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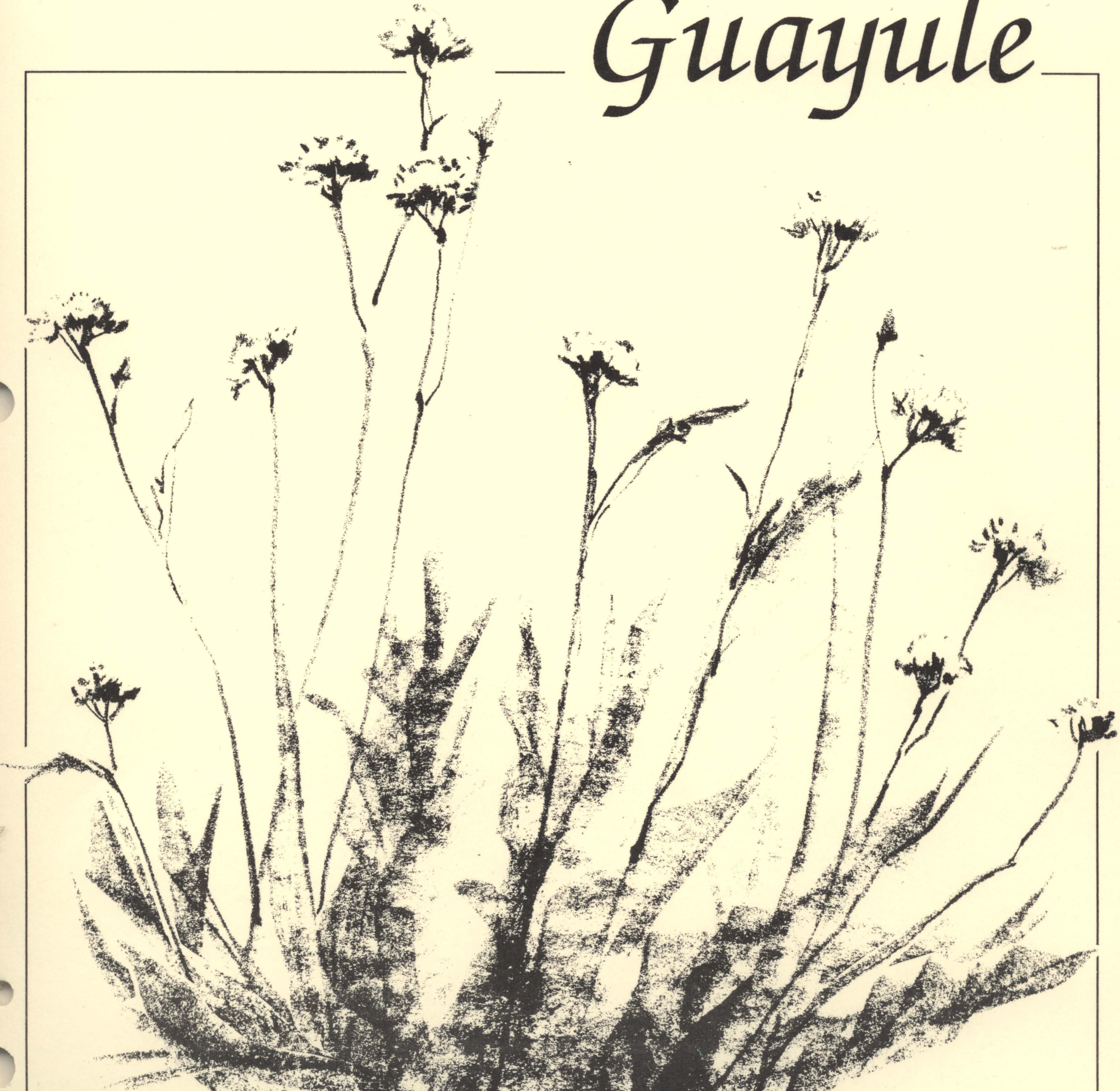
Salt Tolerance of *Guayule*



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Salt Tolerance of Guayule

(Parthenium argentatum)

by

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Cover design by Roxy A. Pike, commercial artist, Department of Agricultural Communications, The Texas Agricultural Experiment Station; Guayule drawing by Karen Glenn, art director, Texas Engineering Experiment Station.

Contents

Summary

Because of the strategic and industrial importance of natural rubber, there has been renewed interest in cultivating guayule *(Parthenium argentatum).* This study was conducted to determine salt tolerance at different stages of growth, mainly for evaluating agronomic potential of guayule in saline areas. Responses to salinity were evaluated by a series of greenhouse experiments and a 5-year field plot test established on Bluepoint loamy sand (Typic Torripsament), using cultivar 593 and various USDA selections.

Guayule seed (NaOCl treated) germinated well in highly saline solutions (up to 23 dS m^{-1}), but emergence and survival of guayule seedlings were reduced significantly even at salinity of irrigation water as low as 1 dS m^{-1}. Guayule hypocotyl and seedlings were highly susceptible to salt damage induced through roots or seedling leaves. Guayule establishment by direct seeding using existing furrow methods would be difficult in saline areas.

The tolerance of guayule to salts improved significantly after the seedling stage. Nursery plants, grown in seedling trays for 10 weeks in a greenhouse and transplanted in the spring, achieved 95 percent survival when irrigated with 4.5 dS m^{-1} water. Growth rates of transplants during the first year were reduced severely by increasing salinity, but shrub yields after two years of growth were reduced by only 15 percent when irrigated with 4.5 dS m^{-1} water and 51 percent when irrigated with 7.0 dS m^{-1} water.

Clipping of shrubs after 2 years caused 16, 27, and 39 percent mortality (averaged over the cultivars) when irrigated with 0.9, 4.5, and 7.0 dS m^{-1} waters, respectively. Mortality rates were especially high in selections N576 and 12229. Shrubs that had survived clipping grew well for the following two years with minimal irrigation (72 mm plus 52 mm rainfall for the two years). Shrub yields, rubber contents, and rubber yields under minimal irrigation were not significantly affected by the saline treatment. Regrowth from the second clipping, under frequent irrigation, was reduced significantly by the saline treatment, for example, 27 and 36 percent shrub yield reductions at irrigation water salinity of 4.5 and 7.0 dS m^{-1}, respectively. The corresponding reductions in rubber yields were 9 and 27 percent respectively. Salt stress generally increased rubber contents, but did not compensate for the reduction in shrub yields. Cultivar differences in shrub yields or rubber contents were statistically significant, but were less than 18 and 13 percent, respectively. Overall, selections 11591 and 11619 produced the largest shrub and rubber yields. The maximum shrub and rubber yields attained with the tested selections were 9.6 Mg ha^{-1} and 490 kg ha^{-1} per year from clipping harvest, respectively.

Guayule has the potential of becoming an agronomic crop in saline areas, but improvements in seedling vigor, rubber contents, and water utilization efficiency are essential. Salt tolerance of established guayule is higher than alfalfa and almost as tolerant as Pima and Upland cotton. However, tolerance at the seedling stage is lower than carrots, one of the most salt-sensitive crops currently grown in the Southwest. Shrub mortality may also become a problem with some selections following clipping, especially when soil salinity exceeds about 5 dS m^{-1}.

Introduction

Guayule *(Parthenium argentatum Gray)* is a desert shrub native to the Chihuahuan Desert of northeastern Mexico and west Texas. Native guayule was utilized as early as 1900 for limited production of rubber (McGinnies and Haase 1975). Cultivation of irrigated guayule began in 1916 in Arizona and was expanded considerably in the southwestern United States during World War II for emergency rubber supplies. Shortly after the war, its production in the United States was discontinued partly because of the development of synthetic rubber.

Recently, however, there has been renewed interest in cultivating guayule. Natural rubber is a commodity of strategic and industrial importance, and the demand is expected to increase worldwide (National Academy of Science 1977). Most synthetic rubber evidently does not have sufficient elasticity, resiliency, and low-heat buildup characteristics for today's high performance requirements (Cornforth et al. 1980). In addition to rubber, resin and wax contained in guayule plants are being assessed as by-products of economic value (Schloman 1988; Palu et al. 1983).

The potential guayule production area in the United States includes Texas, New Mexico, Arizona, and California. With the exception of the Lower Rio Grande Valley and Winter Garden areas of Texas, irrigation is considered necessary for guayule cultivation. Irrigation waters in the southwestern United States usually contain dissolved salts in excess of 800 mg L^{-1}. In the Trans-Pecos, one of the potential guayule production areas in Texas, salinity of irrigation water ranges from 2000 to 6000 mg L^{-1}, and the potential for salt problems is high with most crops (Miyamoto et al. 1984a).

