PERFORMANCE AND DURABILITY OF SHEET METAL, BUTYL RUBBER, ASPHALT ROOFING, AND BENTONITE FOR HARVESTING PRECIPITATION 1/

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INTRODUCTION

Water supplies for livestock are frequently inadequate on semiarid rangelands in the central high plains region because ground water aquifers are not economically accessible or available. The problem is compounded by frequent and extended drought periods. Inefficient use of range forages and poor gains on livestock result from inadequate distribution of available watering sites (11). Farmers and ranchers have attempted to compensate for this by hauling or piping water to suitable range sites; however, the process can be costly and time consuming.

The ancient art of collecting and storing precipitation for agricultural and domestic use has been utilized to provide water supplies in some of the more arid regions of the world (5). The practice is now more commonly referred to as water harvesting and offers potential for a relatively economical and dependable source of water.

In recent years, numerous investigators have devoted their time and talents to perfecting an economical and efficient way to harvest water from natural precipitation. Two basic research techniques have been used: (1) Chemically treating the surface soil to reduce infiltration and increase runoff (1, 4, 5, 6, 7, 10) and (2) covering the soil surface with some type of impervious membrane (2, 7, 10).

The first technique has involved the use of various hydrocarbons such as fuel oil, asphaltic emulsions, latex emulsions, anionic paraffin wax emulsions, salt, and bentonite. They are generally low-cost materials but do not have the durable characteristics to sustain a high degree of water harvest efficiency without periodic maintainance. These materials may also require additional treatment of the soil surface before application to obtain a smooth surface that is relatively free of vegetation and stabilized to reduce excessive erosion.

Impervious membranes such as concrete, sheet metal, and butyl rubber provide greater durability, water harvest efficiency, and lower maintainance; however, initial costs are high. Asphalt roofing and plastic sheeting are much lower in cost and provide the same degree of efficiency but are less durable. Use of most impervious membranes does not require as much soil preparation as the chemical treatments.

Climate, soils, and topography are important factors to consider in the selection of materials for harvesting precipitation in any given area. Of these, climate is the most critical factor because the material used on the catchment area must withstand the annual variations in temperature, wind, solar radiation, and nature of precipitation. These weather conditions are highly variable between geographical regions of

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the country. Thus, a particular water harvest treatment may be successful in one geographical area but will not be suitable in another.

Asphalt compounds with and without a protective surface coating have been used more successfully in the arid southwestern United States (6) than in the semiarid area of the west central and northern Great Plains (9). Extreme variation of temperature in the Great Plains is the main factor that contributes to the rapid deterioration of asphaltic compounds. The incidence of high winds and hail are also more prevalent in the central high plains region. Catchments constructed from more durable materials are necessary in this region to withstand the changeable, versatile weather conditions.

Research on water harvesting techniques was initiated at Akron, Colo., in 1968, to test the durability and effectiveness of sheet metal, butyl rubber, and asphalt roofing membranes and a soil-bentonite mixture. This paper describes the techniques used and reports results and observations made during 1969 through 1972.

EXPERIMENTAL SITE CONDITIONS

The experimental site on the Central Great Plains Field Station near Akron is 4,535 feet above sea level on native rangeland that has never been tilled. The soil is classified as Rago silt loam and is derived mainly from eolean deposits. The subsoil, at a depth of 4 to 8 inches, grades to a clay loam with 20 to 25 percent clay, which, upon drying, contracts to form vertical prismatic aggregates. The site has a slope of about 2 percent.

Local climate is semiarid and typical of the west central Great Plains region. Average annual precipitation is 16.6 inches, with approximately 72 percent occurring in May through August. The area receives an annual snowfall of about 31 inches. Temperatures are highly variable and can range from a minimum of -29° F in January to 107° in July. The mean daily minimum temperatures vary from 8° in January to a mean maximum daily temperature of 80° in July. Mean daily windspeed ranges from 5.6 miles per hour during August to 8.4 mi/h during April. Open-pan evaporation averages about 66 inches per year over a 7-month period beginning in April. Solar radiation is relatively high and ranges from 194 langleys per day in December to 614 langleys per day in June. Solar radiation of over 700 langleys per day is not uncommon during the summer.

EXPERIMENTAL PROCEDURE

Ten plots, 20 feet wide and 100 feet long, were oriented to obtain uniform 2-percent slopes. The plot areas of all treatments, with the exception of the check, were worked lightly with tandem disk to remove sod clumps and obtain a relatively smooth surface. The five treatments consisted of sheet metal, butyl rubber, asphalt roofing, soil-bentonite mixture, and native short grass check. Treatments were replicated twice and randomly located. One replication had a southern exposure and the other a western exposure.

