Sodium Salt Treated Catchments for Water Harvesting

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ABSTRACT

A paired catchment study of field-sized water-harvesting plots showed that precipitation runoff efficiency from an area treated with a spray application of a sodium carbonate salt solution at a rate of 44.9 g of salt per m^2 was 46% of the total precipitation compared to 33% from an untreated catchment for a 3-yr period. After 3 yr the treatment was no longer effective. Runoff efficiency evaluations with a small sprinkler of a 14-yr old, operational-sized, runoff-farming catchment treated with granulated sodium chloride salt mixed into the soil at a rate of 1120 g of salt per m^2 showed that runoff was over 80% of the total precipitation from the treated areas compared to 55% from similar untreated areas. Measured runoff from sprinkler evaluations of treatment effectiveness was higher when distilled water was used than when using the local top water. Soil erosion was not a problem on soils which developed a gravel protective layer on the catchment surface. Water costs from salt treated catchments are estimated at $0.08 to 0.59/1000 L in a 500 mm rainfall zone.

INTRODUCTION

Water harvesting is the collection of precipitation runoff from a prepared catchment surface for later beneficial use. It is a water supply technique that is technically feasible wherever there is precipitation (Frasier and Myers, 1983). The collected water may be used for a variety of purposes such as drinking water supplies for human and animals and for growing crops (runoff farming). Researchers, farmers, and ranchers have used almost every conceivable method of waterproofing or covering the catchment soil surface to increase precipitation runoff. Some typical techniques are covering the catchment area with membranes of artificial rubber, sheet metal, plastics, etc.; chemically treating the soil with asphalts and water repellents of silicone or paraffin wax; and simple clearing and smoothing of the land (Frasier, 1975a).

Many of these treatments are relatively expensive and used primarily for providing drinking water supplies. There is a need in both drinking water supply and runoff farming applications for a low cost catchment treatment which yields a moderate to high runoff percentage of the precipitation. One potential treatment which meets this criterion is sodium salt.

BACKGROUND

On soils which have a clay aggregate component representing at least 15% clay sized particles, ($< 2\mu$), by weight, it is possible to reduce water infiltration by application of a sodium salt. The sodium salt promotes a breakdown of the soil aggregates and the dispersed clay particles migrate with the infiltrating water to a zone where they clog the soil pores and form an impermeable clay lens (Gal et al., 1984). Lambe (1954) conducted extensive permeability studies using sodium chloride, sodium carbonate, and sodium phosphate salts as clay dispersants for sealing soils. Decker (1965) reported that, as early as 1939, Soil Conservation Service technicians were recommending the mixing of sodium chloride salt into the soil followed with compaction as a treatment for reducing seepage from stockponds. Sodium carbonate salt mixed into uncompacted soil has been used for sealing earthen stock ponds in Arizona (Myers and Reginato, 1969; Reginato et al., 1973).

For water harvesting applications, sodium salts can be applied to the soil by either (a) surface application as a dry material or water solution or (b) mixed into the soil during final stages of site preparation. Following a rainfall event or other suitable water application, the catchment surface may be compacted to achieve maximum soil density in the surface soil layers. The mixed soil-salt approach has been used on several water harvesting systems constructed for runoff farming applications with agronomic crops (Dutt, 1981; Dutt and McCreary, 1975; Fink and Ehrler, 1981). The effectiveness of a water harvesting catchment treatment is usually referenced to the quantity of precipitation which occurs in a given period. The precipitation runoff efficiency is defined as the quantity of runoff per unit area divided by the quantity of precipitation per unit area and usually referred to in terms of percent of the precipitation.

Studies were initiated in Israel in 1964 to evaluate sodium salt dispersion of clay aggregates as a means of increasing precipitation runoff. Precipitation runoff was measured during the winter rainy season from 2 × 2.8 m plots treated with various sodium salts. For a three year study period, the precipitation runoff efficiency from the salt treated plots ranged from 55 to 89% of the rainfall. Runoff from smoothed-compacted controls ranged from 39 to 71% and from smoothed only controls from 33 to 51% of the rainfall. There were no apparent changes in runoff effiency of these treatments over the 3-yr study

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interval that *could* be attributed to treatment deterioration. It was concluded that, at the study sites, soil erosion was a serious problem on the plots treated with sodium salts alone and that some form of soil stabilization would be needed (Hillel, 1967).