War-time research indicated that established guayule could tolerate considerable salinity (Retzer and Mogen 1946). Guayule plants which had been grown in saline soils actually had higher rubber contents, although the contents were not high enough to compensate for the reduction in shrub yields. A sand culture experiment involving guayule transplants, however, showed a 40 percent reduction in dry shrub weights when the transplants were grown for 12 weeks with a NaCl solution having the electrical conductivity (EC) of 4.0 dS m^{-1} (Wadleigh and Gauch 1944). This study also indicated that guayule plants were sensitive to Mg. These data suggest that guayule plants are only moderately tolerant to salinity, and that the tolerance could vary depending on the type of salts and the stages of growth.

In 1982, a new round of saline tolerance studies was initiated mainly to determine the agronomic potential of guayule in saline areas. This bulletin is a consolidated summary of the research.

Tolerance at Different Stages

Germination Stage

Guayule is currently propagated exclusively by seed, yet little information is available concerning salt effects on seed germination (the emergence of root radicle). In general, salts are known to reduce germination through increasing osmotic stress and/or by causing specific ion or toxic effects (Bernstein 1974). The osmotic effect may reduce the rate of germination and , if high enough, the final germination percentage. Specific ion effects, usually caused by Na, Cl, and occasionally Mg, may partially be alleviated by increasing the concentration of other ion species such as Ca and SO_4 (LaHye and Epstein 1969). However, it is unknown how guayule seed might respond to salt stress.

Two separate experiments were conducted to evaluate salt effects on seed germination. In the first experiment, four guayule selections (USDA 11604, 11633, 11646, A48118) and one cultivar (593) developed during the Emergency Rubber Project were collected from an experimental plot in El Paso, cleaned, and separated through floatation in acetone. The portion which sank in acetone was soaked, as suggested by Naqvi and Hanson (1980), in a 0.5 percent NaOCl solution (Clorox) for 2 hours and rinsed with distilled water. Fifty seed lots were placed in petri dishes containing various saline solutions (25 ml each) and a bed of sterilized cotton fiber. The saline solutions had electrical conductivity (EC) readings of 0.9 to 22 dS m^{-1} and a Na/Ca ratio of 3, a typical ratio observed in saline well waters of the middle Rio Grande Basin. As an additional treatment, $MgCl_2$ was added in place of $CaCl_2$ up to 60 me L^{-1}. Also in a separate treatment the sodium adsorption ratio (SAR) was increased from 21 to 41 while maintaining the same anion composition and total salinity. The petri dishes were placed in an incubator (diurnal temperature 19° to 22° C), and germinated seed counted periodically in a split plot design (selections as subplot) with five replicates. The seed was considered germinated when the length of the radicle exceeded twice the seed length.

Seed germination began in 3 days and was completed mostly within 1 week. Germination counts made on the 12th day are shown in Figure 1. The percent germination in distilled water ranged from 50 to 85 percent, and some of the low germination may have been caused by poor seed quality. Significant salt effects did not appear until solution salinity increased to approximately 15 dS m^{-1} (or 200 me L^{-1}) in selections 11604, 11633, and A48118; 22 dS m^{-1} (or 300 me L^{-1}) in selection 11646 and cultivar 593.

Increasing Mg concentrations from 0 to 30 to 60 me L^{-1} while maintaining the same total salinity did not affect germination. Increasing the SAR of the incubating solution from 26 to 41 did not cause a significant reduction in germination. The percent of germination differed significantly among the tested cultivars.

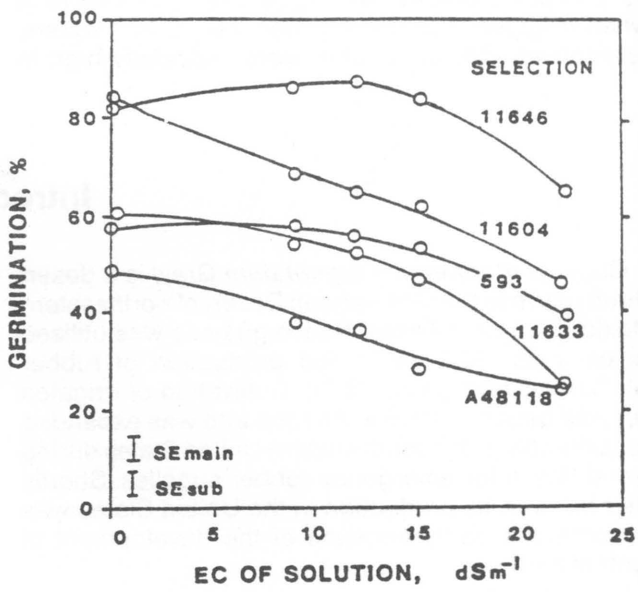

Figure 1. Seed germination of guayule selections as related to the electrical conductivity (EC) of saline solutions at a diurnal temperature regime of 19° to 22° C. SE main, the standard error of the experiment for the saline treatments; SE sub, the standard error of cultivar.

However, when the germination data were normalized by the germination in deionized water, the cultivar effect diminished.

The second germination experiment was conducted in the same manner as the first, except that three vegetable crops (which are known for establishment difficulties) were included for comparison: carrot (*Daucus carota* L. cv. Imperator 58), chile pepper (*Capsicum annum.* L. cv. New Mexico 6-4) and tomato (*Lycopersicon esculentum* M. cv. Rutgers). For guayule, cultivar 593 was used. Saline solutions (Table 1) having somewhat higher concentrations than those used in the first experiment were added to petri dishes, and seed lots (50 each) were incubated under two diurnal temperature regimes; 17°-26° C and 22°-32° C. Germination counts were made periodically for 3 weeks.

Guayule seed germination began in 3 days and was completed mostly within 1 week. Vegetable seed placed in distilled water also started germinating in 4 days and completed germination within 6 days, except for chile pepper which took 8 days. The seed incubated in a saline solution with 12 dS m^{-1} or higher took several more days to germinate. The germination counts made at 3 weeks (Figure 2) indicate that guayule seed germinated better than tomato or carrot seed in the saline solutions. Guayule seed (cv. 593) germinated better in this experiment than in the first experiment, perhaps because of superior seed quality. It is apparent that guayule seed can germinate as well as conventional vegetable crops in saline solutions.

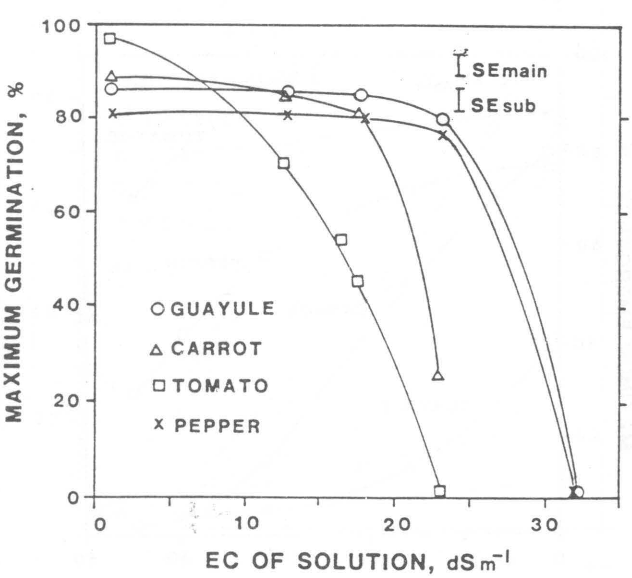

Figure 2. *Seed germination of four crop species as related to electrical conductivity (EC) of saline solutions at a diurnal temperature regime of 22° to 32° C; SE, the standard error of the experiment.*

Emergence Stage

Field reports indicate that it is extremely difficult to obtain good stands of guayule by direct seeding (Tingey and Clifford 1946; Tingey 1952). Guayule seedlings either do not emerge or die after emergence. Seedling emergence apparently decreases rapidly with increasing seeding depth. Naqvi and Hanson (1980), for example, observed a reduction in emergence from 81 to 32 percent when seeding depth was increased from the surface to 12 mm in greenhouse experiments. Emergence also decreases with decreasing seed size (Naqvi and Hanson 1980). Guayule seed, the size of a sand particle, produces a hypocotyl lacking vigor. Salt stress may compound emergence problems, but no quantitative data are currently available.

A greenhouse experiment was subsequently conducted to observe effects of salinity on seedling emergence of guayule. Bluepoint fine loamy sand (calcareous, mixed, thermic Typic Torripsament) was placed in plastic pots (13 cm in diameter) to a depth of 11 cm. Guayule seed (bulk collection and cultivar 593) was placed 50 per pot, 5 mm deep, and the seeded pots were surface-irrigated once a week using 17 mm of various saline solutions (Table 2). Seedling emergence was monitored for 20 days in a greenhouse at a diurnal regime of 19° to 29° C using a split plot design with five replicates. Three pots per treatment were sectioned at different depths 2 weeks after seeding, and salinity of the saturation extract and soil water contents determined by the methods of the U.S. Salinity Laboratory (1954).

Seedlings of both the bulk collection and cultivar 593 began to appear 5 to 6 days after the first irrigation, and emergence was completed in 2 weeks (Figure 3). Thereafter, the stand began to decline in both the bulk collection seed and cultivar 593. Stands decreased with increasing salinity, and only a few seedlings survived at irrigation water salinity of 4.5 dS m^{-1} or greater.

