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EVAPORATION REDUCTION MEASURES FROM WATER AND LAND SURFACES FOR DROUGHT MANAGEMENT

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STATUS REPORT

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ABSTRACT

The evaporation losses from water and land surfaces form a substantial amount. The evaporation loss from shallow lakes and small tanks & reservoirs alone comes to almost 50% of the capacity of the tank. Almost one-fourth to one-half of the water lost from a cropped area is through evaporation from the soil surface. Evaporation reduction from water and soil surfaces is one of the supply oriented drought management measures as it conserves water and enhance or augment available water supplies without creating a new sources of water supply in drought prone areas. The use of commercially available Water Evaporation Retardant Chemicals (WERCs) has been demonstrated by various State Governments and research organisations in saving water against evaporation from water bodies. Surface mulches with mulching materials like crop residues, grasses, leaf litter, straw, gravel, polythene sheets, asphalt etc. have been tried and tested at different places by research institutes & field organisations to reduce evaporation from soil surfaces in cropped areas by restricting air movement and maintaining high vapour pressure near soil surface. The present status of such studies, limitations, adoptability and usefulness in relation to drought management including recommendations for further research would be discussed in this report under Indian conditions.

1.0 INTRODUCTION

1.1 General

One of the supply oriented drought control measures is reduction of water losses by evaporation both from land surface and water bodies. Evaporation control measures have special significance for reservoirs, lakes and irrigation channels and in arid zones where the water supply is very limited and where the water loss due to evaporation may be many times the total water loss in humid zones. Moreover, with the recurrent drought conditions in most part of the country these measures assume much greater significance. Careful application of WERC can reduce evaporation by 50% but economic considerations usually limit the saving that can be obtained in practice to only about 20%. The use of chemicals have been suggested to small tanks in drought conditions for conserving water for drinking purposes. However, the process suggested is too elaborate and much expensive and does not warrant consideration for large reservoirs meeting irrigation requirements. The results produced in the report are the conclusions of various researchers working in different organisations for using WERC's for evaporation reduction.

2.2 Nature and Extent of Problem

The problem of evaporation control has for decades been a matter of practical interest to research engineers and hydrologists involved in water conservation. In our country due to spatial and temporal variation in rainfall, high prevailing temperatures and wind velocities, huge amount of water is evaporated from large tracts. It is estimated that about 70 m-ha-m water evaporates from water & land surfaces out of the total precipitation of 3.92 m-ha-m received in entire country (Bharat Singh, 1987). The total evaporation losses only from water surfaces amount to about 5 m ha m from the total storages of 15 m ha m in the reservoirs, tanks and lakes spread all over the country (Goyal and Sikka, 1986). It has been estimated that a 10,000 hectare lake surface would loose 160 million cubic meters of water each year, which is enough to support more than one million inhabitants of a modern industrial city, or to irrigate 10,000 to 15,000 hectares of crop land (Dunne & Leopold, 1978).

1.3 Scope of Study

Conserving water contained in existing storage facilities, in some situations is the most economic means of providing adequate water supplies. Water lost by evaporation from open water surfaces may equal or exceed the amount that is used beneficially. Moreover, with the drought conditions prevailing over most parts of the country, conservation of water by evaporation reduction measures may be one of the effective drought management strategies. Reducing evaporation losses is particularly desirable for several reasons; water in storage facility requires no additional transportation, pumping, or collection expenses; good quality water is maintained because the salts are not concentrated; and finally no risk is involved in attempting to develop a new supply. The only cost involved is installing and maintaining an adequate method of evaporation reduction.

1.4 Factors Affecting Evaporation

The main factors that affect evaporation from water surfaces are i) temperature of the evaporating surfaces, ii) the water vapour in the air, iii) wind speed iv) atmospheric pressure and v) size of water body. Therefore, the evaporation reduction measures should be the ones which can exercise control over one or more of these factors. The most promising approaches to evaporation reduction include reducing the energy available for evaporation, providing wind baffles on or above the water surface to reduce the transport of water vapour by wind and reducing surface area of water body.

Evaporation from bare soils are controlled largely by temperature gradients within the soil profile. It has been observed that the rate of evaporation from depths greater than about 30 cm is very low. The loss of water due to evaporation from soil surfaces can be saved by placing water tight moisture barriers or water retardant mulches on the soil surface. As evaporation is greatly affected by wind, another method of reducing evaporation could be creation of wind break of trees, fences or taller growing plants depending upon site conditions.

Various studies on evaporation reduction from water bodies and land surface conducted in the country and elsewhere and the results obtained have been critically examined in this report. Limitations of various methods and recommendations for further research and development works have also been included.

2.0 REVIEW OF LITERATURE

2.1 Evaporation Reduction from Water Bodies

The technique of evaporation reduction from water bodies by applying oil at the surface has long been known. Laboratory investigations on the effects of oil film on reducing evaporation from water bodies do not appear to have begun until the 1920 when the experiments as reported by Pockels (1891), Rayleigh (1899) and Devaux (1913) had led to recognition of the existence of films of monomoleculer thickness, capable of reducing evaporation along with a basic understanding of their structure. Hardy (1912, 1913) was the first to suggest that monolayers were formed from polar molecules consisting of a hydrophonic (water repelling) and a hydrophillic (water-attracting) part. Langmuir (1971) supported the hypothesis of orientation of Hardy (1912, 1913) that the monolayer molecules were oriented with the hydrophillic part (a functional group such as a hydroxyl-OH or Carboxyl -COOH) burried in the water, and the hydrophonic part (a hydrocarbon structure) tending to leave the water. The results of early experimental investigations on evaporation reduction by mono layers were not promising. Devaux (1921) recognized the impermeability of multimolecular layers of oil mixture but failed to observe any reduction in evaporation produced by mono layer. Hedestrand (1924) was unable to show any reduction of evaporation by the addition of monolayers of palmitic and Oleic acids. With the use of monolayers of higher fatty acids Rideal (1925) found that the evaporation reduction capability depended on the film pressure or surface concentration. Ramdas (1926, 27) investigated the floating, spreading and scattering properties of the various substances like cetyl alcohol or stearic alcohol forming monomolecular film on water surface to suppress evaporation.