The sheet metal was available in 3- by 5-foot galvanized sheets. Beginning at the lower end, each sheet was laid overlapping one another 1 to 2 inches. The joints were caulked and riveted. Plot borders 6 inches high were formed by bending ends of outer metal sheets 90 degrees to vertical position. A berm of soil was thrown up along the outside of the plot to anchor the membrane.

The butyl rubber sheeting was commercially obtained in 20- by 50-foot sheets, which were spread across the plot by hand. The edges were initially tacked to elevated boards anchored in the soil. This later proved to be a failure when high winds dislodged the sheeting. The plot area had to be reduced to allow enough border to lap over an elevated berm and be buried in the soil along plot edges. This has since completely alleviated any problems associated with high winds.

The asphalt roofing was available in rolls 3 feet wide. The sheeting was sealed with asphalt cement and tacked to 1- by 4-inch boards at all overlapped seams. The boards were pressed into the soil the width of the board so that the sheeting lay flush on the soil surface. Plot borders were formed by tacking the sheet edgings to elevated boards that were anchored in the soil.

The bentonite treatment consisted of applying and mixing approximately 4.5 tons bentonite and 4 pounds atrazine per acre in the top 2 inches of loose soil. A layer of pea-size gravel was spread on the surface. The entire plot was packed with heavy roller to obtain a smooth sloping surface. The check plot consisted of undisturbed native sod.

The lowest corner of each plot was equipped with entrance boxes and 90-degree, V-notch weirs, which were made from 3/8-inch aluminum sheeting and calibrated in a hydraulics laboratory. Rating curves were determined and water-stage recorders installed. The runoff was calculated from hydrographs of flow through the V-notch weir and reported in volume per unit area because the butyl rubber catchments were reduced in size following wind damage in 1970. Runoff was not stored or analyzed for sediment content. Two standard rain gages and a recording rain gage were located in the experimental area to measure precipitation.

From 1969 to 1972, measurements were taken each year over a 6-month period beginning in April. Analysis of variance and Duncan's Multiple Range Test was applied to total runoff for each treatment. Significant difference was determined at the 5-percent level. Correlations between storm rainfall and runoff and between mean monthly rainfall intensity and water harvest efficiencies were made for each treatment.

EXPERIMENTAL RESULTS

Monthly precipitation over a 6-month period for 1969-72 is given in table 1. The 6-month total represents 80 percent of the annual precipitation for the area. The mean 6-month total precipitation over the 4-year period was 2.2 inches below the long term average. All years had below normal amounts, and 1970 was the driest year. Approximately 40 storm events of 0.01 inch or more occurred each year. Storm characteristics of rainfall varied with time of year. Rainfall during the spring occurred from low intensity storms. During the summer months, rainfall increased in intensity, reaching peak intensities during July. Storm intensities decreased in August and September. Incidence of hail is high in the area; however, no severe hail occurred during the reported test period.

The volume of water harvested in summarized in table 2.

The technique for measuring water harvested does not provide an accurate determination of runoff at low flows that result from low intensity storms. Most of the error in volume determinations occurred in the recession portion of the hydrograph, particularly from the impervious membrane catchments. However, since the same measuring devices were used on all plots, reasonable interpretations can be made from relative differences due to treatment effects.

TABLE 1.--Precipitation for April through September at the water harvest site on the Central Great Plains Field Station near Akron, Colo. (1969-72)

	Inches of precipitation					
Month	1969	1970	1971	1972	4-yr avg.	Long term mean 1/
April	0.73	0.87	2.47	0.92	1.25	1.77
May	4.02	2.23	2.80	2.28	2.83	2.98
June	2.31	3.25	1.29	1.80	2.16	2.54
July	2.78	1.85	2.07	2.94	2.41	2.69
August	.45	.44	1.25	3.63	1.44	1.96
September	1.14	.85	2.08	.10	1.04	1.38
Total	11.43	9.49	11.96	11.67	11.13	13.32
No. of storms	35	32	55	43	41	- - -
Mean storm intensity 2/	0.26	0.20	0.19	0.32	0.24	- - -

1/ Monthly mean precipitation over 66-year period at the Central Great Plains Field Station.

2/ Storm rainfall intensity in inches per hour.

TABLE 2.--Mean total monthly volume of water harvested per unit area from 5 surface treatments over a 4-year period at Akron, Colo.

