring of 1985 until the final harvest in February 1986, plant conditions for the lowest salt treatment remained essentially unchanged (Table 7); plant mortality increased 10 to 20% in the 3.2 dS/m treatment; while the 6.5 dS/m had only 15 to 30% survival at harvest.

Rubber Content. Neither salinity nor plant population influenced the rubber content of shoots in 1984 (Table 4) or 1985 (Table 5). In the 1986 harvest, however, the rubber content of shoots was reduced about 1% by either increased salinity or reduced population. The lack of large changes with either salinity or population is the major reason why no enhanced rubber production was found from a moderate salt stress or increased plant population. The average rubber content of the shoots for all three harvests and for all treatments was 7.9%. The rubber content of the shoots for the lowest salt treatment increased slightly from 7.7% for 31-month-old plants to 8.2% for 55-month-old plants that had been pollarded.

The rubber content of root crowns harvested in 1985 compared favorably with that of the shoots (7.8% for shoots and 8.5% for roots). Salinity increased the rubber content of the roots significantly from 7.7% in the two lowest salt treatments to 9.7% in the highest salt treatment. The results were quite different, however, when 55-month-old plants that had been pollarded 2 years earlier were harvested. Neither salinity nor population influenced rubber content but the average content was only 5.1%. The reason for the drop in rubber content from 8.5% in 1985 to 5.1% in 1986 is unknown.

The average rubber content on a whole plant basis (shoots plus root crown) for the lowest salt treatment was 7.9% in 1985 and 7.6% in 1986; 8.2 and 6.3% for the 6.5 dS/m salt treatment, respectively. These rubber contents are notably higher than the average values reported by Bucks and Nakayma (1986) of 5.2% for 2-year-old plants and 5.8% for 4-year-old plants for several varieties grown at Mesa, Arizona or the average value of 4.2% for several varieties grown west of Phoenix by Fangmeier et al. (1985) but are slightly lower than values reported from Israel (Mills et al. 1987).

The lack of response of shoot rubber content to salinity for 31- and 43-month-old plants is in agreement with the results of Maas et al. (1986); although their average rubber contents were somewhat lower than those reported here.

Resin Content. The average resin content of shoots was consistently higher than rubber content for the 1984 (8.8 vs. 8.1%) and 1985 (8.6 vs. 7.8%) harvests but slightly lower (7.4 vs. 7.7%) in 1986. Unlike rubber content, however, resin content was significantly higher for the more saline treatments in 1984 and 1985 (Tables 4 and 5) but there were no significant differences with salinity in the 1986 harvest (Table 6). Increased plant population enhanced resin content of shoots in 1985 but had no effect for the other two harvests. The results for roots were somewhat different; increased salinity reduced resin content in 1985 but had no significant effect in 1986. Increased population improved resin content of roots for both root harvests.

The averaged resin content of the shoots for all three harvests and for all treatments was 8.4%. The mean resin content for the lowest salt treatment was 8.0%, indicating an overall increase in resin with increased salinity level; a similar increase was caused by a tripling of the plant population. The average resin content on a whole plant basis for the lowest salt treatments was 7.9% for the 1985 harvest and 7.1% in 1986. These resin contents are similar to those presented by Bucks and Nakayama (1986) but higher than the values reported by Fangmeier et al (1985).

Dry Matter Production. Dry matter production for the three harvests is also presented in Tables 4, 5, and 6. For every harvest and for both roots and shoots, increasing salinity reduced dry matter production significantly. Plant population also influenced dry matter production significantly but the results were not as anticipated. As plant population increased, shoot weight decreased while root weight increased. These results are in contrast to those reported by Tingey (1952) where increased plant population resulted in increased dry matter and rubber production. The weight of the root crowns were too small to compensate for the loss in shoot weight so that total plant weight was reduced as population increased. Note that plant roots after 4 years were smaller than those after 3 years of growth. This effect is consistent at all salinity levels and all populations. A similar harvest technique was used in harvesting both years; thus, the probable explanations is translocation from the roots to the regrowing shoots after clipping. This hypothesis is supported by a reduction in both rubber and resin contents of the roots.

The rate of dry matter production is of importance when deciding when to harvest for maximum growth benefit. Considering only shoot growth for the nonsaline treatment and averaging the three plant densities, the average monthly rates of dry matter production of shoots for each harvest period were 259 kg/ha/month for the clipped shoots in 1984, 203 kg/ha/month for the shoots when the entire plants were harvested in 1985, and 401 kg/ha/month for shoot regrowth from 1984 to 1986. Combining the weights of the shoots harvested in both 1984 and 1986 the monthly average growth rate was 321 kg/ha for the 4-year-old plants that were pollarded compared to 203 kg/ha for the 3-year-old plants that were not pollarded. This supports the recommendation of pollarding although it should be noted that shoot growth was very high during the fourth year for ther pollarded plants. Monthly growth rates for the 3.2 dS/m salt treatment were about 10% less than the 1.2 dS/m treatment.