Further observations on the evaporation reduction effect of various monolayer forming substances were made by langmuir and Langmuir (1972). Baranaev (1937), Sklytarenko and Baranaev (1938), Glazov (1938), Kheinaman (1940), Docking, Heymann, Kerley and Mortensen (1940) etc. All these investigators reported the superiority of Cetyl alcohol (hexadecanol)$C_{16}H_{33}OH$ and possibly Stearyl alcohol (Octadecanol) $C_{18}H_{37}OH$ over other evaporation retardants, although quantitative results as reported varied to some extent. Langmuir and Schaefer (1943) experimentally investigated the importance of purity of the monolayer forming substance by noting that the contamination of 1 part in 1,800 of certain organic material in the monolayers could reduce the effectiveness of the film layer 60 percent. Heymann and Yoffe (1942, 1943) reported that films of 5 microns thickness consisting of paraffin oil containing spreaders of high molecular weight, may reduce evaporation of water to

15 percent of the original value. Powell (1943) showed experimentally that for a given oil there is an optimum thickness for which the rate of evaporation from the underlying water surface has a minimum value. Gilby and Heymann (1948) made a study of evaporation through duplex films 1-100 microns thick. A duplex film is a multimolecular film which is thick enough for the film forming substance to have the same physical properties as in bulk and yet thin enough for the effect of gravity to be neglected. It may be obtained by spreading a hydrocarbon oil with the aid of suitable spreaders. They found that the efficiency of duplex films in reducing evaporation increased with the wind velocity. With films more than 10 microns thickness even a wind of 8 miles per hour did not increase the rate of evaporation, the total evaporation resistance was proportional to the thickness of the film and depended on the nature of the spreader.

Field tests using multimolecular films of oil (Rohwer, 1933; Docking et.al., 1940; Heymann and Yoffe, 1943) were not successful due to easy damage of film by wind action, rain and dust and once broken film did not reform. Mansfield (1953) of Australia pointed out that although monomolecular films present in general less resistance to water vapour transfer than multimolecular films, they might still be more suitable for reservoir evaporation control because of their better endurance under field conditions, and this realization gave a new impetus to further laboratory research.

Rosano and La Mer (1956), compared the ability of monomolecular films of esters, acids and alcohals, as well as some mixtures of these substances, to reduce evaporation. They found that, in general, the compressible films were poor retardants whereas the films exhibiting high resistance to lateral compression retarded evaporation more effectively. Further laboratory work on the influence of the spreading technique, the purity of the material, and the film pressure, or the evaporation resistance of monolayers has been reported by La Mer and his co-workers (La Mer and Robbins, 1958; Robbins and La Mer, 1959; LaMer and Barnes, 1959; Barnes and La Mer, 1960, 1962a, 1962b; LaMer and Aylmore and Healy, 1963).

Mansfield (1955a, 1956) showed that only long chain alcohols having self sealing properties are capable to form strong monolayers which can withstand the ravages of dust, wind and waves. Mansfield (1956, 1958) conducted extensive experimental studies using long chain alcohols particularly hexadecanol in pure form mixed in various proportions with octadecanol and found that the addition of small amounts of octadecanol increased the evaporation resistance of a hexadecanol film. On the basis of laboratory experiments, it was assumed, that the resistance to evapaoration of the monolayers of higher homologues of the hexadecanol rises with the length of the hydrocarbon chain. The efficiency of these compounds as evaporation retardants is, however, increasingly hampered by their progressing high melting points which reduce their ability to spread on the water surface. To overcome this difficulty new compounds for evaporation reduction, derived from long chain alcohols were synthesized, in Japan in 1956 (Mihara, 1961, 1962; Mihara and Nakamura, 1962), and, later in India (Deo, Sanjana, Kulkarni, Gharpurey, Biswas, 1960) and the U.S.S.R.(Ogarrev and Trapeznikov, 1963). These compounds, which incorporate a molecule of ethylene oxide (CH_2CH_2o) at the hydroxyl and of the long chain alcohol thus forming glycol monoalkyl ethers or alkoxy-ethanols ($R-OCH_2CH_2OH$) were found to be superior to the previous compounds.

For reducing evaporation from large reservoirs, techniques have been developed by spreading powder from a boat (Mansfield, 1967, 1974) or spraying a suspension or dispersion on to the water surface from nozzles around the edge (Reiser, 1969; Crow and Mitchell, 1975; Frasier and Myers, 1968; Myers, 1965b). Continuous application from the upwind side is desirable as the film drifts with the wind and is disrupted by waves (Crow and Mitchell, 1975; Dick and Marchello, 1969). The chemical is also lost through biodegradation evaporation diselution and crystallization (Mansfield, 1974). Mahmoud and Bashi (1980) experimented with a combination of polystyrene beads and Cetyl alcohol and found it to be more effective than either on its own. In Australia, promising experiments are being conducted with a plastic mesh that floats on the water surface and retains the powered Cetyl alcohol in position (Mansfield, 1974; Brown, 1974).

During the scarcity year in 1985-86 in the Gujarat State two types of chemicals were reportedly used, one was in powder (Lumps) form i.e. Acilol (Trade name), by Rajkot Irrigation Circle, Rajkot (Gujarat) to reduce evaporation losses from three reservoirs. The results achieved are given in table-1 (Mistry, 1987).

Table-1

Sl. No.	Name of Reservoir	Chemical used	Average water saving in reservoir
1.	Aji-I	Powder form	20%
2.	Bhadar	Powder form	16%
3.	Nyari-I	Paste form	16.5%

Source: Mistry, J.F. (1987)

In theory, a complete film can reduce evaporation by 50% (Mansfield, 1967) but raised water temperature under the film can actually result in higher evaporation from uncovered areas. Economic considerations usually limit the saving that can be obtained in practice to only about 20% as concluded by Cluff, 1966; Cruse, 1960; Frasier et.al, 1968 from studies conducted abroad.

Kulkarni and Kapre (1987) carried out experimental trials during period 1977-78 to 1979-80 on reducing the evaporation losses by using monomolecular film of long chain alcohols in National Chemical Laboratory, Pune. They suggested the use of chemicals (Linoxyde CS-40) to small tanks in drought conditions for conserving water for drinking purposes. However, the process suggested is too elaborate and much expensive and does not warrant consideration for large reservoirs meeting irrigation requirements. Since results of most of the studies with alcohol have been discouraging, yielding reductions of only 10% -35% in field tests(Cruse and Harbeck, 1960; Cluff, 1966) alternative measures will need to be discovered for having an effective control of evaporation from water bodies.