	Runoff in gallons per square yard					
Month	Sheet Metal	Butyl Rubber	Asphalt Roofing	Bentonite	Grass Check	Potential
April	3.40	2.68	3.07	0.0	0.0	7.01
May	9.13	7.79	8.17	2.25	.74	15.88
June	6.82	6.79	6.73	1.90	.61	12.12
July	8.89	8.87	8.34	5.33	1.72	13.52
August	4.82	6.33	3.77	1.91	.04	8.08
September	2.52	2.50	2.22	.44	.06	5.84
Total 1/	35.58a (6.34")	34.96a	32.30a	11.83b	3.17b	62.45 gal/yd²
Efficiency 2/	56.9	56.0	51.7	18.9	5.1	100

1/ Means among treatments with same letter are not significant at the 5-percent level.

2/ Percentage of precipitation that results in runoff from the catchments.

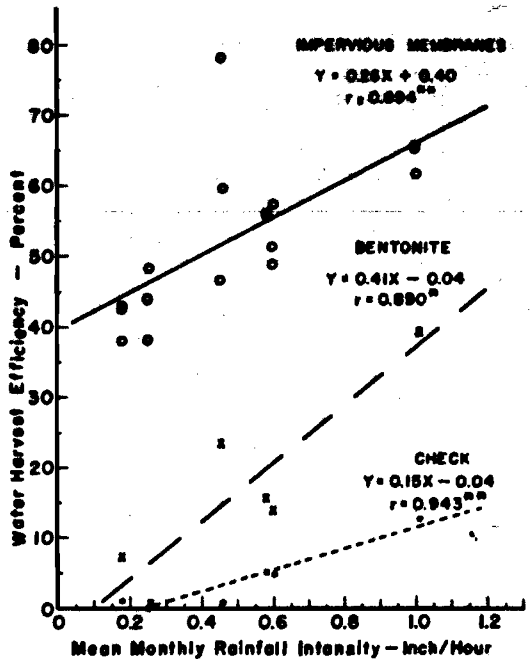

FIGURE 1.--Relationship showing effect of rainfall intensity on water harvest efficiency of different treatments. (* = 1-percent level of significance; ** = 5-percent level of significance.)

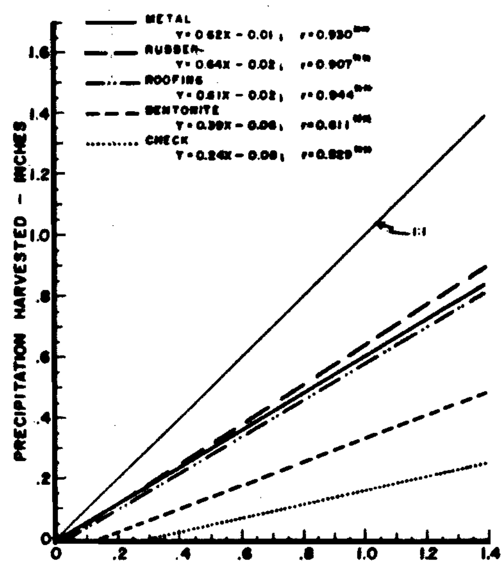

FIGURE 2.--Relationship between storm rainfall and precipitation harvested from 5 different treatments.

Treatment Effects

The monthly volume of water harvested from any given treatment was related to the monthly precipitation. Average annual volume of water harvested from the impervious catchments (sheet metal, butyl rubber, and asphalt roofing) were significantly different than that harvested from the soil-treated catchments (bentonite and check). The butyl rubber and sheet metal catchments have yielded similar amounts of runoff every year. The asphalt roofing was comparable in amount of water harvested to both the sheet metal and butyl rubber plots the first year, but annual amounts have since tended to decrease with time. Water harvested from the bentonite treatment was almost four times the amount from the check plot. The difference in mean of total period values between the bentonite and check treatments was only 0.04 gallons per square yard from being statistically significant at the 5 percent level.

Water harvest efficiency is the percentage of precipitation that results in runoff. Values of 56 percent were obtained from the sheet metal and butyl rubber treatments (table 2). The asphalt roofing treatment harvested 52 percent. Bentonite reduced infiltration, to some extent, as 19 percent of the precipitation was harvested compared with 5 percent from the check plot. The efficiency was considerably lower than the 95 to 100 percent expected from the impervious membrane catchments. Previous discussion alluded to the difficulty of accurately measuring low or trickle flows through V-notch weirs on the impervious treatments. This was not so much the case on flows from the bentonite and check treatments because the recession portions of the hydrographs from these treatments were more abrupt.