Soil water contents at 0-11 mm depth one day after irrigation averaged 0.14 kg kg^{-1} and those immediately before irrigation 0.06 kg kg^{-1} or about 0.1 MPa in soil water suction. Soil salinity measured 2 weeks after seeding (or immediately before the third irrigation) showed high salt accumulation at 0-5 mm depth (Figure 4), presumably due to salt deposition during water evaporation.

The seed germination study mentioned earlier indicated that guayule seed germinates within 3 to 5 days when solution salinity is less than about 15 dS m^{-1}. Soil salinity readings obtained immediately before irrigation (Figure 4) were not high enough to inhibit seed germination. Salinity levels shortly after irrigation are presumably lower, thus most seed must have germinated. Upon germination, guayule root radicles usually extend several cm below the seeded zone

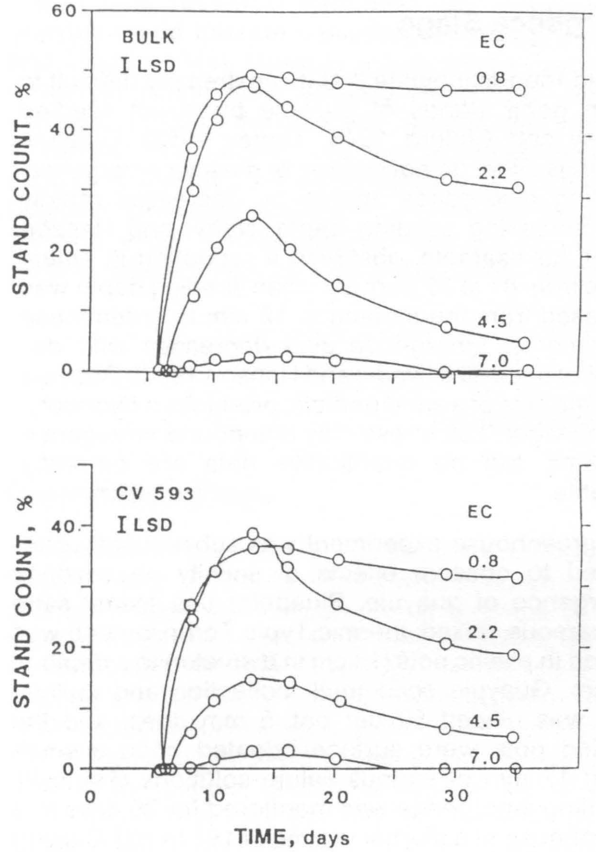

Figure 3. *Seedling stand counts of guayule (bulk seed collection and cv. 593) grown in greenhouse pots surface-irrigated weekly with saline solutions.*

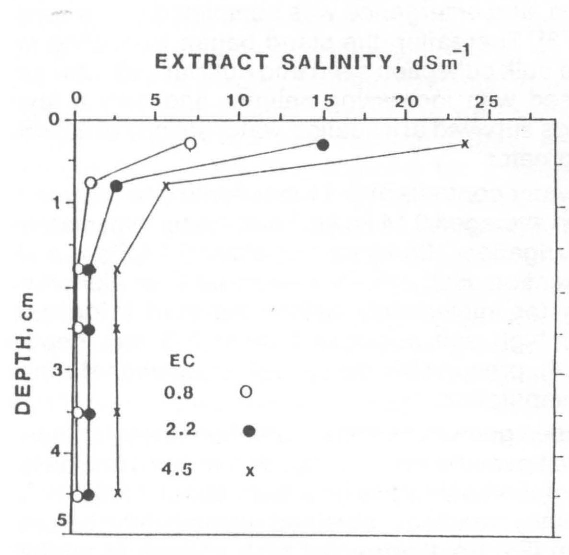

Figure 4. *Salinity of the soil saturation extract measured 2 weeks after seeding at different depths of potted soils which had been surface-irrigated with various saline solutions.*

within one week. Soil salinity at such a depth (Figure 4) was, however, low.

A hypothesis was then sought to explain low emergence of guayule when irrigated with saline waters. Since the highest salt accumulation had occurred at the soil surface (Figure 4), it was hypothesized that emergence was reduced due to mortality of hypocotyls when pushing through the salted-soil surface. Under this hypothesis, emergence would have little relationship to the ability of seed to germinate in high saline solutions, but rather to the ability of hypocotyls to withstand high salinity.

An emergence experiment was conducted in greenhouse pots to test this hypothesis using guayule and, for comparison, three vegetable crops mentioned earlier (carrots, chile, and tomato). Seed lots (50 each) were placed 3 mm deep, and the potted soils were surfaced-irrigated first with distilled water. At the first sign of seedling emergence (3, 4, 5, and 6 days for guayule, tomato, carrot, and pepper, respectively), a 3 mm layer of salted-loamy sand was placed over emerging seedlings. The salted-sand had saturation extract salinity readings of 11, 16, 32, 40, and 46 dS m^{-1}. (These readings are comparable to those observed in the top 3 mm soil layer when irrigated with waters of 0.8 to 7.2 dS m^{-1}). The pots were subirrigated with tap water until the salted-layer became wet at 4.5 to 6 day intervals. Emergence through the salted-layer was then recorded.

The results of this experiment revealed a striking difference in emergence among the crops tested (Figure 5). Guayule had the lowest emergence and

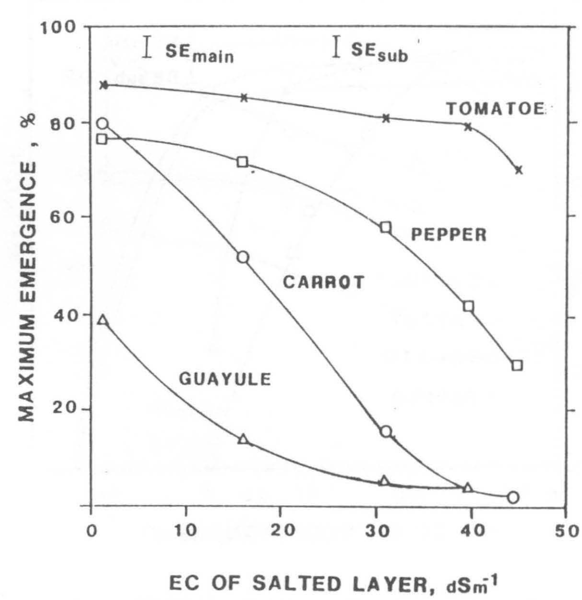

Figure 5. *Seedling emergence of four crop species through a 3 mm layer of salted-loamy sand placed on emerging seedlings.*

tomato the highest, in direct contrast to the germination data shown in Figure 2. Since the layer of salted-sand was applied after germination of the seed, the reduction in emergence observed must be attributed to a post-germination problem, presumably hypocotyl mortality. It appears that guayule hypocotyls are exceptionally sensitive to salinity.

Seedling Stage

The effect of salts on seedling growth and mortality rate is an important concern during the seedling stage of most crops. Crop seedlings are vulnerable to salt damage, not necessarily because salt tolerance at this stage is lower than at later stages, but because the roots are short and present in the soil surface where soluble salts usually accumulate (Bernstein 1974). Guayule seedlings remain small (less than 2 cm tall with a cotyledon length of 2 to 3 mm) for a period of 1 to 2 weeks after emergence. According to various field reports, seedling mortality is high during this period, yet the role of salinity is not known.

Three greenhouse experiments were performed for evaluating salt effects on seedling mortality, using the same materials as the previous emergence experiments; cv 593, Bluepoint fine loamy sand, and the three vegetable crop species. Seed was planted in pots and placed in a greenhouse where diurnal temperatures were regulated between 23° to 36° C. When the first true leaf emerged (10, 12, 15, and 17 days after seeding to guayule, tomato, carrot, and pepper, respectively), one set of pots was transferred to a greenhouse compartment with a diurnal temperature regime of 22° and 32° C. Seedling roots, leaves, and stems were then separately exposed to different levels of salinity for 15 days. Seedling root exposure to salinity was achieved by subirrigation with the saline solutions given in Table 1 every 4 to 6 days. Seedling leaf exposure to salinity was achieved by spraying saline solutions (Table 1) onto the seedling leaves until completely wet. The pots with sprayed plants were subirrigated with tap water. Seedling stem contact with high salinity was achieved by placing salted-loamy sand to a depth of approximately 3 mm around the seedling stems, then subirrigating with water of low salinity until the salted-sand layer bacame wet. Desiccated seedlings were counted 15 days after the treatment of roots or stems, and 6 and 9 days after the first and the second spraying of seedling leaves.