2.2 Evaporation Reduction from Soil Surface

The possibility of applying long chain alcohols like hexadecanol and octadecanol to reduce water losses from soil surfaces received little attention until very recently. The effect of hexadecanol on the evaporation of water from soil appears to depend on the texture of the soil specifically on size of soil particles. Wooley (1962) has found that water evaporation from sand was reduced by 33 percent for 2mm sand and by 18 percent for 0.2 mm sand, while there was no reduction at all for clay or loam soil. Similar results (26.5

percent for sand, 4.1 percent for loam) were obtained by Atsatt (1963) and Mistry and Blood Worth (1963). This is in contrast with results reported by Mallik (1962) and more recently by Olsen, Watanable, Clark and Kemper (1964). Mallik (1962) found hexadecanol to be effective in reducing evaporation from Poona black soil to the extent of 30 percent from a Weld loam. According to Olsen et al.(1964), the mechanism of evaporation suppression from soil differs from that observed on a free water surface. In soil, hexadecanol allows the surface layer to dry and creates a diffusion barrier to water loss by vapour transfer. Lemon (1956) observed that hexadecanol reduce evaporation of water from soil by changing the soil properties that influence the capillary rise of water.

Venkataraman and Padmanabhamurthy (1962) observed significant decreases in evaporation from experimental tanks having soils mixed with large doses of Cetyl alcohol in both solid and emulsion form. In anaother study Bahl (1962) observed significant reductions in evaporation by covering saturated soil with monolayers of cetyl and stearyl alcohols. Besides, moisture can be conserved for useful purposes in the soil by the use of surface mulches. Straw mulching is known for soil moisture conservation (Bansal et al., 1971; Lal, 1974; Jalota & Prihar, 1979) but the magnitude of these favourable effects is dependent upon several factors, viz., prevailing weather and season, soil type and topography, initial soil moisture content, nature and extent of mulch, amount & intensity of rainfall etc. (Prihar et al., 1968; Lal, 1976; Nicou and Chopart 1979; Lattanzi et al., 1974).

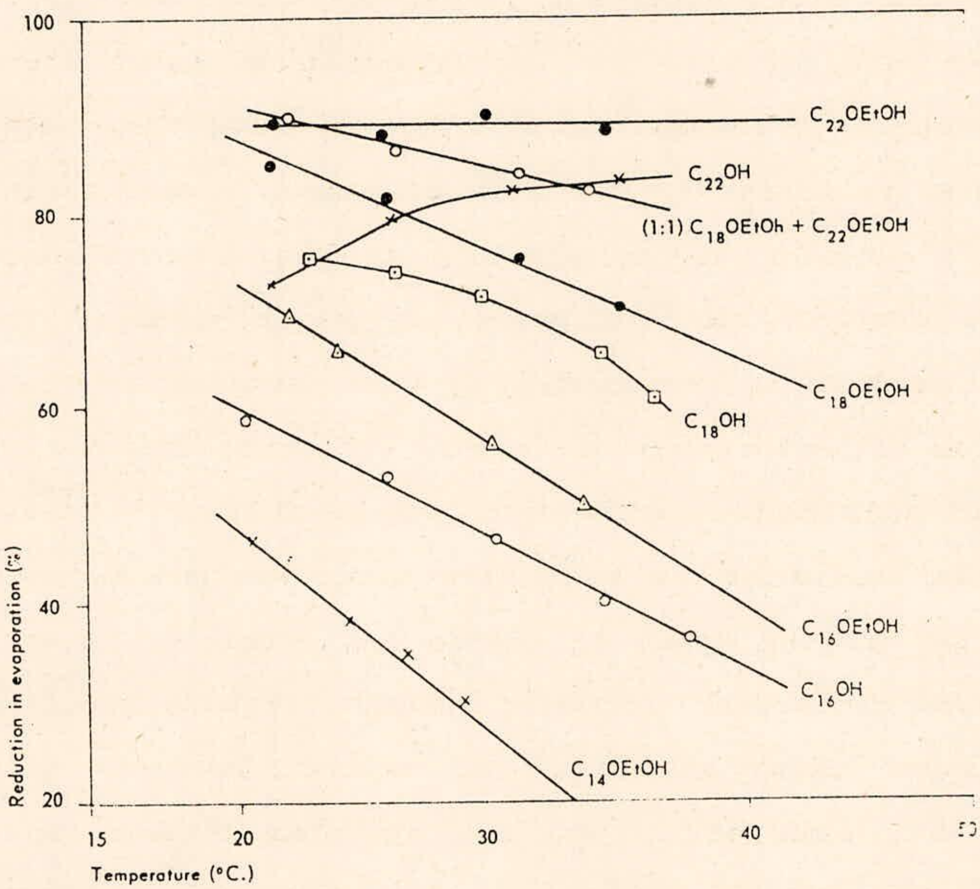

FIG. 2 Evaporation reduction as a function of temperature for monolayers of long-chain alcohols (C_nOH) and alkoxy ethanols (C_nOEtOH). From Deo, Sanjana, Kulkarni, Gharpurey and Biswas (1960).

3.0 EVAPORATION REDUCTION MEASURES FROM WATER SURFACES

The distinctive hydro-climatic features of arid lands which are frequently affected by droughts are charcterised by high levels of incidence radiations, conditions of low humidity and strong winds and high seasonal temperature variations. Such conditions are prone to heavy water losses by evaporation from water storage structures like reservoirs, stock tanks and farm ponds which have large surface area open to air. For vapourisation of water there must be a source of energy. In addition to this, there must be a transfer mechanism in the form of vapour pressure gradient i.e. a greater vapour pressure at the water surface compared to that of the air above the water surface. The evaporation process is accelerated by wind. Keeping in view, the mechanism of evaporation & factors affecting evaporation the evaporation reduction strategies may include: i) Checking the solar radiation to reach the water surface by some barrier using various types of covers and alcoholic layers, ii) increasing reflectance of water surface or iii) reducing the wind speed using artificial or natural barriers such as fences and trees etc., and iv) reducing surface area exposed for evaporation. Additional, the evaporation control measures could also be classified as below:

i) Measures while designing & installing the storage structure

ii) Measures on existing storage structures.

3.1 Measures While Designing and Installing the storage structure.

The various measures are given as below:

3.1.1 Locating reservoir at high altitudes

At high altitudes the meteorological conditions do not favour evaporation. It is, therefore, at higher altitude reservoir lose less water per unit surface than do reservoirs in lower altitudes. Hence, while deciding location this fact may be borne in mind specially if water conservation is prime aim.