In agreement with previous findings that shoot dry weight accounts for 2/3 of the plant total, shoot weight in the 1985 harvest was 70% of the total plant weight. This percentage was independent of salinity but dropped from 76% at the low population to 65% at the high population. As can be noted in Table 5 this change was caused by a reduction in shoot weight as population increased coupled with an increase in root weight. The double harvest of shoots in the half of the plots clipped in 1984 altered the shoot percentage drastically. With two shoot harvests and reduced root weight, the shoot dry weight was 86% of the total plant weight for the low salt treatment.

Rubber Production. As salinity increased, rubber production was decreased significantly for both shoots and roots for all harvests (Tables 4, 5, and 6). The piece-wise linear relationship between rubber production and soil salinity is illustrated in Fig. 3. Rubber yields for the clipped shoots in 1984 and the total plant (shoots plus root crowns) in 1985 and 1986 were plotted as a function of the average electrical conductivity of saturated soil extracts assuming a 90 cm deep root zone. The rubber yields were taken as the average values for the three plant populations. The piece-wise linear salt tolerance equation as proposed by Maas and Hoffman (1977) is $Y = 100 - 6.1$ $(\overline{\overline{EC}}_e - 7.5)$ where Y is the relative rubber yield and $\overline{\overline{EC}}_e$ is the soil salinity averaged over soil depth (0 to 90 cm) and from planting to harvest. The salt tolerance threshold value is 7.5 dS/m with a standard error of 1.6 dS/m and the slope is 6.1% per dS/m with a standard error of 1.5%. An additional result confirming the curve is the predicted salinity value for zero yield. The equation predicts zero yield at 24 dS/m. From Fig. 1 note that $\overline{EC}_e$ had reached 22 dS/m in October 1984 and that by April 1985 more than 85% of the plants in the 9.4 dS/m treatment had died (Table 7).

Water-use-efficiency, defined as the amount of rubber produced per unit of water applied, decreased as salinity increased. The amount of water consumed was assumed to be the amount of water applied (irrigation plus rainfall, Table 2) reduced by the leaching fraction given above. The amount of water required to produce 1 kg of rubber in the 55-month-old plants increased from 32 m^3 for the nonsaline treatment to 40 m^3 for the 6.5 dS/m treatment; the water-use-efficiency dropped from 0.031 kg/m^3 to 0.025.

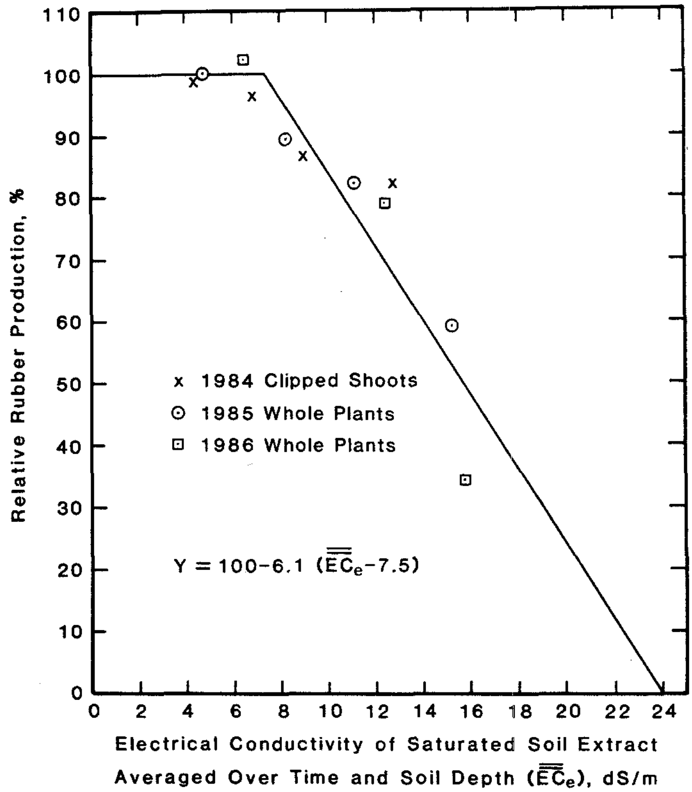

Fig. 3. Salt tolerance of guayule based upon rubber production

Salinity – Population Interactions

The major objective of the experiment was to determine if an increase in plant population would compensate for the loss in rubber production caused by soil salinity. The statistical test for an interaction between soil salinity and plant population is given for each measure of guayule production for each harvest (Tables 4, 5, and 6). The only statistically significant interaction for the pollarded shoots in 1984 was rubber content. For the harvest of pollarded shoots in 1984, the interaction between salinity and population was not statistically significant for either rubber or resin yield. At low levels of soil salinity, rubber contents tended to be higher for high populations while at high levels of salinity rubber content was higher for low populations. In 1985 the only significant interaction for rubber or resin yield was for the rubber yield of shoots. The interaction was the reverse of what was anticipated; as salinity increased, increased population caused shoot yields to be depressed more not less than under nonsaline conditions. This interaction with rubber yield occurs because of a similar interaction with dry matter production of shoots. The interaction was also significant for the dry weight of roots but it did not cause an interaction for either rubber or resin. No significant interactions were found for the 1986 harvest. Thus, increased plant population did not interact with soil salinity to enhance rubber or resin production as salinity increased.

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