In 1965, an undisturbed 1.0 ha watershed with 10% clay in the soil, near Tucson, AZ was treated with granulated sodium chloride salt spread on the soil surface at a rate of 47 g of salt per m^2. During subsequent rain storms the salt dissolved and was translocated into the upper surface layers of the soil profile. During a single storm event of 74 mm, the treated area yielded 10.3% runoff compared to 0.4% from an adjacent untreated area (Cluff and Dutt, 1966). Cluff et al. (1972) reported that the runoff efficiency from the area declined with time and there was an apparent downward migration of the dispersed clay lenses.

From 1960 to 1984, studies were conducted by the authors at the U.S. Water Conservation Laboratory, Phoenix, AZ and the University of Arizona, Tucson, AZ to further investigate the use of sodium salt treatments for water harvesting. The primary objective was to evaluate the effectiveness of the salt treatments, both surface applied and mixed with the soil, for improving the precipitation runoff efficiency. Two approaches were used in the studies: (a) measuring runoff from salt treated areas during naturally occurring precipitation events and (b) using a small sprinkler on specifically prepared areas and operational water harvesting research areas to artificially apply water. The surface applied sodium salt treatment was evaluated at the U.S. Water Conservation Laboratory's Granite Reef Water Harvesting test site near Mesa, AZ. Evaluations of sodium salts mixed into the soil followed with soil compaction were conducted on two separate runoff farming research installations. One site was located on the University of Arizona's Page Ranch test site near Oracle, AZ and the other site on the U.S. Water Conservation Laboratory's Runoff Farming test site near Camp Verde, AZ.

METHODS AND MATERIALS

In 1965, two ridge and furrow plots were constructed at the Granite Reef Water Harvesting test site. The soil was a Tremant gravelly sandy loam (fine-loamy, mixed, hyperthermic Typic Haplargid) containing less than 10% clay (< 2μ). The plots were 30.5 m (100 ft) long, 6.1 m (20 ft) wide, constructed with a rubber tired road grader in the shape of a shallow 'V'. Sideslopes were 10% with a 3% gradient along the bottom of the 'V'. The outlet of each plot drained into a buried 5600 liter concrete tank. The collected water was pumped from the tanks through a water meter after each runoff event.

Following construction, runoff was measured from the plots for pretreatment period of 12 May 1965 to 16 Apr 1966. On May 13, 1966, the soil surface of one plot (R-4) was sprayed with a 10% solution of sodium carbonate salt at a rate of 44.9 g of salt per m^2. The other plot (R-2) was left untreated. During the pretreatment period and the first year following treatment, a limited number of samples of runoff water were collected from each plot for each storm event for total sediment content and particle size (hydrometer) analysis.

Soil Mixed and Compacted Salt Treatment

Site Descriptions

Page Ranch: The Page Ranch test site is a runoff farming facility for growing grapes. The soil was a Whitehouse loam (fine, mixed, thermic Ustollic Haplargid). The soil texture analysis of the surface 7 cm was 46% sand, 33% silt, and 21% clay. The runoff farming system, installed in 1970, consisted of a series of large 'V'-shaped catchments with 4% sideslopes. The bottom of the 'V' was on a 2% gradient. The catchment area was treated by mixing granulated sodium chloride salt into the top 5 cm of soil at a rate of 1120 g of salt per m^2, Following a 10 mm rainfall, the area was compacted with a 4500 kg vibratory roller (Dutt and McCreary, 1975). In 1981, a set of small salt treated test plots were installed to evaluate precipitation runoff characteristics from salt treated areas. The plots were 2 m wide by 3 and 6 m long on slopes of 1, 5, 10, and 15%. Granulated sodium chloride salt was mixed into the soil surface at a rate of 1120 g salt per m^2 and compacted with a vibratory roller. Total precipitation runoff was volumetrically measured after each runoff event (Evett and Dutt, 1985).

Camp Verde: The Camp Verde test site, installed in 1978, was used for growing conifers. The soil was a Glendale silty loam, (mixed calcareous, thermic Typic Torrifluvent) with 11% sand, 76% silt, and 13% clay. Level-contour terraces, 37.5 m long, were formed with a rubber tired road grader. Catchment surfaces, 3.0, 6.0, and 9.0 m wide, were smoothed and cleaned of trash and rocks with a tractor drawn landscraper which simultaneously mixed granulated sodium chloride salt into the top 5 cm of the soil surface at a rate of 1120 g of salt per m^2. Following a rain of 7.0 mm, the area was compacted with a vibratory roller. A separate small plot, 2.22 m wide by 6.0 m long with a runoff collection tank was installed with the same treatment to monitor the precipitation runoff efficiency of the treatment (Fink and Ehrler, 1981).