3.1.2 Keeping the lower area/volume ratio of water body

For exposing less water body volume ratio can be kept lower while designing the structures. For small ponds and tanks low dykes can be built for cutting of shallow portions of the storage basin. This technique for reducing evaporation involves minimizing the surface area to volume ratio by utilizing a compartmented reservoir with a pump to keep the water concentrated minimising its exposure to the atmosphere.

3.1.3 Minimising exposed surface through reservoir regulation

In a reservoir and river system consisting of both high altitude and low altitude reservoirs, it might be possible to operate the system in a way to present the least exposed surface for the system as a whole, specially during the seasons of high evaporation loss. Barnes (1978) observed that significant savings can be made by applying this technique.

3.1.4 By constructing artificial aquifers

In south Africa, sand filled dams have been used since 1907 for the conservation of water (Wipplinger, 1958; Burger and Beaumont undated). These are built across water courses to trap layers of coarse sand during floods and thus form an artificial aquifer which can be trapped by wells or drains. Construction of such sand filled dams is done in stages to prevent the ponding of sediment laiden water that could lead to the deposition of fine grained materials. This idea has been extended in Arizona (Cluff et al., 1972) and Western Australia (Barnes, 1974) to the placement of carefully selected aquifer materials in storages to gain greater recoverable supplies than are possible with sand dams. Keeping the water table 600 mm below the surface of a fine sand virtually eliminated evaporation and it was reduced by 50% when the water table was at 300 mm (Hellwig, 1973b). It was further suggested that reducing the content of particles less than 0.1 mm diameter from 9% to 7% reduced evaporation by an additional 25% with the water table at 300mm. This indicates that capillary rise is an important mechanism in the transport of evaporating water and that at least the surface layers of the aquifer should be of coarse material.

3.2 Measures on Existing Structures

3.2.1 By Monomolecular films

Evaporation research on small ponds has shown that up to 25% of evaporation losses could be prevented by applying and maintaining a chemical film, or monolayer of hexadecanol on the water surface (Crow, 1961). Other researcher working with small ponds have also reported similar results (Korborg et al., 1963; Cluff and Resnick, 1964; Meinke and Waldrip, 1964). Small ponds serve nicely as research tools, but economic analysis has shown that evaporation suppression using monolayers on a small pond is not competitive with other methods of evaporation control (Cluff, 1966).

For the success of evaporation suppression system on large lakes a continuous monolayer of long chain alkanols is required which could stay against the wind action. This monolayer should be dispersed in a non-toxic solvent forming a stable evaporation resistant layer on water surface. The evaporation resistance of monolayers on a water surface has been found to depend on many factors, among them the film pressure, the temperature of the water, the wind velocity and the purity of the film forming substance are important ones. A brief description of effects of these factors as observed by various researchers is as below:

i) Film Pressure:

The resistance to evaporation of the monolayers of fatty acids has been found to be largely independent of surface pressure while the monolayers of pure long chain alcohols (C_nH_{2n+1} OH) have exhibited an increase of evaporation resistance with the surface pressure (Rosano & La Mer, 1956; Mansfield, 1956; La Mer and Barnes, 1959, Barnes and La Mer, 1962a, La Mer, Aylmore and Healy, 1963). The evaporation resistance of long chain alcohols containing upto 22 carbon atoms as well as glycol monoalkyl ethers, $C_nOC_2H_4OH$ (or $R\text{-}OE_tOH$) have been studied by Deo, Kulkarni, Gharpurey and Biswas (1961, 1962c). Their results are given in table -2 and are also shown in figure 1. It is seen that the resistance values are in general lower for the glycol ethers (shown as C_nOE_t OH) than for the corresponding alcohols (shown as C_nOH) at the same pressure. At high film pressures, however, the position is reversed and the glycol ethers exhibit higher evaporation resistances.

Table 2

Chain	Surface pressure (dynes/cm)		Specific resistance (Sec/Cm)	
	n-alcohols	n-alkoxy ethanols	n-alcohols	n-alkoxy ethanols
C_{16}	39.65	50.40	2.0	2.9
C_{18}	35.20	48.90	4.8	8.1
C_{20}	32.3	-	6.9	-
C_{22}	25.85	47.2	9.2	>35

Source: Deo, Kulkarni, Gharpurey and Biswas (1961)