Water harvesting efficiencies were affected by intensity of rainfall. The impervious membrane catchments have yielded up to 80 percent of the precipitation from individual short duration, high intensity storms during the summer months. The efficiency decreased from the low intensity storms, which are more prevalent during the spring and fall seasons. A general relationship between storm intensity and water harvest efficiency is shown in figure 1. Mean monthly values were used to illustrate the relationship. The impervious membrane treatments showed similar relationships and, therefore, were grouped together. Though a general trend is shown, the degree of efficiency response to storm intensity was not as great from the impervious membranes as that from the bentonite treatment. Correlations showed that, for the bentonite treatment, 79 percent of the variation was due to storm intensity compared with 48 percent for the impervious membrane treatments. The check treatment showed least response to storm intensity; however, 89 percent of the variation in water harvest efficiency was due to storm intensity. The correlation was statistically significant at the 1-percent level for the membrane and check treatments and at the 5-percent level for the bentonite treatment.

Rainfall-Runoff Relationships

Regression analysis was made on rainfall-runoff relationships of all individual storm events yielding runoff over the 4-year period. The relationships are graphically illustrated in figure 2. More than 145 events were included in the analysis for the impervious membrane treatments. The bentonite and check treatments had 47 and 18 runoff events, respectively.

The rainfall-runoff relationships for the impervious treatments were similar. More than 80 percent of the variation in runoff could be attributed to storm rainfall. Regression coefficients for sheet metal, butyl rubber, and asphalt roofing were 0.6 inch of runoff per inch of rainfall.

Response of runoff to rainfall from the bentonite was less than that from the impervious membrane treatments, but more than that from the check treatment. Runoff increased 0.39 inch from every inch of rainfall with a correlation coefficient of 61 percent whereas the check plot yielded 0.24 inch runoff per inch of rainfall with a correlation coefficient of 53 percent. All correlation coefficients were significant at the 1-percent level.

Runoff threshold, or amount of rainfall necessary to produce the first increment of runoff, varied for most treatments. The runoff threshold for sheet metal and butyl rubber has been consistently 0.01 and 0.02 inch, respectively. That for the asphalt roofing has been 0.03 inch, but this threshold is increasing with the gradual deterioration of the asphalt roofing surface. The runoff threshold for the bentonite and check varied with frequency and intensity of rainfall, but has averaged 0.15 and 0.33 inch, respectively.

Annual water harvest efficiencies vary from year to year, depending on the frequency and intensity of rainfall. Figure 3 provides a graphic illustration of how annual water harvest efficiency of each treatment has changed over the 4-year period. With the exception of 1970, when wind damaged the butyl rubber plots, both the sheet metal and butyl rubber membranes have similar efficiencies. They were as effective in 1972 as in 1969 when installed. Water harvest efficiency for the asphalt roofing was as high as that of the sheet metal and butyl rubber during the first 2 years but has since shown a tendency to decrease due to deterioration of the asphalt. The variation in water harvest efficiency for the bentonite and check treatments is primarily due to the frequency and intensity of storms. Vegetation is gradually reoccurring on the bentonite treatment. However, it has not appeared to effect any significant changes in water harvest ability. No efforts have been made to curtail the growth of vegetation on the bentonite plots. The grass on the check plots has not materially changed since the experiment began.

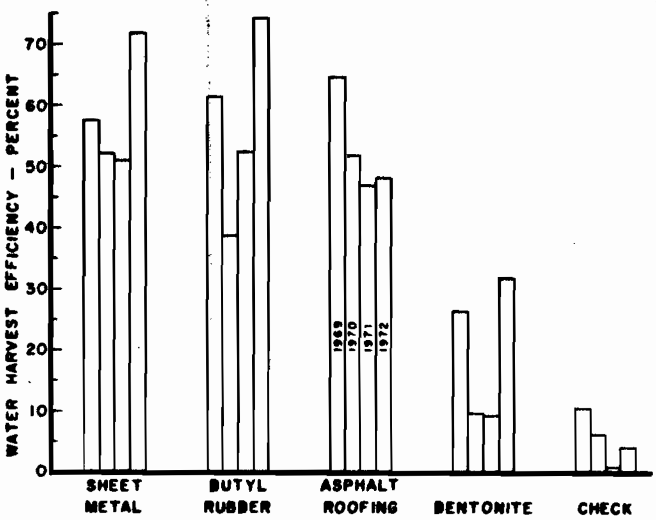

FIGURE 3.--Annual variation in water harvest efficiency for 5 different treatments (1969-72).