When seedling roots were exposed to salinity, guayule exhibited the highest mortality, followed by carrot and chile pepper (Figure 6). Mortality increased greatly with increasing ambient temperatures. When seedling leaves were sprayed with saline solutions, guayule again exhibited the highest mortality among the crops tested, and mortality generally decreased with elevating temperatures (Figure 7). Increasing temperature resulted in lower relative humidity, which might have reduced salt absorption as discussed by Moser (1975) and Grattan et al. (1981). When seedling stems were exposed to high saline solutions (equiva-

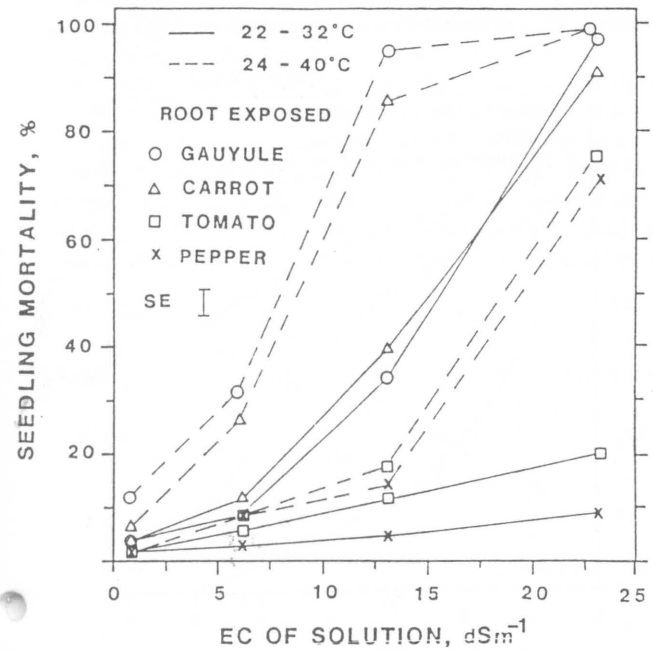

Figure 6. *Seedling mortality of four crop species when their root systems were exposed for 15 days to various saline soil solutions under ambient temperature regimes of 22°-32° C (solid lines) and of 24°-40° C (dotted lines).*

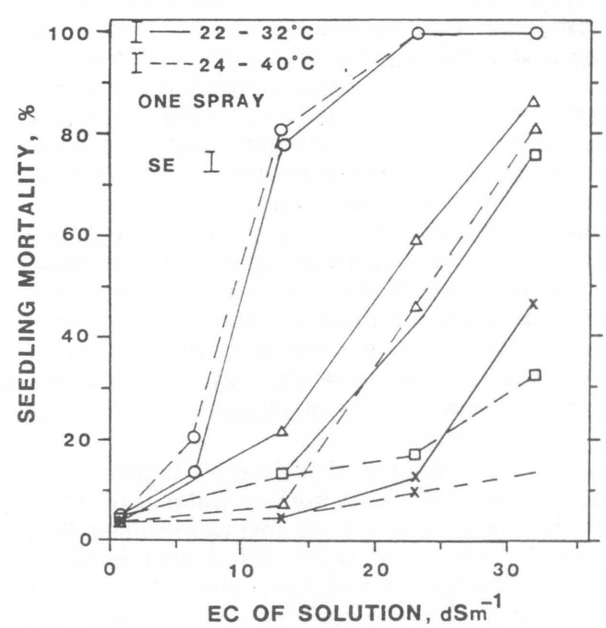

Figure 7. *Seedling mortality of four crop species when seedling leaves were sprayed with various saline solutions under ambient temperature regimes of 22°-32° C (solid lines) and of 24°-40° C (dotted lines).*

Table 1. Composition of saline solutions used for the second seed germination experiment and seedling mortality experiments.

Water No.	EC dS m⁻¹	TDS me L⁻¹	SAR	Na	Ca	Mg	HCO_3	Cl	SO_4
	$dS\ m^{-1}$	$me\ L^{-1}$		me L^{-1}					
1	0.8	9	5	6.4	1.9	0.7	2.4	4.7	1.9
2	12	150	19	99	33	18	2.4	117	30
3	18	225	24	148	49	27	2.4	192	30
4	23	300	28	198	66	36	2.4	267	30
5	32	450	34	297	99	54	2.4	418	30

No. 1: municipal water supply, city of El Paso.
No. 2-5: ion composition similar to typical saline groundwater of the middle Rio Grande

lent to salinity of seawater), mortality increased only by 5 to 20 percent in guayule, and by 10 percent in carrot. A further examination revealed that mortality was confined to small seedlings whose leaves were in contact with the salted-sand. It appears that the stems of seedlings are very tolerant to salinity.

The above experiments indicate that seedling mortality is associated largely with root or leaf but not stem exposure to the salts accumulated at the soil surface. According to the emergence experiments mentioned earlier, seedling emergence is also controlled by the salts accumulated at the soil surface. It should then be possible to increase plant stands through water application which minimizes salt accumulation at the soil surface. To examine this possibility, the third greenhouse experiment was conducted in a manner similar to the first seedling emergence experiment described earlier. Seed of the bulk collection and cultivar 593 were placed 5 mm deep and irrigated in three different ways: (1) surface-irrigated every 2 days at a rate of 0.88 cm per application, (2) surface-irrigated every 7 days at a rate of 1.7 cm, and (3) subirrigated every 2 days by placing the pots in a shallow pan containing the designated saline solutions. The water application rates given above were the amount required to provide a leaching fraction of 30 percent. Stand counts were taken periodically for 30 days. Soil samples were also collected from the top 1 cm and analyzed for electrical conductivity of the saturation extract.

The results indicated significantly higher plant stands with high frequency surface water application (Figure 8). (The results from cv. 593 were similar, thus they are omitted). The worst stand was obtained under the subirrigated condition. The salinity of the saturation extract of the soil samples collected from the top 1 cm was the lowest under every 2 days surface irrigation, followed by weekly surface irrigation, and every 2 days subirrigation (dashed lines in Figure 8).

Establishment Stage

Since guayule establishment by direct seeding is unreliable and seed is currently scarce and costly, guayule is established in the field mostly by transplants. Bare-root transplants were once used, but recently transplants have been grown in nursery trays or other forms of seedling containers or cartridges. Several field reports from Arizona and California indicate high rates of survival when such transplants were irrigated (Bucks et al. 1983). One report from Pecos, however, indicated poor establishment when transplants were irrigated with saline waters having EC of 5 dS m^{-1} (personal communication with Dr. J. Moore, TAES Pecos Station). It is however, uncertain if this was caused by high salinity

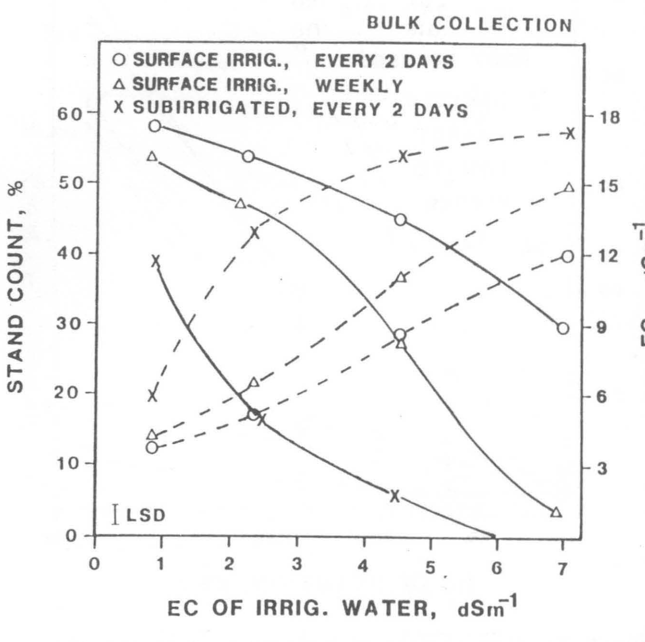

Figure 8. *Stands of guayule seedlings measured 30 days after seeding as affected by water application methods and salinity of irrigation solutions.*

or by other reasons. The following study was conducted to evaluate salt effects on the survival rate and growth of guayule transplant.

Field plots (unit plot size of 6 x 7 m established on Bluepoint loamy sand) was used to evaluate the effect of saline waters on transplant survival and growth. Six USDA selections (11591, 11605, 11619, 11646, 12229, and N576), one hybrid developed in California (4265XF), and cultivar 593 were evaluated. Seedlings were grown in a greenhouse for 10 weeks in nursery trays having an individual seedling cavity size of 2.5 x 2.5 cm square at the top, and tapered to a depth of 5 cm. Seedlings, about 4 cm tall, having 6 to 8 secondary leaves and a firm root-ball, were transplanted on April 23, 1982 into the field plots bedded as shown in Figure 9. Prior to transplanting, the plots had received 30 cm each of four simulated irrigation waters having salinity of 0.9, 2.4, 4.6, and 7.2 dS m^{-1} (solutions 1 through 4 and 6 of Table 2). Salinity of these solutions was slightly higher than those used in the greenhouse experiments, because salinity of tap water which was used as stock water had increased. The water numbered 6 was provided to evaluate Mg effects. Seedlings were planted 30 cm apart along the rows in a split plot with salinity as the main plot and cultivars as subplots in four replicates using a total of 80 plants per cultivar per treatment.