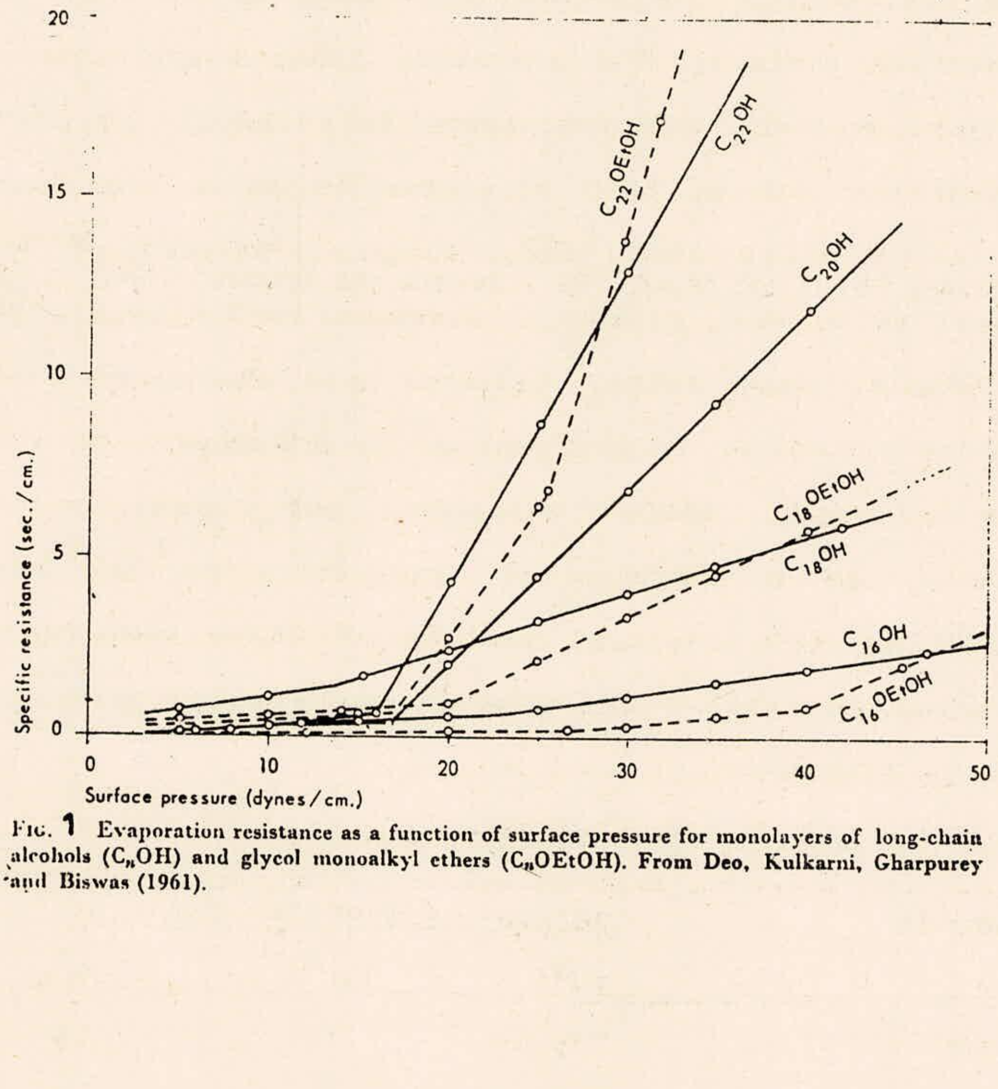

FIG. 1 Evaporation resistance as a function of surface pressure for monolayers of long-chain alcohols (C_nOH) and glycol monoalkyl ethers (C_nOEtOH). From Deo, Kulkarni, Gharpurey and Biswas (1961).

ii) Temperature:

From the studies on monolayers of fatty acids, Archer and La Mer (1955) concluded that the logarithm of specific resistance of a given monolayer could be represneted as a linear function of the reciprocal of the absolute temperature. Mansfield (1956, 1958b) has found that within the temperature range of 20°C to 30°C evaporation resistance of monolayer remains approximately constant. However, the resistance fell rapidly at higher temperatures and at 50°C reistance is about one fourth of its value at 20°C. Deo, Sanjana, Kulkarni, Gharpurey and Biswas (1960) and Shukla, Deo, Sanjana and Kulkarni (1962) as well as Shukla, Kulkarni, Gharpurey and Biswas (1963) and Shukla, Deo, Katti, Kulkarni and Gharpurey (1963) measured reduction in evaporation by monolayers of long-chain alcohols, alkoxy ethanols, and their various mixtures, as a function of temperature in the range of 20°C to 40°C. Typical results at these temperatures are shown in table-3 and some of the results are reproduced in figure -2.

Table -3

Compounds	Percent evaporation reduction		
	23°C	30°C	35°C
C_{18}-OH	75.25	70	64
C_{18}-OC_2H_2OH	84.75	77.5	72.5
C_{18}-$(OC_2H_4)_2OH$	73.75	66	60
C_{18}-$(OC_2H_4)OH$	22.75	17.5	15

Ramdas (1962) with the assistance of Narsimhan, Venkataraman and Bahl summarises the effect of temperature on efficiency of WERCs (Table-4).

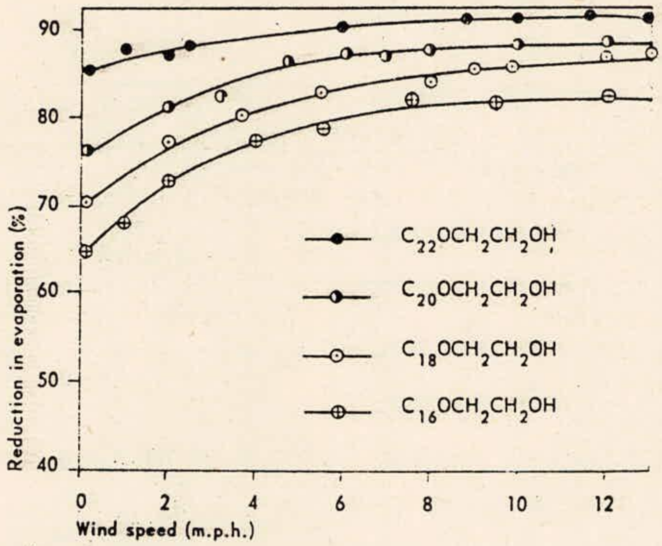

FIG. 3 Evaporation reduction as a function of wind speed for monolayers of alkoxy ethanols ($C_nH_{2n+1}OCH_2CH_2OH$). From Shukla and Kulkarni (1962).

TABLE 4

Temperature oC	Percentage Reduction in Evaporation due to monomolecular films of Cetyl Alcohol	Stearyl Alcohol	Cetyl-stearyl alcohol (50-50)	OED-70	OED Suspension	OED Green	OED-NC
18.5	-	-	-	-	91.5	-	-
20	60	82.5	80.3	90.6	-	88.4	-
25	-	-	-	85.0	86.9	79.1	-
30	35	70.5	64.7	80.7	82.9	75.8	-
32.5	-	-	-	-	80.8	-	-
35	-	-	-	75.6	-	73.1	78.7
40	24	55.9	54.7	70.3	71.6	68.8	74.4
50	18	42.9	40.7	52.3	57.0	54.9	61.6
60	13.	30.9	29.1	33.4	38.9	38.7	41.4
65	-	26.5	24.9	31.5	32.2	31.9	34.0

Notes: (1) Wind speed 2 to 3 m.p.h.; duration of experiments twelve minutes. Area of water surface 50 cm^2.

(2) Cetyl alcohol - $CH_3(CH_2)_{14}\ CH_2OH$
Stearyl alcohol - $CH_3(CH_2)_{16}\ CH_2OH$
*OED-70 - $C_{22}H_{45}O(CH_2)_2\ OH-C_{13}H_{37}O(CH_2)_2OH$ plus CMC (Carbonate methyl cellulose soluble in water)

*OED (Suspension)

*OED (Green)

*OED- NC

*Samples received from Dr. Mihara, National Institute of Agricultural Sciences, Tokyo

iii) Wind Velocity

Chemical film applied to lake surfaces for evaporation suppression are greatly affected by the local wind speed and direction. Favourable wind speed and direction are essential for maximum effectiveness of evaporation suppressing films. Shukla and Kulkarni (1962) observed the efficacy of the monolayers of alkoxy ethanols and the corresponding alcohols as water evaporation retardants over the wind speed range of 1-13 miles per hour. The relative evaporation reduction for alkoxy ethanols plotted against wind speed is shown in figure-3. Mistry (1981) has given wind velocity ranges versus conditions of lake surface for formation of evaporation retardant film as given in table 5:

Table 5

S.No.	Wind pattern	Wind velocity Km/hr.	Lake conditions
1.	Stormy	40 & above	Lake surface remains agitated and is not conductive to form effective film
2.	Windy	39 to 25	Film broken up by waves exposing pockets of lake surface as to direct heat of the sun.
3.	Smooth	24 to 10	
4	Calm	9 to 0	Film does not disturbed by small ripples on the lake surface

iv) Purity of the Material

Barnes and La Mer (1962b) and La Mer and Aylmore (1962) investigated evaporation resistances of commercial samples of hexadecanol and octadecanol, and their mixtures in various proportions. They concluded that these commercial alcohols, which are mixtures of substances of different structure but mainly of primary and to some extent secondary alcohols, are considerably inferior to pure materials.