Sprinkler Runoff Evaluation Procedure

A small plot sprinkler was used to estimate the runoff efficiencies from the various salt treated areas. Water was applied to a 1-m^2 area on the catchment surface from a single, low-pressure, wide-angle, fine-drop size, full-square nozzle. The test area, in the center of the spray pattern, was defined by a metal shield sealed to the soil surface by a foam rubber cushion on top of a bentonite clay layer. The shield was designed to prevent any water splash into or out of the test area. The runoff water from the soil surface was collected from the lower edge of the plot with a vacuum pickup for measurement in a graduated plastic chamber. Wind disturbance of the spray was minimized with a 2 m high wind curtain fastened to a metal framework around the test area. Water sprayed outside the 1-m^2 test area was collected in a channel and conveyed away from the area. The spray application rate was set prior to testing by placing a metal pan over the test area and adjusting the water pressure at the nozzle until a constant spray rate of 45 to 50 mm/h was achieved. Without shutting off the spray, the metal pan was removed and the water sprayed directly onto the test area. Each test run lasted for 10 to 15 min or until a constant runoff rate was achieved. The treatment runoff efficiency was determined by plotting the cumulative water applied vs. the cumulative runoff.

The best fit straight line from linear regression analysis was fitted to all data points after initiation of runoff. The x-axis intercept was the threshhold amount of water required for runoff. The slope of the line was the runoff efficiency after runoff had started (Frasier et al., 1979).

Personal discussions with various researchers supported our concern for the effect of the quality of the applied water when using 'rainfall simulators' for evaluating salt treated areas. There was an apprehension that sprinkler derived results using water which contained various cations, especially sodium, calcium, magnesium, and potassium might be different than would be obtained using rainwater or distilled water. Agassi et al. (1985) showed that the quality of the water used in rainfall simulator studies on sodic soils changed the measured infiltration rates. Infiltration rates using water with an electrical conductivity of 0.5 dS m^{-1} was reduced by up to 50% compared to infiltration rates measured with water with an EC of 0.01 dS m^{-1}.

To evaluate the effect of water quality on our test results, the measured runoff efficiency as determined by the portable sprinkler was evaluated by using both distilled water and Tucson city tap water in the sprinkler tests at Page Ranch. During each test, a 50 mL sample of the runoff water was collected for chemical analysis of sodium, potassium, calcium, and magnesium, and for electrical conductivity. The electrical conductivity was measured on a conductivity bridge and elemental analysis by atomic absorption.

Sprinkler tests were run at the Page Ranch test site in Dec. 1982 and Apr. 1984, 12 and 14 yr after treatment respectively. Two general locations were selected on the salt treated area (Salt-1 and Salt-2) and an untreated site outside the salt treatment area. Within each of the locations, three sites were randomly selected for sprinkler evaluation. Analysis of variance was used to determine if differences among treatments were significant.

The design of the large runoff farming areas at Page Ranch does not allow for measurement of precipitation runoff. To estimate the precipitation runoff from the salt treatment on the soils in the area, a set of small runoff plots were constructed in 1982 with the same procedure used on the large areas (Evett and Dutt, 1985). We used these plots to obtain a relative comparison of sprinkler derived runoff values to actual precipitation runoff values. One set of sprinkler tests were run on 3 of the plots in Dec. 1982 with both tap and distilled water. The characteristics of the plots used were: 3 m long, 10% slope; 6 m long, 5% slope; and 6 m long, 1% slope.

Sprinkler tests were run at the Camp Verde test site in Feb. 1984 on three sites on the salt treated area and at two sites on an untreated area. All individual test sites were selected at random. The sprinkler results were compared to actual precipitation runoff measured from the small salt treated plot adjacent to the main areas. The rainfall-runoff efficiencies and threshold rainfall amounts from the small plot were determined using linear regression analysis of the separate rainfall events as described by Frasier (1975b).