After planting, the simulated irrigation waters mentioned above were applied with a gated pipe to the center dip of the bed (Figure 9) to pack soils around seedling root balls and to minimize salt accumulation in the beds. Until the end of May, irrigation waters were applied weekly at 2.05 cm per application or 4.1 cm on the basis of wet ground surface area, which is slightly less than the potential evaporation rate of 4.6 cm/week estimated by the Penman combination method (Penman 1963). In June, irrigation was reduced to twice a month using the same rate per application. During July and August, the plots were irrigated through conventional furrows twice a month at 4.1 cm per application. Irrigation during 1983 was made at 6.2 cm per application when 70 percent of

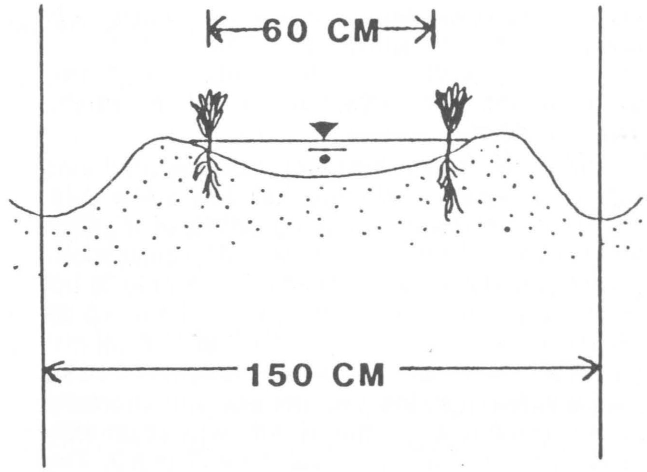

Figure 9. *The cross-sectional sketch of the crop bed used for the guayule transplant experiment.*

the available water in the 60 cm rootzone was depleted. A neutron probe was used to measure soil water storage. The total amounts of irrigation waters applied for 2 years were 169, 159, 142, and 101 cm for waters having salinity of 0.9, 2.4, 4.6 and 7.2 dS m^{-1}, respectively. Transplanting experiments were repeated in June 1983 with irrigation twice a week until the end of July. The rainfall for the 2-year period amounted to 27 cm.

Transplant mortality and plant height were monitored periodically. Toward the end of the first growing season (19 weeks after planting), crown volumes (assuming an oval sphere) were estimated from height and crown diameter. All shrubs were harvested in February 1984 by clipping at 5 to 7.5 cm above the root crown. Dry weight was determined after defoliation, and rubber and resin contents measured by petroleum ether and acetone extraction methods, respectively (Tipton and Gregg 1982). Leaves were analyzed for Na, Ca, and Mg concentrations with an atomic absorption unit after 20 percent HCl extraction,

Table 2. Composition of irrigation solutions used for emergence as well as field plot tests.

Water No.	EC dS m^{-1}	TDS me L^{-1}	SAR	Na	Ca	Mg	HCO_3	Cl	SO_4
				me L^{-1}					
1	0.9	9	5	6.4	1.9	0.7	2.4	4.7	1.9
2	2.2	25	8	16	7.7	1.0	2.4	17	5
3	4.5	50	11	33	11.0	6.0	2.4	27	20
4	7.0	82	14	53	19.0	10.6	2.4	46	34
5	8.2	100	16	66	22.0	12.0	2.4	57	40
6*	2.3	25	8	12	3.0	10.0	2.4	17	5

*This water was used only for the field plot experiment.

and Cl by the $AgNO_3$ titration method following 0.2 N HNO_3 extraction (Chapman and Pratt 1961). Soil samples were collected periodically at a depth increment of 30 cm and analyzed for salinity of the saturation extract.

Transplant mortality in the spring planting continued for about 12 weeks, and thereafter only a few died. Mortality increased with increasing salinity of irrigation water from 4.6 to 7.2 dS m^{-1} (Table 3). The corresponding salinity of the saturation extract in the top 30 cm during 40 days after transplanting was 3.2 and 4.8 dS m^{-1} in the saturation extract or 11.7 and 17.6 dS m^{-1} in soil solution at a mean soil water content of 0.11 kg kg^{-1}, respectively. In the summer planting, mortality increased greatly, while soil salinity was essentially equal to that of the spring transplanting (Table 3). The daily maximum temperature during the first 4 weeks after the spring planting averaged 26°C as compared to 37°C after the summer planting. The rainfall after the spring and the summer plantings was comparable, 11 and 18 mm, respectively, for the first 5 weeks.

The average plant heights of the eight selections showed an increase of a few cm during the first 4 weeks after planting irrespective of the saline treatments (Figure 10). Thereafter, a significant diffference in plant height appeared among the saline treatments. Salinity of the saturation extract in the top 60 cm during the period of July through September, the peak growing period, averaged 1.1, 3.1 and 5.2 dS m^{-1} in the saturation extract (or 2.7, 7.5 and 12.7 dS m^{-1} in soil solution at a mean soil water content of 0.09 kg kg^{-1}) when irrigated with waters of 0.9, 4.6 and 7.2 dS m^{-1}, respectively. Plant heights measured

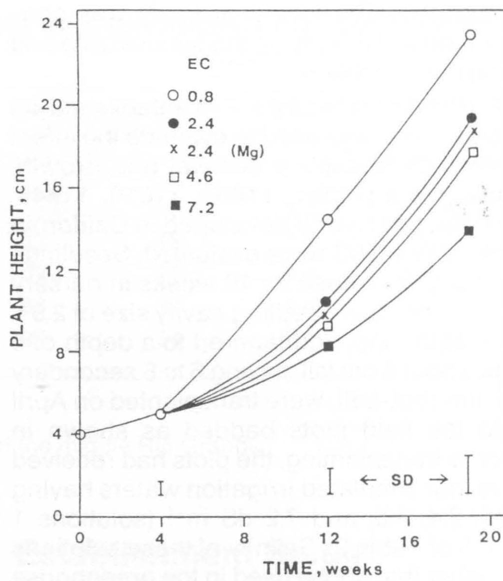

Figure 10. *Plant heights of guayule transplanted in April and grown with various saline waters.*

12 weeks after the summer planting were about 1/3 of the heights obtained after the spring planting.

Plant heights measured at the end of the first growing season (19 weeks after planting) averaged 24, 19 and 14 cm, when irrigated with waters of 0.9, 4.6 and 7.2 dS m^{-1}, respectively (Table 4). The corresponding crown volumes averaged 6,300, 3,700

Table 3. Transplant mortality of guayule selections measured 12 weeks after spring (April 23) and summer (June 9) transplanting in loamy sand irrigated at three levels of salinity.

	Spring Transplant			Summer Transplant		
EC of Irrig. Water	0.9	4.6	7.2	0.9	4.6	7.2
EC of Sat. Extract	0.9	3.2	4.8	1.0	3.3	4.9
EC of Soil Solution[2]	1.8	6.4	9.6	2.0	6.6	9.8
		%			%	
4265XF	0a[3]	0a	6a	14a	28a	67a
11591	2a	0a	10a	20a	25a	85a
12229	7a	8a	11a	18a	37a	88a
593	2a	0a	20a	10a	57b	84a
11619	2a	9a	20a	-	-	-
11605	2a	5a	32b	-	-	-
N576	5a	9a	35b	-	-	-
Average	3	5	21	16	37	81

[1] Electrical conductivity of saturation extract made from soil samples from 0 to 30 cm depth.

[2] Electrical conductivity of soil solution at a mean soil water content estimated as $(SW/MS)^{0.88} EC_e$ where SW the saturation water content, MS the mean soil water content of the field soil and 0.88 the increase in EC per unit increase in salt concentrations.

[3] Numbers in columns followed by the same letter are not significantly different at a 5 percent level by the DMR test used at each salt level.

Table 4. Plant height and individual crown volumes of guayule selections measured at the end of the first growing season 19 weeks after the spring planting.

	Plant Height			Crown Volume		
EC of Water	0.8	4.6	7.2	0.8	4.6	7.2
EC of Sat. Extract[1]	1.2	3.3	5.2	1.2	3.3	5.2
EC of Soil Solution	2.7	7.5	12.7	2.7	7.5	12.7
		cm			000 cm^3	
N576	26a[2]	21a	17a	7.9a	4.8a	2.8a
12229	25a	22a	15ab	6.8a	4.3a	1.7b
11591	25a	22a	14b	6.7ab	4.5a	1.6b
11605	25a	21ab	13b	6.9a	4.4a	1.3b
11619	23a	18b	14b	6.0b	3.1b	1.6b
11646	23a	19b	14b	6.0b	3.9a	1.5b
4265XF	23ab	17b	13bc	5.6bc	2.9b	1.2b
593	20b	16b	11c	4.4c	2.7b	0.9b
Average	24	19	14	6.3	3.7	1.6

[1] Electrical conductivity of saturation extract made from soil samples from 0 to 60 cm depth.