Trapeznikov and Ogarrev (1963) investigated the ability to reduce evaporation of mixtures of normal hexadecanol and secondary hexadecanol $CH_3-(CH_2)_4-CHOH-(CH_2)_9-CH_3$. They inferred that the evaporation resistance of mixtures upto 1:1 proportions of the two alcohols approximates to that of pure hexadecanol but that it falls rapidly to zero with further increase in the proportion of the secondary alcohol. By studying the equilibrium pressure and spreading rates they concluded that the evaporation resistance of these mixtures is determined by the monolayer of the normal hexadecanol which displaces the less surface active secondary alcohol from the nonolayer on to the microcrystals for quantities of secondary alcohol in excess of 50 percent the normal hexadecanol is no longer able to displace all the secondary alcohol from the monolayer.

Chemical retardants used for evapaoration control are fatty alcohols. Cetyl Alcohol, also called Hexadecanol ($C_{16}H_{33}OH$) was one of the first to be used on experimental basis. Table-6 gives a list of countries where Cetyl alcohol was successful used. Stearyl Alcohol also called Octadecanol ($C_{18}H_{37}OH$) forming strong monolayer has also been in use. However, it is concluded from studies conducted abroad that a mixture of Cetyl and Strearyl alcohol was more effective in hot climate. These alcoholic substances require organic solvents like petrol, while spirit, mineral turpentine, synthetic thinners, Kerosene, indicator oil. These alcohols can be dispensed in solid or liquid forms.

Experimental work on evaporation reduction is reported to have been carried out in India by various institutes. Some of them are:

i) Irrigation Department Division, PWD, Bombay.

ii) Central Soil and Materials Research Station(CSMRS) New Delhi.

iii) Institute of Hydraulics & Hydrology, Poondi, Madras.

iv) Karnataka Engineering Research Station (KERS), Karnataka.

v) Central Public Health Engineering Institute(CPHEI), Nagpur.

vi) Central Salt and Marine Chemical Research Institute Bhavnagar(Guj).

TABLE 6

Sl. No.	Name of the Country	Place of experiment	Percentage saving effected	Remarks
1.	Australia	Reservoir of areas from 2 to 20 acres	20 to 70%	
2.	Japan	Evaporation Pans over a period of three months in summer.	53%	O E.D. Paste
3.	U. S. A. (South west Research Institute)	Laboratory experiments.	13 to 60%	
4.	Australia (C.S I R.O.)	—	52%	
5.	U. S. A.	1,00,000 gallons capacity aerator tank 30 ft diameter and 14 ft deep.	11% 33%	Sept. 14 to 23 & Oct. 11 to 18 August 30 to Sept. 7
6.	South Dakota (Pactola Reservoir)	Pactola	14%	
7.	Nairobi	Reservoir area 6.5 acres	30%	
8.	Tabora, Tanzania	Reservoir of 105 ac. waterspread	30%	
9.	Malaya		11%	
10.	Spain	Reservoir areas 31 acre.	35% 31%	4% solution in white spirit 35% solution kerosene

vii) National Environmental Engineering Research Institute (NEERI), Nagpur, Maharashtra.

viii) MERI, Nasik.

ix) Andhra Pradesh Engineering Research Laboratory (APERL), Hyderabad, Andhra Pradesh.

x) Gujarat Engineering Research Institute (GERI), Baroda, Gujarat.

(Chandra and Sikka, 1987).

Results of the studies as reported, indicate no toxic effect on aquatic life and no change in water quality. Evaporation Losses can be reduced in the range of 10 to 35 percent at a cost of Rs.0.40 to 0.60 per thousand litres of water saved. The details of field experiments, conducted by above mentioned organisations with percentage savings in evaporation reduction are given in table 7 (Chandra & Sikka, 1987). It can be concluded from the table that during the period January to June considerable amount of water can be saved by the application of Water Evaporation Retardant Chemicals (WERCs). The cost of evaporation reduction by WERCs of various projects is given in table 8 (Chandra & Sikka, 1987). Various States adopted water conservation methods like compartmentalisation and use of chemical retardants. The status of water conservation methods applied by using chemicals and mulches is as follows:

i) Gujarat

Chemical retardants were being used in 12 reservoirs and another 3 are planned. The effectiveness of

TABLE - 7

Percentage Saving in Evaporation Losses Achieved in Different Reservoirs/Tanks in India for Drinking Water Supplies.

Sl. No.	Name of reservoir/ project	Location	Period of Study	Average wind Velocity km/hr	Average % saving in evaporation reduction
1	2	3	4	5	6
1.	Kukkarhalli Lake	Mysore	Jan.59-May 59 (5 months) Fen.61-Apr.61 (3 months)	-	14.4 11.7
2.	Welwhan Lake	Lonavala	Feb.16-May 61 (4 months)	-	9.6
3.	Aji Lake[a]	Rajkot	Apr.68-June 68 (3 months)	23	16.5
4.	Indira[b]	Pune	1977-78 1978-79	15 -do-	38.19 35.20
5.	Kedaipur PT[b]	Nagpur	1977-78 1978-79 1979-80	- do- - do- -do-	34.78 16.01 15.87
6.	Ramgarh Lake[c]	Jaipur	Apr.85-July 85 (4 months)	14	23.4
7.	Foy Sagar[c]	Ajmer	Jan.86-June 86 (6 months)	8	35.0
8.	Maja dam[c]	Bhilwara	Jan.86-July 86 (7 months)	10	30.0
9.	Osman Sagar[c]	Hyderabad	Apr.86-June 86 (3 months)	14	33.0
10.	Nyari-I dam[c]	Rajkot Div.	Dec.85-May 86 (6 months)	12	16.5
11.	Aji-I[a]	Rajkot Div.	Dec.85-May 86 (6 months)	11	20.0
12.	Bhadar[a]	Rajkot Div.	Dec.85-May 86 (6 months)	11	16.0
13.	Ten Reservoirs[a & c] (Average)	Rajkot Irrig. Circle	Dec.85-May 86 (6 months)	-	11.08