RESULTS AND DISCUSSION

Surface Applied Salt Treatment

Paired plot comparison techniques were used to evaluate the effectiveness of the salt treatment at the Granite Reef Test Site. During the pretreatment period, a total of 237.3 mm of rainfall in 35 separate storms was recorded at the site. Individual storm sizes varied from 0.4 to 25.7 mm. Total runoff from the two plots was 78.5 and 79.1 mm from 23 to 20 events, respectively as shown in Table 1. Linear regression analysis of the accumulated runoff of one plot versus the accumulated runoff of the other plot indicate that the runoff of the two areas were identical (correlation coefficient of 0.9997).

After treatment, the runoff precipitation efficiency from the treated plot averaged 71% of the total precipitation for the remainder of the year, 1966, compared to less than 50% from the untreated plot (Table 1). Average annual runoff efficiency declined for both plots in the succeeding years. The variable amounts of annual precipitation, number of storms, and individual storm amounts and intensities made it difficult to estimate the effectiveness of the salt treatment based only on total runoff. Fig. 1 shows the best fit linear regression line of the annual accumulated runoff of the treated plot R-4 vs. the untreated plot R-2 and illustrates that the salt treatment was effective for 3 yr. Comparison of the cumulative runoff from the two plots for the years

TABLE 1. RAINFALL AND RUNOFF AMOUNTS AND MEAN RUNOFF EFFICIENCY FROM A PLOT TREATED WITH SODIUM CARBONATE SALT AND AN UNTREATED PLOT AT THE GRANITE REEF WATER HARVESTING TEST SITE

	Rainfall		Runoff					
			R-2 (untreated)			R-4 (treated)		
Year	Events, no.	Total, mm	Events, no.	Total, mm	Efficiency, %	Events, no.	Total, mm	Efficiency, %
Pretreatment:								
12 May 1965–16 Apr 1966	35	237.3	23	78.5	33.1	20	79.1	33.3
Post treatment:								
1966*	20	178.8	8	84.7	47.4	8	125.1	70.7
1967	23	274.6	12	75.9	27.6	12	104.0	37.9
1968	11	123.6	8	31.3	25.3	8	37.7	30.9
1969	32	232.8	16	46.1	19.8	15	41.9	18.0
1970†	13	162.5	9	48.8	30.0	8	40.7	25.0

*First event on 19 Jun 66
†Last event on 3 Oct 70

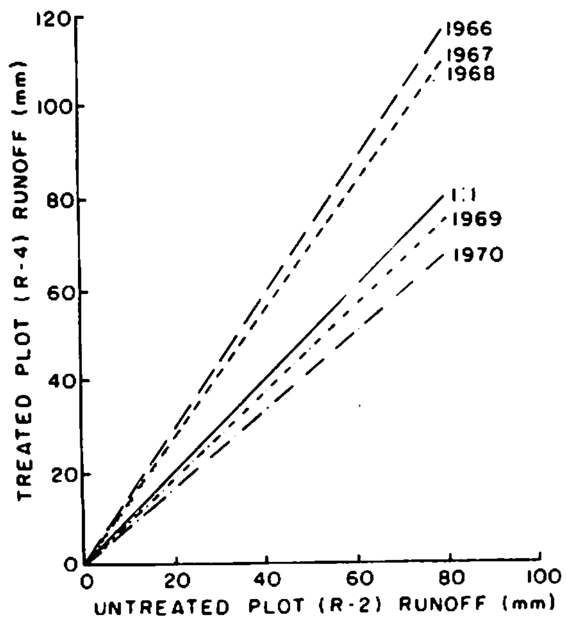

Fig. 1—Comparison of the best fit linear regression lines of the accumulated runoff from a plot treated with sodium carbonate and an untreated plot by years (1966 to 1970) at the Granite Reef test site.

1969 and 1970 shows a major decline in runoff from the treated plot. The salt treatment was no longer effective for increasing precipitation runoff.

Water samples for total sediment concentration analysis were collected from the two plots for six storm events prior to and two storm events following treatment. The limited number of samples precludes any definitive conclusions but there are indications that the treatment did not increase erosion as shown in Fig. 2. Particle size analysis showed no change in relative concentrations of sand, silt, and clay in the sediment samples. The relatively stable erosion rate is attributed to a gravel 'desert' pavement which had formed on the soil surface during the pretreatment period. The gravel covering provided an effective protective layer to the soil surface as described by Simanton et al. (1984).