[2] Numbers in column followed by the same letter are not significantly different at a 5 percent level.

and 1,600 cm^3 per plant, or 41 and 75 percent reduction when salinity of irrigation water increased from 0.9 to 4.6 and 7.2 dS m^{-1}, respectively (Table 4). Shrubs in the lowest saline treatment grew to the extent of leaving no space between them along the row. Selection N576 produced the largest crown volume and cultivar 593 the smallest.

Shrub, rubber, and resin yield data obtained after two years are presented in the next section along with regrowth data. Likewise, the quantities of water used to produce unit quantities of shrub, rubber, or resin are discussed in the next section.

Varietal differences in leaf Na, Ca, and Mg concentrations (expressed on the basis of dry leaf matter) were small, mostly less than 15 percent, and statistically insignificant. Only the average concentration of the eight selections of cultivars are shown in Figure 11. Calcium concentrations were very high, and decreased significantly with increasing salinity of irrigation waters. Leaf Cl concentrations were also relatively high, ranging from 7 to 10 g kg^{-1} and increased linearly with Cl concentrations in irrigation waters.

Regrowth

Guayule establishment by direct seeding is currently unreliable, and establishment by transplanting is costly. Repeated harvests of regrowth from clipped plants seem to be ideal (Garrot and Ray 1983). However, little is known about salt effects on regrowth or yields of rubber from clipping. The following field study was conducted to evaluate salt effects on regrowth and rubber production from clipped plants.

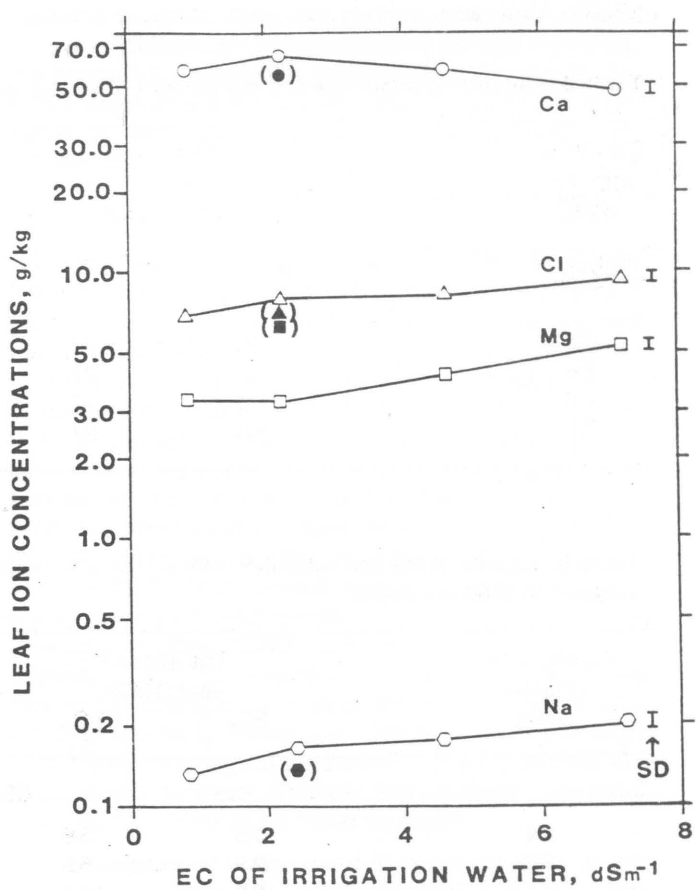

Figure 11. *Leaf ion concentrations of 2-year-old guayule as related to salinity of irrigation water.*

The experimental plots used were the same as those used for the establishment experiment described in the previous section, but because of reduced research funding only half of the original plots were used (or up to 40 plants per cultivar per treatment). The first clipping was made at 5 to 7.5 cm above the root crown in February 1984 after 2 years of growth. The clipped plants were grown for 2 years (1984 and 1985) under limited irrigation and for an additional one year (1986) under intensive irrigation (Table 5). Irrigation in 1982 and 1983 was made (April through mid September) when 70 percent of the available soil moisture in the top 60 cm had depleted, and in 1986, March through mid September at 60 percent depletion. Irrigations in 1984 and 1985 were applied in April and again in August of each year. Plots were fertilized twice a year at 50 kg N ha^{-1} using ammonium sulfate. Shrub stand counts were taken in the spring and at the end of each growing season. Soil salinity was measured three times per season, using the saturation extract of soil samples collected at a 30 cm interval to a depth of 90 cm. Harvested shrubs (defoliated top portion) were analyzed for dry weight, and rubber and resin contents by the methods described in the previous section.

Results of soil saturation extract analyses (Table 6) indicate that soil salinity did not change greatly during the regrowth period when irrigated with waters of comparatively low salinity (0.9 and 2.2 dS m^{-1}). At higher salinity in irrigation waters, soil salinity readings increased considerably during the regrowth period. However, salinity of soil solutions, estimated by an equation in a footnote of Table 3, was greater during the 1984-85 seasons than during the 1986 season, because of lower soil moisture contents.

Clipping caused substantial shrub mortality (Table 7). Mortality rates ranged from 5 to 60 percent and were affected significantly by the saline treatments as well as by cultivar. Selections 11229 and N576 registered mortality less than 20 percent, except at the highest salt level. All mortality had occurred after the first clipping, and the shrubs simply did not show regrowth. The shrubs which had regrowth survived for the rest of the test period, including the period of severe water stress during the 1984-85 seasons.

Shrub yields (average of seven selections and one cultivar) decreased significantly with increasing salinity (Table 8). An exception was the second harvest following the 1984-85 season where shrubs were grown with minimal irrigation. High water stress reduced shrub growth, especially in the plots irrigated with low salt water. The shrub yields listed were computed based on the average dry weight of the shrubs harvested from the area of complete stand

Table 5. Harvesting sequence and the amount of various saline waters applied.

Salinity of irrigation water	First two years (1982, 1983)		Next 2 years regrowth (1984, 1985)		Additional 1 year regrowth (1986)	
dS m^{-1}	Irrigation	Rain	Irrigation	Rain	Irrigation	Rain
			cm			
0.8	169	27	70	46	121	19
2.4	159	27	70	46	105	19
4.6	142	27	70	46	74	19
7.2	101	27	70	46	74	19

Table 6. Salinity of the soil saturation extract (EC_e) and the estimated salinity of soil solutions (EC_s) at a mean soil water content* in 0-60 cm depth.

Salinity of irrigation water	The second year (1983) EC_e	EC_s	Regrowth 1984-1985 EC_e	EC_s	Regrowth 1986 EC_e	EC_s
			dS m^1			
0.8	1.6	3.9	1.9	5.9	2.0	4.4
2.2	2.9	6.9	3.5	11.0	3.8	8.3
4.5	5.2	12.4	6.2	19.5	7.7	16.9
7.0	6.0	14.3	6.7	21.1	8.9	19.6

*Mean soil water contents of 1983, 1984-85 and 1986 seasons were 0.095, 0.07, and 0.10 kg kg^{-1}, respectively.

Table 7. Mortality of shrubs after clipping harvest of 2-year-old shrubs.

Salinity of irrig. water	0.9	2.2	4.5	7.0	
Salinity of sat. ext.	1.6	2.9	5.2	6.0	
Salinity of soil soc.	3.9	6.9	12.4	14.3	Avg.
Mortality			%		
N576	20	38	61	59	45a
11229	37	38	40	37	38a
4265XF	17	22	35	40	29b
11646	10	20	16	53	25bc
11619	15	25	11	29	20c
593	14	21	15	25	19c
11605	11	15	20	28	18c
11591	5	15	15	20	14c
Average	16a	24b	27b	36c	26

LSD_{main} = 6.9, LSD_{sub} = 14, $LSD_{sub(level)}$ = 29.

times 43,800 plants per ha, a theoretical plant population for the planting spacing used. The actual yields in the two low salt treatments were considerably smaller than the listed value, because of shrub mortality, and can be computed by multiplying by the percent of stands. The actual yields from the two high salt treatments were greater than the estimate based on the proportional reduction caused by stand losses by as much as 30 percent, because of the increases in the size of the shrubs grown next to the dead shrubs.

Shrub yield differences among the selection were statistically significant, but the magnitude of the difference was mostly small, for example less than 18 percent except for selection 4265XF and at the highest salt level (Appendix I). Selection N576 produced the largest shrub yield in the first two years, but suffered high mortality after clipping, along with selection 12229. The actual yields from these selections were much smaller than listed values. Overall, selection 11591 gave the largest yield, and cultivar 593 the smallest yield (Appendix I).