(a) : Cetyl-Stearyl alcohol (Powder form)
(b) : Linoxyd CS - 40 (Paste form)
(c) : Ceto - Stearyl alcohol (Paste form) (ACILOL - TA - 1618 WER)

TABLE - 8

Cost of Evaporation Reduction by WERCs*

Sl. No.	Name of reservoir	Location	Year of study and duration.	Cost of water saved/ cu.m (1000 litres)	Average % saving in evaporation reduction.
1.	Aji lake	Rajkot	1968 (3 months)	0.04	16.5
2.	Indira PT	Pune	1976-77 1977-78 1978-79	0.27 0.30 0.40	35.00 38.19 35.20
3.	Kedarpur PT	Nagpur	1977-78 1978-79 1979-80	0.34 0.59 0.56	34.78 16.01 15.87
4.	Ramgarh Lake	Jaipur	1986 (first 15 days only)	0.30	23.4
5.	Ten Reservoirs of Saurashtra	Rajkot Irrigation Circle	1985-86 (5-6 months)	0.58	11.08

* Cost of applying water evaporation retardant chemical including cost of materials, labour & equipment usage.

the method is felt after middle of January. Evaporation losses are estimated to reduce by about 15-20 percent. The method is generally limited to tanks with surface area up to 45000 acres. Inter connection of tanks by pipes is also being tried.

ii) Andhra Pradesh

Chemical retardants have been experimented successfully with in storage tanks around Hyderabad to reduce evaporation losses.

iii) In Haryana, Madhya Pradesh, Karnataka, Orissa & Punjab the application of Water Evaporation Retardants (WER) was not successful due to prevailing high wind velocity and smaller size of ponds.

An impediment in the use of chemical retardants appears to have been their limited availability indigeneously. However, the National Chemical Laboratory, Pune has started manufacturing such chemical retards e.g. 'LINOXYDE CS40' . Besides some private concerns have also reported to have developed evaporation retardant chemical (Mistry J.F., 1981).

Dosage of WER

Reported effective dosages vary in the range of 20 gms to 200 gms per acre per day depending upon factors like temperature and wind velocity.

3.2.2 By Energy Reducing Methods

Recent approaches for evaporation reduction have concentrated on reducing the energy available for evaporation, either by reducing the amount of solar energy entering the stored water or by reducing the transport of water vapour above the water surface. The most effective of these methods are initially more expensive than monomolecular layers, but in the long run prove durable and efficient. Cooley (1975) summarized the levels of evaporation reduction achieved by various energy reducing methods by various researchers using different materials. Attempts to reduce evaporation by dyeing water a lighter colour have not been particularly successful to date. Wind barriers have not been researched in detail, but one study indicates that wind baffles do not reduce evaporation significantly (Crow and Manges, 1967). Shading the water surface with plastic sheeting has been a more successful evaporation retardant, but there are cost problems with the construction of large scale support structures and problems with strain and wind damage to the supported shade material (Drew, 1972).

Floating water covers, the most widely researched evaporation control method to date, exhibit effective results, ease of use, and low maintenance requirements. These covers act both as reflectors and as vapour barriers The covers range from small individual particles such as Perlite ore (Cooley and Cluff, 1972), polystyrene beads and wax blocks (Cooley and Meyers, 1973; Mahmoud and Bashi, 1980; Meyers and Frasier, 1970), to larger pieces, such as polystrene sheets, rafts and butyl sheets (Cluff, 1975; Cooley, 1970) and complete one piece covers

Table : 9 Evaporation reduction achieved by various energy-reducing methods

Method	Area of water surface covered %	Evaporation reduction %
1) Changing the water colour:		
Dye in water	100	6-9
Shallow, coloured pans	100	35-50*
2) Using wind barriers:		
Baffles	-	11
3) Shading the water surface:		
Plastic mesh	47	44
Blue polylaminated plastic sheeting	100	90
4) Floating reflective covers:		
Perlite ore	78	19
Polystyrene beads	78	39
Wax blocks	78	64
White spheres	78	78
White butyl sheets	86	77
Polystyrene sheets	80	79
Polystyrene rafts	100	95
Continuous wax	100	87
Foamed butyl rubber	95	90

* Evaporation from white pan compared with that from black pan.

Source: Cooley, 1975.

such as continuous wax covers (Cooley and Meyers, 1973). Table-9 compares the results obtained with these methods. However, these results have been reported under greatly varying conditions. Of these methods it was found that continuous wax, polystyrene raft and butyl rubber (Cliff, 1972; Cooley and Meyers, 1973; Dedrick et al., 1973) are the most readily available and the least difficult to install. For continuous wax method paraffin wax is used, like that used for canning which melts at 53^0 to 54^0C and forms a continuous cover during summer months. This wax can either be placed on the surface as blocks which will later be melted by the sun to form a wax layer (about 3mm thick) or melted with a heater and sprayed or poured on the water. Polystyrene rafts are constructed of 1.2 x 1.2m sheets of expanded polystyrene, 25mm thick, coated with emulsified asphalt and covered with a layer of chips. They are then coupled together using a clamp made of PVC pipe. An outer frame of 32 mm diameter PVC pipe is used as a bumper for the rafts. Continuous covers of low density closed call synthetic rubber sheeting, available as 1.2 m wide roll stock have been fabricated for use on water storage tanks. Covers have been fabricated from materials 5 and 6 mm thick.

All the three covers-continuous paraffin wax, polystyrene rafts and foamed rubber have been found to reduce evaporation by 85 to 95 percent. The cost of water saved in high evaporation areas compares favourably with alternate water sources. (Cooley, 1975).

3.2.3 Wind Breaks

A dense barrier from ground level can be most effective in suppression of evaporation as the wind plays a very important role in enhancing evaporation. Vegetable wind breaks can serve the purpose but evapotranspiration losses have to be substracted from evaporation savings. Crow, (1963) carried out study on effectiveness of non-vegetable wind breaks on reduction of evaporation from small reservoirs and found that with the barrier spacing to height ratio of 16:1, the evaporation was reduced by 9 percent when average wind speed was 10 m.p.h.

