A NOVEL METHOD OF EVAPORATION SUPPRESSION IN A WATER HARVESTING SYSTEM

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Abstract

A demonstration agrisystem located in an area receiving less than 250 mm rainfall annually has been constructed through a cooperative program between the City of Tucson and the University of Arizona. Mondell pine, aleppo pine, jojoba, grapes, eucalyptus, olives, and other crops were cultivated in a 4 ha NaCl treated catchment system designed to concentrate rainfall on plants and channel excess water into a system of storage reservoirs. Evaporation was reduced from an 80 foot diameter above ground reservoir by means of 225,000 plastic film cans, at a cost of approximately 50 cents/ft^2. Data acquired from evaporation pans indicates a 50 to 70 percent reduction in evaporation of the stored water.

Additionally, this research has provided data that 1) demonstrates the economic potential for agriculture of currently retired farmland, 2) investigates the feasibility of applying water harvesting method for agricultgural purposes in a semiarid region, and 3) evaluates water harvesting as an alternative to meet the ever increasing demand for water.

Introduction

Approximately 33 percent of the earth's land surface can be classified as arid or semiarid. These regions are marginal agricultural areas by definition, either because of the lack of precipitation or because of its lack of uniformity. Thus the harvesting of water in these regions for agricultgural use during long periods of little or no rainfall is of critical importance, especially for the cultivation of perennial crops.

Because of increasing populations in many of these areas and the concommitment increase in water requirements in recent years, a great deal of interest has been generated in the use of water catchment systems to store harvested rainwater for use as supplemental irrigation water. The major problem of such systems during long-term storage is loss from seepage and evaporation. Techniques to reduce losses from seepage include treating or coating the interior of the storage reservoir with compounds such as sodium chloride, and materials such as bentonite clay, soil cement, synthetic membranes, and poured concrete linings. Evaporationally losses of water in storage reservoirs, however, are much more difficult to control. Generally, there are four approaches for evaporation suppression: 1) reducing the water surface area, 2) decreasing the wind velocity directly over the reservoir, 3) decreasing the input of solar energy that penetrates the water surface, or 4) covering the reservoir with some impermeable barrier.

The purpose of this study has been to investigate a system of evaporation suppression in conjunction with a water harvesting agrisystem. In 1982 a 4 ha water harvesting agrisystem was developed in Avra Valley, Arizona on land purchased by the City of Tucson for its water rights and retired from groundwater irrigated agriculture. The University of Arizona, College of Agriculture, with support from the City of Tucson established the system: 1) to demonstrate a potential and economic use for retired farmland, 2) to indicate the City of Tucson's commitment to water conservation and land management by determining the feasibility of farming with rainfall as the sole source of water, and 3) to show the City's concern for all sectors of the water using community.

Methods of Evaporation Control

Three major approaches have been used to suppress evaporation: 1) application of chemicals, 2) use of floating devices; and 3) use of physical covers.

Chemicals of choice are those that form thin, monolayer films on the water surface. A number of researchers (Shanmugam, 1968; Crow and Mitchell, 1975; Rutherford and Byers, 1973; and Nicholaichuk, 1978) have found that covering the surface with hexadecanol and octadecanol reduce evaporation from 18 percent to 47 percent (Nicholaichuk, 1978; Rutherford and Byers, 1973), depending on geographical location and meteorlogical parameters. In a study in which reflective properties were carefully assayed, Beard and Gainer (1970) found that different monolayers with hypothetical reflective properties reduced evaporation from 25 to 45 percent. Although Garrett (1971) found that application of monolayer films inhibits small wave formation (thus inhibiting water vapor transport into the atmosphere), Crow and Mitchell (1975) found disruption of continuous cover of the monolayer film from high wind speeds and/or shifting winds, resulting in excessive evaporation. In general, the two major problems with using monolayer film are the high cost of maintenance and the disruption of the surface coating by ambient meteorlogical conditions. Cluff (1981) noted that a monolayer film is more cost effective on a large scale than on a small one; thus its commercial application on small agricultural reservoirs has been precluded.

A number of other researchers have experimented with a variety of floating devices to suppress evaporation. Crow and Manges (1967) compared the use of chemical and nonchemical techniques for suppressing evaporation by testing wind baffles, styrofoam, and polypropylene mesh individually and in combination with chemical films. The authors found that a combination of polypropylene mesh and monomolecular film reduced the effects of wind speed at the water surface and also reflected incoming radiation. Myers and Frasier (1970) studied the use of calcium carbonate dust, silica sand, polystyrene beads, chopped styrofoam, and perlite to reduce evaporation. Reduction ranged from 21 percent for water repellent sand to 64 percent for chopped styrofoam. In another study, Cooley and Cluff (1972) found that perlite ore reduced evaporation by approximately 19 percent; however, the authors observed that floating perlite becomes saturated, loses its buoyancy, and thus becomes useless as a means of reducing evaporational losses. In general, the major problems with other floating devices (styrofoam, mesh, beads, etc.) include susceptibility to wind removal and deterioration due to ultraviolet radiation.