Rubber contents increased with increasing salt stress during the 1982-83 and the 1986 seasons, but the magnitude of the increases was fairly small; 8 g kg^{-1} (or 13 percent of the control) and 7 g kg^{-1} (12 percent), respectively (Table 8). The effect of the saline treatments on rubber content was significant at 5 and 10 percent levels in 1982-83 and 1986 harvests, respectively. Rubber contents during the 1982-83 season were highest at the lowest level of salinity. This may have been caused by a longer period of water stress, since the shrub in the plots were the largest. Rubber contents were also affected significantly by cultivar, but the magnitude of the difference was rather small, at most 10 g kg^{-1} (Appendix I). Selection N576 had the highest rubber contents in the first two harvests, and selections 11619 and 12229 in the third harvest.

Resin contents were highest at the lowest salt level and often decreased with increasing salinity. However, the saline treatment was statistically not a significant factor even at the 10 percent level in all of the three harvests. Resin contents were influenced highly significantly by selection. Selection N576 and hybrid 4265XF had the highest resin content, and cultivar 593 the lowest in all of the three harvests (Appendix I).

Rubber yields were highly significantly affected by the saline treatment in the first harvest, and at a 5 percent level in the third harvest. In the second harvest, salt effects were significant only at the 10 percent level. The magnitude of yield reduction when irrigated with water of 4.5 dS m^{-1} was 13 percent in the first harvest and about 20 percent in the subsequent harvests (Table 8). The greater reduction observed in the second and the third harvest was probably due to the increase in soil salinity (Table 6). Rubber yields were affected highly significantly by cultivar. In the first harvest, selection N576 produced the largest yield (Appendix I), but this selection as well as selection 12229 suffered high mortality after clipping (Table 7). Selections 11591 was among the top rubber producers in all of the three harvests with minimal mortality. Selection 11619 did not rank high in the first harvest, but was among the top producers in regrowth harvests. Cultivar 593 produced the least quantity of rubber in all three harvests.

The amount of water used to produce 1 kg of dry shrub ranged from 2.0 to 2.6 m^3 (or 2000 to 2600 tons of water to produce 1 ton of dry shrub) in the first harvest (Table 8). The water use, however, declined to 1.5 to 2.1 m^3 per kg of shrub and 22 to 38 m^3 per kg of rubber in the subsequent harvests (Table 8).

Table 8. Shrub yields, rubber contents, resin contents, rubber yields, and water use efficiency averaged over the eight guayule selections.

EC of irrig. water (dS m^{-1})	0.9	2.2	4.5	7.0
DRY SHRUB (Mg ha^{-1})				
1982-83**	9.8a[1]	8.6ab	8.3b	4.9c
1984-85	6.4	6.2	5.4	5.4
1986*	8.6a	7.2ab	6.2b	5.5b
RUBBER CONTENT (g kg^{-1})				
1982-83*	61a	62a	65ab	69b
1984-85	82	76	76	76
1986	55	58	64	62
RESIN CONTENT (g kg^{-1})				
1982-83	88	77	78	81
1984-85	86	80	78	88
1986	103	97	84	89
RUBBER YIELD (kg ha^{-1})				
1982-83**	620a	530a	540a	340b
1984-85	520	470a	410	410
1986*	490a	420ab	400b	340b
WATER USED/SHRUB (m^3 kg^{-1})				
1982-83	2.0	2.1	2.0	2.6
1984-85	1.8	1.9	2.1	2.1
1986	1.6	1.7	1.5	1.6
WATER USED/RUBBER (m^3 kg^{-1})				
1982-83	33	35	31	38
1984-85	22	25	28	28
1986	29	30	23	26

**, *: significant at the 1 and 5 percent levels, respectively.

[1] Numbers followed by the same letter in row are not significantly different at a 5 percent level.

Overall Assessment

The single most striking characteristic of guayule identified by this program is the large differences in salt tolerance at different stages of growth. Most crops do show stage differences in salt tolerance, but not to the extent observed here.

Guayule was most susceptible to salts at the emergence to seedling stage. In fact, guayule was more susceptible to salts than carrots. Carrots are one of the most difficult crops to establish in saline areas, and stand failures are common when furrow irrigated with water of 1 dS m^{-1} or more (Miyamoto et al. 1984a). Low saline tolerance may also be a reason why native guayule stands are not reported on saline soils. Conversely, extensive emergence of volunteer seedlings are reported in field plantings after rainfall.

The reason for high susceptability of guayule hypocotyls and seedlings is not known. Microscopic observations show that guayule leaves are covered with trichomes and readily absorb water, whereas seedling leaves of many crops have a waxy surface which repels water. This difference in wettability may partly explain why guayule seedlings die so easily when brought into contact with saline waters.

Guayule becomes less susceptible to salts after the seedling stage, but not abruptly. At the end of the first season after transplanting, plant size (measured as crown volume) was still reduced by 41 and 75 percent when irrigated with waters of 4.6 and 7.2 dS m^{-1}, respectively. (The mean salinity of the saturation extract in 0 to 60 cm depth was 4.3 and 5.6 dS m^{-1}, respectively.) Wadleigh and Gauch (1944) reported a 40 percent reduction in top dry matter when transplants of an unspecified selection were grown in sand culture for 14 weeks with a NaCl-nutrient solution having EC of approximately 4.0 dS m^{-1}. Our data coincide with theirs. Growth responses of guayule after seedling transplanting are comparable to those of most vegetable crops.

Growth differences among the saline treatments during the second growing season decreased; for example, only a 15 percent reduction in shrub dry weight at salinity of irrigation water of 4.6 dS m^{-1}. Overcrowding of stands when irrigated with the low salt water may have partly contributed to reducing the shrub yield differences. However, it appeared that guayule became tolerant to salts as the plants became firmly established. Differences in shrub yield among the saline treatments decreased further during the regrowth phase. Established guayule is almost as salt tolerant as Pima and Acala cotton grown in the Southwest (Longenecker 1973).

The reason why guayule becomes tolerant to salts after the seedling stage is not known, but several possibilities can be suggested. First, the development of an extensive root system may supply sufficient water to overcome high osmotic stress. Second, the mature root system may deter Na uptake or store Na in the roots. Leaf analysis of established guayule shows exceptionally low concentrations of Na (Figure 11). According to the data of Wadleigh and Gauch (1944), Na ions cause greater growth reduction than Ca at the same osmotic pressure. Sodium secretion from mature leaves is another possibility.

Another unexpected finding was that guayule requires large quantities of water to produce biomass. In the present study, the total water use (irrigation plus rainfall) was up to 196 cm for the first two years and 140 cm for the last one year. Drainage losses were kept minimal by applying water less than field capacity. Shrub yields increased roughly in proportion to increasing irrigation. A separate study (Miyamoto et al. 1984b) and the work performed at Yuma, Arizona (Bucks et al. 1984) demonstrated that this linear relationship exists for up to 3 cm of water application for the first two years. This water consumption rate cannot be considered low, and is comparable to alfalfa, one of the highest water-consuming crops grown in the Southwest. The amount of water used to produce 1 kg of dry shrub (top portion only) per ha ranged from 2.0 to 2.6 m^3 in the first harvest, which is about twice the value for alfalfa given by Hanson and Samis (1979). The amount of water used to produce shrub tops was reduced by about one-third in the regrowth harvest, as the root system had already been established. Guayule shrubs can tolerate drought, but they are not efficient in water use.

Implication To Cultivation

Direct Seeding

Guayule establishment by direct seeding has been difficult due to lack of seedling vigor. This study indicates that salinity compounds establishment difficulties. Salinity of water used for direct seeding establishment must be as low as possible. In addition, water must be applied in such a way as to minimize salt accumulation at the soil surface. The results shown in Figure 8 illustrate this point. Trickle or high frequency sprinkler should be preferred over furrow methods for establishing guayule by direct seeding. In fact, Bucks et al. (1983) reported 65 percent emergence and 34 percent seedling survival after 2 months when sprinkler-irrigated with water of 1.4 dS m^{-1} for 8 days and twice a week thereafter in loamy sand in Yuma, Arizona. Field reports using furrow methods indicate frequent failures. Tingey (1952) in California, for example, reported plant stands less than 10 percent of the sown seed under furrow irrigation. Salinity of the water used was not specified, but salinity of most irrigation water in that region rarely exceeds 1 dS m^{-1}. We obtained a 30 percent initial stand when furrow-irrigated twice a day for 35 days with water of 0.8 dS m^{-1}, and the stand later declined to 10 percent, similar to the results of Tingey (1952). When water of 4.5 dS m^{-1} was used, no seedlings survived. Stand counts observed in these field tests are considerably lower than those observed in the greenhouse, presumably because of higher water evaporation rates and other stress factors present in the fields. Surface seeding with some sort of anti-evaporants may improve the success rates of guayule establishment. Above all, improvements in seedling vigor must be made if guayule is to be established by direct seeding without costly modification of water application methods.