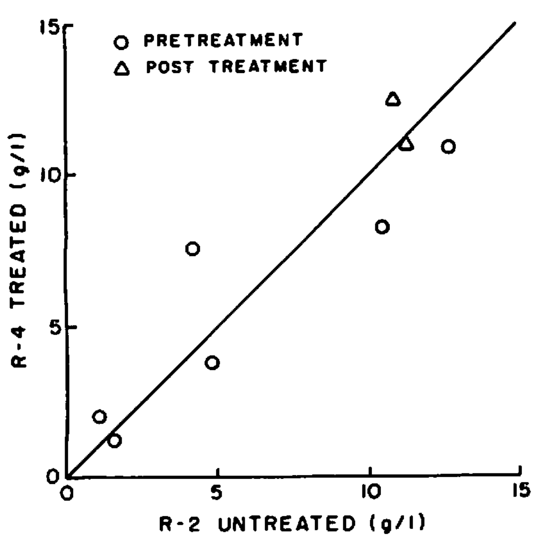

Fig. 2—Comparison of the pretreatment and post treatment sediment concentrations from a plot treated with sodium carbonate and an untreated plot at the Granite Reef test site.

TABLE 2. MEAN RUNOFF EFFICIENCIES AT THREE LOCATIONS ON THE SALT TREATED RUNOFF FARMING CATCHMENTS AND AN UNTREATED AREA AT THE PAGE RANCH ON TWO DATES AND WITH TWO SPRINKLER WATER QUALITIES

Treatment	Runoff efficiency					
	Dec 1982		Apr 1984		Mean	
	Tap, %	Distilled, %	Tap, %	Distilled, %	Tap, %	Distilled, %
Salt-1	66	84	64	80	64.7 bB†	81.9 aA
Salt-2	83	79	60	81	70.9 aB	80.0 aA
Untreated	77	73	55	54	65.8 bA	63.5 bA

Analysis of variance results:

Source of variation	df	Sum of squares	Mean square	F Ratio	Significance
Year	1	1111.1	1111.1	18.6	*‡
Spray water quality	1	612.9	619.2	10.2	*
Soil treatment	2	770.0	385.0	6.4	*
Interactions:					
Year x Water	1	127.5	127.5	2.1	ns§
Year x Treatment	2	441.4	220.7	3.7	ns
Water x Treatment	2	519.2	259.6	4.3	*
Water x Year x Treatment	2	364.7	182.4	3.1	ns
Error	24	1436.3	59.8		

†Values in a column with different small letters are significantly different ($P<0.05$). Values in a row with different capital letters are significantly different ($P<0.05$).
‡Significant at $P<0.05$.
§Designates no significance.

Soil Mixed and Compacted Salt Treatment

Page Ranch: Analysis of the sprinkler derived runoff data measured on the large runoff farming catchments showed an interaction of water quality and treatment as shown in Table 2 ($P < 0.05$). The runoff efficiencies from the salt treated areas using distilled water were significantly higher than those measured with tap water. There were no differences in the runoff efficiencies from the untreated areas. These results support the conclusions of Agassi et al. (1985) that the electrolyte concentrations of the applied water can affect the water infiltration rate. This can be an important factor in rainfall simulation studies on some soils.

There was also a difference in runoff efficiencies between the year of test. At the time of the Dec. 1982 tests, the soils were moist from several recent rainfall events. This antecedent moisture was a contributing factor in the high runoff efficiencies measured on the untreated area and may have influenced the runoff from the treated areas. The Apr. 1984 evaluations were conducted following an extended dry period. The runoff efficiencies of the untreated areas were less with the dry soil condition in Apr. 1984 than was determined for Dec. 1982. The effect of the spray water quality on the treatment runoff efficiency was not overly apparent during the 1982 tests. We attributed this to the wet soil condition which would reduce the ion concentration differences between the soil water and the spray water. In the 1984 tests on the drier soil, the ion concentrations in the soil water were more sensitive to the quality of the spray water as hypothesized by Agassi et al. (1985).

The quantity of water required to initiate runoff (threshold runoff) was less with distilled water than with tap water ($P < 0.05$). These results, shown in Table 3, support the conclusions derived from the runoff data; namely that infiltration was less with a corresponding incresae in runoff when distilled water was used versus that with tap water.