A number of investigators (Cluff, 1967; Cooley, 1970) have studied a variety of materials that can be used to cover a small pond or reservoir. Crow (1973) found that one inch thick styrofoam rafts covering 48 percent of the surface area reduced evaporation 35 percent. When the rafts were painted white, 45 percent of the surface area reduced evaporation by 49 percent. Cluff (1972) has also investigated the use of expanded polystyrene sheets joined to form a continuous raft. Problems with styrofoam, however, include loss of cover due to high speed winds and destruction from ultraviolet radiation. In another study, Cluff (1977) found that crushed expanded polystyrene reduce evaporation by about 50 percent; however, heavy winds overturned the film, causing it to become wetted, thus reducing the effectiveness of the material to 10 percent.

The Challenge

In 1982, the Office of Arid Lands Studies with support from the City of Tucson undertook the development of a water harvesting agrisystem on retired farmland in Avra Valley. The Avra Valley region averages less than 255 mm rainfall annually. Evaporation as measured at the University of Arizona in Tucson (30 km southwest of Avra Valley) approximates three meters/year (Table 1). Thus one of the major priorities of this project has been the development of a method that would effectively reduce evaporational loss from the main storage reservoir.

Table 1

Average Evaporation as Recorded in Tucson at the University of Arizona
for the Period 1963 - 1973
(Adapted from Sellers and Hill, 1974)

Month	Evaporation (mm)	Evaporation (in.)
January	98.55	3.88
February	134.11	5.28
March	193.04	7.60
April	268.48	10.57
May	381.00	15.00
June	410.21	16.15
July	374.65	14.75
August	308.36	12.14
September	284.73	11.21
October	202.18	7.96
November	124.71	4.91
December	80.26	3.16
	2860.28	112.61

The Solution

During the course of investigating the various devices and methods of evaporation suppression, we have found that plastic film cans appear to provide a long-lasting protective cover that effectively reduce evaporational loss. Four kinds of film cans are available: 1) black plastic film cans, 2) gray plastic film cans, 3) clear plastic film cans, and 4) metal film cans. Because metal film cans are not redily available and tend to oxidize, they were discarded early in this study.

Clear plastic, gray plastic, and black plastic film cans were placed in 37.5 cm by 36.8 cm (14.8 x 15 inches) brown plastic evaporation pans. Evaporational loss was reduced by 55 to 70 percent, depending on the time of year and the type of film can (Table 2).

Table 2

Evaporation Reduction as Determined from Evaporation Pans

Type of Cover	Evaporation (mm)	Mean (mm)	Evaporation Reduction (%)
	Feb. 15 - Feb 21		
Uncovered	31 31	31	
Black plastic flim cans without caps	26 27	26.5	14.5
	February 21 - April 11		
Uncovered	289 292	290.5	
Black plastic film cans	84 86	85	70.7
Clear plastic film cans (w/ water)	81 90	85.5	70.6

Table 2 (Continued)

Evaporation Reduction as Determined from Evaporation Pans

Type of Cover	Evaporation (mm)	Mean (mm)	Evaporation Reduction (%)
	April 11 - May 9		
Uncovered	289 282	285.5	
Black plastic film cans	109 106	107.5	62.3
Gray plastic film cans	84 79	81.5	71.5
	May 9 - June 15		
Uncovered	577 561	569	
Black plastic film cans	253 255	254	55.4
Gray plastic film cans	224 235	229.5	59.7

During the period of February 21 through April 11, 1983, clear plastic film cans containing a small amount of water effectively reduced evaporation by 70.6 percent. In general, however, there were three problems encountered when using the clear plastic cans: 1) they tended to leak and thus would float too low in the water; 2) they do not reduce evaporation as effectively as do the black plastic containers, which do not permit the transmission of sunlight energy into the water; and 3) they tend to break down after a year of exposure to direct sunlight.

Black plastic film cans reduced evaporational loss by 62.3 percent in the period of April 11 through May 9, 1983, and by 55.4 percent during the period of May 9 through June 15, 1983, (Table 2) Gray plastic film cans were slightly more effective than the black plastic film cans in reducing evaporational loss during both these periods, possibly because of greater reflectivity. Although gray plastic film cans have many of the same desirable qualities as the black plastic film cans, they are not as readily available.

The black plastic film cans do not leak and are not subject to destruction by ultraviolet radiation (Figure 1). These results correspond with an earlier report in which black, all plastic balls (polyethylene with a 2 to 5 percent admixture of carbon black), 45 mm (1/3 inch) in diameter were used to reduce odors emenating from noxious liquids (Anonymous, 1972). The authors of this study found that the addition of carbon black rendered the material resistent to ultraviolet radiation.

In addition to resistance to the destructive effects of ultraviolet radiation, black plastic film cans also appear effective in reducing wave action on the surface (Figure 2). The film cans increase the boundary layer resistance to evaporation by decreasing the wind velocity at the water surface. Unlike spherical objects, the cylindrical form of the film cans also reduce any tendency to roll in the wind. The cans are also self adjusting to varying changes in water levels.

Black plastic film cans therefore appear to be an effective, low cost, durable, wind stable method for reducing evaporation from small reservoirs.

Figure 1. Black plastic film cans covering the 450 m^2 surface area of the main reservoir at the Avra Valley Water Harvesting Agrisystem.

Figure 2. Black plastic film cans reducing surface wave action.

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