Establishment by Transplants

Transplanting is the most reliable method currently available for establishing guayule. However, several precautions should be taken. Spring or fall is undoubtedly preferred to summer for transplanting (Table 2). Quality and size of the transplants are also important. Salinity of the water does not need to be as low as that for direct seeding, but the rate of transplant growth can be reduced if salinity of water exceeds 1 to 2 dS m^{-1} (Figure 10). If reduced rates of transplant growth are acceptable, and salt accumulation in crops is minimized, water having salinity up to about 4.5 dS m^{-1} can be used without risking significant transplant losses (Table 2). Off-centered planting or double row planting as used in our experiment are preferred, especially when water of high salinity is used for irrigation. Sprinkler irrigation would be an alternative to furrow methods for transplant establishment. Salt damage from sprinkling of saline water, although many exceptions exist, becomes severe in most crops when salinity of irrigation water exceeds about 4 dS m^{-1} and sprinkled during day hours (Moore and Murphy 1979). Since guayule is sensitive to foliar absorbed salt damage (Figure 7), salt damage to guayule seedlings can occur even at low salinity.

Clipping Harvest

Guayule establishment by direct seeding is currently unreliable, and establishment by transplanting is costly. Clipping harvests seem to be an alternative, but shrub mortality can be a problem. The extent of mortality observed here after clipping was greater than those reported in Arizona (Garrot and Ray 1983). Most mortality occured in the spring, and the shrubs had been water-stressed before clipping. Mortality appeared to have been associated with characteristics of selections and salinity (Table 7). Maas et al. (1984) also reported mortality rate of 36 percent when shrubs grown in 12 dS m^{-1} treatment for two years were clipped. In their experiment, shrub mortality continued and by the fourth year, most plants irrigated with 9 and 12 dS m^{-1} died. Mortality problems can be minimized by selecting cultivars which have low rates of mortality and/or by controlling soil salinity below about 5 dS m^{-1}. At present, selections 11591 and 11619 may be good choices. Replacing dead shrubs with new transplants is an option, but may be impractical in low value crops like guayule. The frequency of clipping would depend largely upon the yield levels desired, availability and quality of irrigation water, and, to some extent, row and plant spacing and cultivars. If high yields are the principal objective, yearly clipping with frequent irrigation on close-spaced planting would be necessary.

Some of the earlier research in California (Hunter and Kelley 1946; Tingey 1952; Veihmeyer and Hindickson 1961) indicated that water stress increased rubber contents as well as rubber yields. This study and those reported earlier (Miyamoto et al. 1984b; Buck et al. 1984) also show that stressing guayule increases rubber contents, but not to the extent of offsetting the reduction in shrub yields. Likewise, salt stress was reported to increase rubber contents (Retzer and Mogen 1946). This study confirmed this finding under frequent irrigation. However, the increase did not offset reduction in shrub yields. If high yields per acre are the primary concern, guayule must be grown with low water stress and low salt stress.

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Appendix I

Soil salinity, shrub yield, resin contents, and rubber yields of guayule selections and a cultivar

	1982-83				1984-85				1986			
SALINITY STATUS*						dS m^{-1}						
ECi*	0.9	2.2	4.5	7.0	0.9	2.2	4.5	7.0	0.9	2.2	4.7	7.0
ECe	1.6	2.9	5.2	6.0	1.9	3.5	6.2	6.7	2.0	3.8	7.7	8.9
ECs	3.9	6.9	12.4	14.3	5.9	11.0	19.2	21.1	4.4	8.3	16.9	19.6
SHRUB YIELDS						Mg kg^{-1}						
N576	10.6a	9.7a	9.9a	6.9a	5.7bc	4.6c	(4.4)bc	(4.9)ab	8.9a	6.6ab	(5.2)b	(6.1)a
11591	11.7a	9.8a	9.8a	5.3ab	7.7ab	7.6a	6.7a	5.8ab	9.7a	7.7ab	6,5ab	5.7a
11619	9.9ab	8.1bc	8.5	6.1a	6.7abc	7.4a	5.6abc	6.1ab	9.4a	8.9a	6.9ab	6.6a
12229	9.9ab	8.9ab	8.1a	5.3ab	7.7ab	8.6a	5.7abc	6.6a	9.5a	7.5ab	6.2ab	5.1a
11646	9.9ab	8.9ab	8.8a	4.3b	5.2c	5.2bc	4.9abc	(4.9)ab	5.7b	5.6b	5.7ab	(5.6)a
11605	10.0ab	9.7a	8.7a	4.1b	5.5c	4.3c	5.7abc	5.2ab	9.5a	6.0b	5.6ab	5.0a
593	8.7bc	6.8c	6.5b	2.6c	4.6c	4.9bc	4.0c	4.3c	7.8ab	5.2b	5.2b	4.6a
4265XF	7.6c	6.5c	6.3b	4.5ab	8.3a	6.8ab	6.3ab	5.1ab	8.8a	9.3a	8.2a	5.2a
Ave.	9.8	8.6	8.3	4.9	6.4	6.2	5.4	5.4	8.6	7.2	6.2	5.5
RUBBER CONTENTS						g kg^{-1}						
N576	73a	73a	77a	84a	90a	85a	91a	68c	43d	53bc	67ab	68ab
11591	53c	57bc	63b	64bc	75b	75ab	74bc	73abc	51cd	58ab	70a	72a
11619	54c	54c	56b	60c	90a	73ab	74bc	70bc	63ab	59ab	66ab	69ab
12229	58bc	60b	57b	74ab	85ab	74ab	75bc	83ab	72a	58ab	64ab	62bc
11646	63b	65b	61b	66bc	77ab	74ab	61c	79abc	58bc	65a	56b	53c
11605	66b	65b	67ab	69bc	84ab	77ab	84ab	84a	53bcd	55abc	63ab	72a
593	58bc	61b	71a	72b	72b	68b	78b	84a	51cd	65a	67ab	62bc
4265XF	60b	63b	64b	66bc	84ab	81ab	74bc	72abc	52cd	47c	58b	40d
Ave.	61	62	65	69	82	76	76	76	55	58	64	62
RESIN CONTENTS						g kg^{-1}						
N576	113a	85a	95a	104a	102a	87a	89a	102ab	117ab	112a	100a	96b
11591	82bc	74abc	81bc	77bcd	81c	78a	73c	86cd	96bc	83bc	93ab	83bc
11619	82bc	75abc	72cd	72cd	80cd	79a	78bc	81d	90c	91abc	86ab	83bc
12229	93b	81ab	80bc	83bc	94ab	84a	86ab	85cd	108abc	112a	85ab	82bc
11646	90b	81ab	84b	82bc	89bc	86a	89a	93bc	105abc	102ab	89ab	94b
11605	82bc	72bc	80bc	78bcd	86bc	85a	74c	82cd	99bc	83bc	72bc	77bc
593	73c	64c	65d	68d	66d	66b	66c	67e	86c	79c	62c	61c
4265XF	86b	80ab	72cd	87b	90bc	75ab	71c	109a	123a	111a	89ab	135a
Ave.	88	77	78	81	86	80	78	88	103	97	84	89
RUBBER YIELDS						kg ha^{-1}						
N576	770a	710bc	760a	580a	510abcd	390bc	400a	330b	380c	350ab	350a	410a
11591	620bc	560bc	620b	340b	580abc	570ab	500a	420ab	490bc	450ab	460a	410a
11619	530bcd	440cd	480bcd	370b	600abc	540ab	410a	430ab	590ab	530a	460a	460a
12229	570bcd	530bcd	460cd	390b	650ab	640a	430a	550a	680a	440ab	400a	320ab
11646	620bc	580ab	540bc	280bc	380cd	400bc	300a	390ab	330c	360ab	320a	300ab
11605	660ab	630ab	580bc	280bc	460bcd	330c	480a	440ab	500bc	330b	350a	360ab
593	500cd	410d	460cd	190c	330d	330c	310a	360ab	400c	340b	350a	290ab
4265XF	460d	410d	400d	300bc	700a	550ab	470a	370ab	460bc	440ab	480a	210b
Ave.	590	530	540	340	530	470	410	410	480	410	400	350

The numbers in parentheses are less credible than others due to high shrub mortality.

*ECi = salinity of irrigation waters; ECe = salinity of the soil extract; ECs = salinity of soil solutions.

Appendix II

A conversion table for selected units

Category	SI or Metric Units	To Convert to	Multiply by
Area	ha	acre	2.47
Depth of irrigation	m	inch	39
	cm	inch	0.4
Plant population	ha^{-1}	plant/acre	0.405
Rubber, resin	$g\ kg^{-1}$	%	0.10
Salinity	$dS\ m^{-1}$	mmho/cm	1.00
		ppm	735
Soil water content	$kg\ kg^{-1}$	% by wt.	100
Soil water suction	MPa	bars	10
Temperature	C	F	9/5 x C + 32
Volume	m^3	gallons	264
		ft^3	35.3
Water use	$m^3\ kg^{-1}$	gal/lb	120
Yield	$mg\ ha^{-1}$	lb/acre	892
		tons/acre	2.24

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1M—1-90