The quantities of the analyzed constituents in the runoff water were less with distilled water than with tap water. The results of the chemical and conductivity

TABLE 3. MEAN THRESHOLD RAINFALL AT THREE LOCATIONS ON THE SALT TREATED RUNOFF FARMING CATCHMENTS AND AN UNTREATED AREA AT THE PAGE RANCH ON TWO DATES AND WITH TWO SPRINKLER WATER QUALITIES

Treatment	Threshold rainfall					
	Dec 1982		Apr 1984		Mean	
	Tap, mm	Distilled, mm	Tap, mm	Distilled, mm	Tap, mm	Distilled, mm
Salt-1	4.1	2.2	4.1	2.7		
Salt-2	2.8	2.8	2.9	2.3		
Untreated	2.7	2.8	4.2	3.7		
Mean†					3.5	2.8

Analysis of variance results:

Source of significance variation	df	Sum of squares	Mean square	F Ratio	Significance
Year	1	1.39	1.39	1.55	ns§
Spray water quality	1	4.77	4.77	5.35	*‡
Soil treatment	2	3.07	1.54	1.73	ns
Interactions:					
Year x Water	1	0.14	0.14	0.16	ns
Year x Treatment	2	3.10	1.55	1.74	ns
Water x Treatment	2	4.11	2.05	2.30	ns
Water x Year x Treatment	2	0.60	0.30	0.33	ns
Error	24	21.28	0.89		

†Means are significantly different ($P<0.05$).
‡Significant at $P<0.05$.
§Designates no significance.

analysis are shown in Table 4. With the exception of sodium, the quality of the runoff water was approximately the same as the spray water. There was more sodium in the runoff water than in the applied spray water and, as expected, more sodium in the runoff water from the sodium salt treated areas than from the untreated areas This is attributed to sodium in the clay aggregate complex which was detached and transported in the runoff water.

The measured runoff efficiency from the small test plots at Page Ranch were the same on the 5 and 10% slopes with no discernible differences between the two spray water qualities. Runoff efficiency on the 1% slope plot with the distilled spray water was higher than with the tap water. The sprinkler derived runoff efficiences and threshold runoff values with distilled water, shown in Table 5, were very similar to the rainfall-runoff efficiences reported by Evett and Dutt (1985) for the same plots.

Camp Verde: Runoff efficiencies, determined using sprinkler applied water, were 19 and 73% for the untreated and treated sites, respectively. Correspondingly, threshold runoff values were 4.4 mm on the untreated soil and 2.6 mm on the salt treated area (Table 6). These tests were conducted using the locally available tap water which was of similar quality to the Tucson tap water. The differences in measured runoff efficiencies from the treated and untreated areas were greater than might have been expected based on the Page Ranch results. The average precipitation runoff efficiency per year as computed from rainfall-runoff data

TABLE 4. MEAN AND 90% CONFIDENCE INTERVAL OF RUNOFF WATER CHEMICAL AND ELECTROLYTIC ANALYSIS FROM SPRINKLER TESTS WITH TAP AND DISTILLED WATER ON PAGE RANCH RUNOFF FARMING SITE

	Type of spray water		Test location					
			Salt-1		Salt-2		Untreated	
Chemical	Tap	Distilled	Tap	Distilled	Tap	Distilled	Tap	Distilled
Dec 1982:								
Sodium*	60	1	59±43	24±6	70±12	30±2	64±2	8±4
Potassium	3	<1	3±2	2±2	4±2	2±2	5±2	1±2
Calcium	76	5	67±2	5±2	70±8	6±2	76±4	12±16
Magnesium	13	<1	12±2	2±2	13±2	2±2	14±2	3±2
Electrical conductivity†	0.75	0.04	0.75±0.06	0.14±0.06	0.88±0.35	0.20±0.04	0.81±0.02	0.13±0.14
Apr 1984:								
Sodium	37	1	55±4	15±4	61±12	22±16	42±2	10±6
Potassium	2	<1	3±2	1±2	5±2	1±2	8±8	3±2
Calcium	36	2	34±4	2±2	34±4	4±6	37±4	2±2
Magnesium	11	<1	11±2	1±2	12±2	2±2	11±2	2±2
Electrical conductivity	0.48	0.02	0.54±0.04	0.09±0.04	0.60±0.02	0.11±0.02	0.51±0.04	0.07±0.02

*Relative amounts of sodium, potassium, calcium and magnesium are shown as parts per million (ppm).
†Electrical conductivity given as dS m^{-1}

TABLE 5. COMPARISON OF SPRINKLER DETERMINED RUNOFF EFFICIENCIES AND THRESHOLD RAINFALL AMOUNTS TO RAINFALL-RUNOFF RESULTS FROM SALT TREATED PLOTS AT PAGE RANCH