Durability Characteristics

Any material used in building water harvesting catchments has to endure freezing and thawing, wetting and drying, solar radiation, wind, and hail. Sheet metal, though expensive, has shown to be rather resistant to all weather conditions. It should be galvanized or treated to prevent corrosion. Sheet metal, as well as other impervious membranes, must be securely anchored to prevent damage by wind.

The sheet metal plot with a south exposure has been uplifted twice by strong winds. In both occurrences, northerly wind gusts reached 45 to 55 mi/h. The sheet metal plot with a west exposure was not affected in either windstorm. This would tend to indicate that some consideration might be given to avoid locating catchments on areas with abruptly changing slopes leeward and downhill from the strongest prevailing wind direction.

The butyl rubber has not shown any evidence of deterioration, but the membrane has not been subjected to a severe hailstorm. Extra care is necessary to properly bury and cover the edges of the membrane so that rodents cannot burrow under the membrane edges. This was the reason for failure following the initial laying of the membrane. Once holes are made by rodents, subsequent high winds can dislodge the entire membrane.

Asphalt roofing is an economical membrane for use on catchments, but its long term effectiveness is questionable without periodic maintainance. The asphalt became soft and pliable under high temperatures. In this condition, the membrane was easily punctured by rabbits and windblown large tumbleweeds crossing the plots. Though the membrane was laid flush on the surface, soil has not provided a firm base. If the membrane were laid on a solid platform, such as that provided for on building roofs, the material would presumably have a longer effective life. Numerous small cracks developed in the membrane wherever the asphalt roofing came in contact with the soil, but not where it came in contact with the boards underlying the seams. When open cracks and holes occur, water leaks through and vegetation soon emerges. Construction costs would increase substantially if some type of firm base were necessary to support asphalt roofing.

The bentonite treatment yielded more runoff than the untreated grass check. Presumably, the increase was due to reduced infiltration, but part could be attributed to removal of vegetation. Herbicide (atrazine) was applied to temporarily curtail all vegetative growth. A herbicide would not be practical for use on water harvesting catchments when the intended use is for livestock water supplies. The herbicide is apparently deteriorating because some vegetation is reoccurring. It is a matter of time as to how fast the catchment area will be completely vegetated a and what effects, if any, vegetation will have on runoff.

The check plots contain primarily the short, warm growing season grasses, which are drought tolerant. They have not changed in consistency or species for years. The grass has never been subjected to grazing or clipping.

Water Quality

No attempt was made to analyze the quality of water from the catchments. Some indication of sediment content was made by observing the sediment deposited in the entrance boxes to the weirs. The boxes were cleaned once each year at the beginning of the runoff season. Entrance boxes below the sheet metal usually contained very little sediment. The butyl rubber and asphalt roofing plots had more sediment in the entrance boxes. Most of the sediment on the impervious membrane treatments originated from deposition of windborne dust or fine soil.

The bentonite and check plots had more sediment deposition in the entrance boxes than did all other treatments. However, there did not appear to be much difference in sediment content between the bentonite and check treatments. The compacted layer of pea-sized gravel on the bentonite treatment was effective in reducing plot erosion. Consideration is being given to installing collection tanks below the entrances on one replication to determine both quality and quantity of the runoff water. The quantity will be compared with that determined from the runoff hydrograph and any consistent error resulting from the comparison would be used to correct previous runoff records.

CONCLUSIONS

Durability, cost, performance efficiency, topography, and soil type are important factors for consideration in any design of an effective water harvesting catchment. The practice can provide an economical source of good quality water. A major deterant to using the practice has been costs.

Surface membranes that are known to have durable characteristics are expensive. However, excluding concrete, surface membranes do not require much time and labor on preliminary soil preparation such as smoothing or leveling. Any soil preparation can be eliminated if suitable sites for catchments are carefully selected. Impervious membranes may be constructed on any slope with the same degree of expected efficiency.

Chemically treated soils for water harvesting catchments consist of less expensive materials for construction, but more time and labor is required both in preliminary preparations of the soil surface and treatment. The water harvest efficiency of these treatments may be increased by constructing catchments on steeper slopes than normally used provided precautionary measures are utilized to control erosion.

No attempt was made to make an economical appraisal of the treatments described in this paper because of the suspected error in runoff measurement as mentioned under "Treatment Effects." An evaluation will be made following further investigations on the measuring technique. Such an evaluation will not only include cost of materials, depreciation, and interest on investment but time and labor as well.

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