Plot description		Sprinkler				Rainfall*	
Length, m	Slope %	Runoff efficiency		Threshold rainfall		Runoff efficiency, %	Threshold rainfall, mm
		Tap, %	Distilled, %	Tap, mm	Distilled, mm		
3	10	80	88	2.1	2.4	88	3.0
6	5	79	82	2.4	2.0	82	3.8
6	1	47	71	6.6	3.0	77	3.5

*From Evett and Dutt, 1985

TABLE 6. MEAN AND 90% CONFIDENCE INTERVALS OF RUNOFF EFFICIENCIES AND THRESHOLD RAINFALLS FROM SPRINKLER EVALUATION OF SALT TREATED CATCHMENT AT CAMP VERDE RUNOFF FARMING SITE

Treatment	Runoff efficiency, %	Threshold rainfall, mm
Salt	73±14	2.6±0.4
Untreated	19±22	4.4±1.2

collected from the monitored plot at the site ranged from 39 to 57% of the total yearly precipitation for the 4-yr period 1980 to 1983 (Fink and Ehrler, 1986). The runoff values measured onsite reflect a large number of small storms which add to the total precipitation but product no runoff. The sprinkler derived results are more representative of the runoff which occurs from a single event of moderate depth.

COST EVALUATION

Frasier (1984) estimated the following costs for the sodium salt treatment. Sodium salt chemicals costs were \$0.20 to \$0.50/m^2. Installation costs are highly variable depending upon actual site conditions and available labor and equipment. Site preparation cost was estimated at \$0.05 to \$0.20/m^2, bringing the total installation cost to be \$0.25 to \$0.70/m^2. Amortizing the costs over the life of the treatment, estimated at 5 to 10 yr, at 6% interest using a capital recovery factor procedure (Linsley and Franzini, 1979) yields an average annual cost of \$0.02 to \$0.17/m^2 for the installation. Estimated annual maintenance costs add \$0.01 to \$0.05/m^2 resulting in a total annual cost of \$0.03 to \$0.22/m^2. With an average runoff efficiency of 75%, the cost of the collected water in a 500 mm rainfall zone is \$0.08 to \$0.59/1000 L. These values are very competitive with other water harvesting techniques. Frasier (1975b) estimated water costs at \$0.06 to \$1.73/1000 L (1974 costs) for various water harvesting catchment treatments that had a runoff efficiency of at least 75%.

SUMMARY

A paired catchment study on field sized plots at the Granite Reef test site near Phoenix, AZ, showed that precipitation runoff efficiency for a three year period from a catchment spray treated with 10% solution of sodium carbonate salt at a rate of 44.9 g of salt/m^2 was 46% of the precipitation compared to 33% from the untreated control catchment. After 3 yr the treatment was no longer effective.

Sprinkler tests on an operational runoff farming test site near Oracle, AZ, treated with granulated sodium chloride salt mixed into the surface showed that the quality of the test water may affect the measured runoff efficiency. Runoff efficiencies were higher with distilled spray water than with tap water. There were no differences between the types of spray water on untreated soil. Evaluations following a dry period showed that runoff efficiency from the salt treatment using distilled water was 81% of the applied water compared to 54% from the untreated area. Water quality analysis of the runoff water from the sprinkler tests indicated that, with the exception of sodium, the salt treatment did not affect the runoff water quality. There was *slightly* more sodium in the runoff water from the salt treatment compared to the untreated area. Good correlations in runoff efficiency values were obtained in comparing the sprinkler derived results measured on a set of small salt treated test plots to actual rainfall-runoff derived results.

On a runoff farming site near Camp Verde, AZ, runoff efficiency from the sodium salt treated area was 73% compared to 19% from an untreated area. There was a corresponding decrease in the threshold runoff for the treated over the untreated areas.

Based on limited analytical data and observations during runoff events, soil erosion was not a problem on soils which developed a gravel layer on the soil surface. The gravel covering provided an effective protective layer over the soil surface.

Annual amortized costs including maintenance of the salt treatment is estimated at \$0.03 to \$0.22/m^2. In a 500 mm rainfall zone the cost of collecting the water would be \$0.08 to \$0.59m^2/1000 L. On suitable soil types with properly designed shapes to minimize soil erosion, the sodium salt treatment can be a cost effective method for increasing precipitation runoff for water harvesting applications.

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