3.2.4 Air-bubbling

This technique is based on the concept of shifting of warmer surface water from colder water in bottom and is useful for deep reservoirs. A mechanism is required for air bubbling to artifically mix the water and breaks up the stratification. In this way colder water rises to the surface and the evaporation thereby is reduced. In studies carried out on Lake Wohlford, California the elimination of thermal stratification during May, June & July reduced the evaporation by 15 percent. (Korberg, 1962) but the evaporation was increased by 9 percent in September, October and November and so the net reduction was about 6%.

4.0 EVAPORATION REDUCTION FROM SOIL SURFACES

Evaporation from soil is dependent on meteorological factors but it is also dependent on soil properties particularly on the moisture content of the soil. The evaporation rates from saturated soil surface do not differ greatly from these of a water surface at the same temperature. However, for unsaturated soils, the rate of evaporation may be limited by the rate at which moisture is transferred from below, even though meteorological conditions might favour faster rates. The temperature of an exposed soil surface varies more than the surface of a water body because of the greater specific heat of soil particles. Consequently, both diurnal and seasonal evaporation rates have a wider range for soil surfaces than for water. The diurnal range is illustrated by the formation of dew or frost when night time soil temperature drops below the dew point. Evaporation losses are most rapid from the soil surface because the particles there are most directly exposed. As the surface dries, the rate of evaporation depends (a) on the rate at which liquid water can be supplied to the surface; or (b) on the rate of the movement of vapour particles from the lower layers of the soil to the surface. Movement of liquid water to the surface is important where water tables are shallow. Evaporation from fine textured soils effects water tables to greater depths than evaporation from coarse textured soils. On upland soils, unaffected by the water table, the depth to which evaporation proceeds depends on soil structure and porosity. Coarse sandy soils and soils with large cracks and cleavages dry more rapidly and to lower depths than fine textured compact soils (Lassen, Lull and Frank, 1952). Shallow soils dry more completely than deep soils when exposed to the same drying conditions and the moisture content of a soil dried by evaporation through its surface increases with depth (Rowe and Colman, 1951).

The conditions of precipitation are an important consideration for determining evaporation from soil surface. Where precipitation is concentrated in a short season of the year and where during the remainder of the year drying conditions prevail, the surface layers of soil can dry to extremely low moisture contents. In humid regions, the drying periods are shorter and the soil will not dry far below the surface and so even the shallow soils may maintain a relatively high moisture content (Colman, 1953).

In bare soils in the absence of plant cover evaporation is the only process by which soil water returns to the air. The presence of plants and continuous tree cover greatly reduce evaporation from the soil surface. Although plants withdraw water themselves and transpire it to the atmosphere yet the evaporation from soil covered with plants and forest floor is 10-80 percent of that from bare soil. A large proportion of rainfall evaporates from arid zone soil and rock surfaces. It has been estimated that about 25-50 percent of the water lost from a crop is evaporated from the soil surface (Viets, 1966). Evaporation from bare soils is controlled largely by temperature gradients within the soil profile. For similar meteorological conditions above the surface, more evaporation occurs under the conditions of upward than downward soil heat flux. An important feature of arid zone is the fact that in gravels, sand dunes, and sandy river beds rates of evaporation from depths greater than about 30 cm is very low. The evaporation losses from soil surfaces can be reduced by placing water tight moisture barriers or water retardant mulches on the soil surfaces. Evaporation can also be reduced by creating wind breakers in the form of trees, fences or taller growing plants or grass depending upon the site conditions. Various methods used for evaporation reduction from soil surface are discussed below:

4.1 Plant Residues

The residues of previous crop are left in the field and the new crop is planted directly without making the soil surface loose and porous. Evaporation losses get reduced because of residues and hard soil surface as compared to loose soil surface. In this method effective weed control is essential as the number of tillage operations gets reduced. In a study conducted at Central Soil and Water Conservation Research and Training Institute, Dehradun it is reported that surface mulching increased the yield of wheat by 23% when mulching was done from September to April (i.e. upto harvest of wheat), 36.3% higher yield of wheat was recorded under deep tillage conditions which indicate that application of surface mulching towards fag end of monsoon is beneficial from higher field point of view (Annual Reports, CSWCR& Training Institute, D.Dun, 1981, '84).

The effect of various quantities and duration of mulches on soil & water losses have also been studied. The application of grass mulches reduced soil loss and run-off in run-off plots planted with maize crop as indicated in studies done in Dehradun. A higher dose of mulch was found to be more effective in checking soil & water losses. Studies conducted in Bellary on another method called vertical mulches revealed that vertical mulches considerably increased available soil moisture & crop yields. Vertical mulching can be done by digging trenches of 40-50 cm depth, 15cm wide and 10-16 m long in which plant residues e.g. Jowar stubbles can be stuffed vertically such that they provide 10 cm above ground level. Such mulches act as intake points & guide the water to sub-soil. During severe drought conditions of 1973, in a study in Bellary significant grain yields were reported in plots with vertical mulching as compared to near crop failure in control plots. The vertically mulched plots were also reported to have increased grain and straw yields along with about 4-5 times higher moisture than control plots. Studies at

Bellary concluded that favourable effects of vertical mulches on crop yields and moisture conservation lasted for 4-5 successive years and was recommended as feasible and profitable system of moisture conservation for semi-arid tracts (Annual Reports, C.S.W.C.R. & Training. Institute, Dehradun, 1981, 1984, Bellary, 1980).

4.2 Gravel, Paper, Plastic and Straw Mulches

A layer of gravel as thin as 5-10 cm. helps in conserving soil moisture, however, cost involved, frequently redeposit the gravel on the surface and interference with mechanical cultivation are main problems associated with gravel mulching. Use of paper and polythene mulches has been done for weed control, increasing soil temperature and speed up plant germination and growth, their use as evaporation suppresant is under investigation. Studies have shown encouraging results in favour of use of paper and plastic mulches for water conservation (Doss et al.,1970). Straw mulching conserved soil moisture in mentha through reduction in evaporation (fig.4). Compared with unmulched soil, 0-15 cm layer of the mulched soil contained 0.5 -3.0 percent higher moisture (Khera et al 1986). Mulch also showed similar increase in soil moisture content with other crops, viz. sugarcane (Sandhu et al., 1980) sorghum (Sandhu et al.,1986), forage maize (Khera et al., 1976; Singh and Sandhu, 1979) etc. Moisture conservation with straw mulching was generally greater with high level of irrigation.

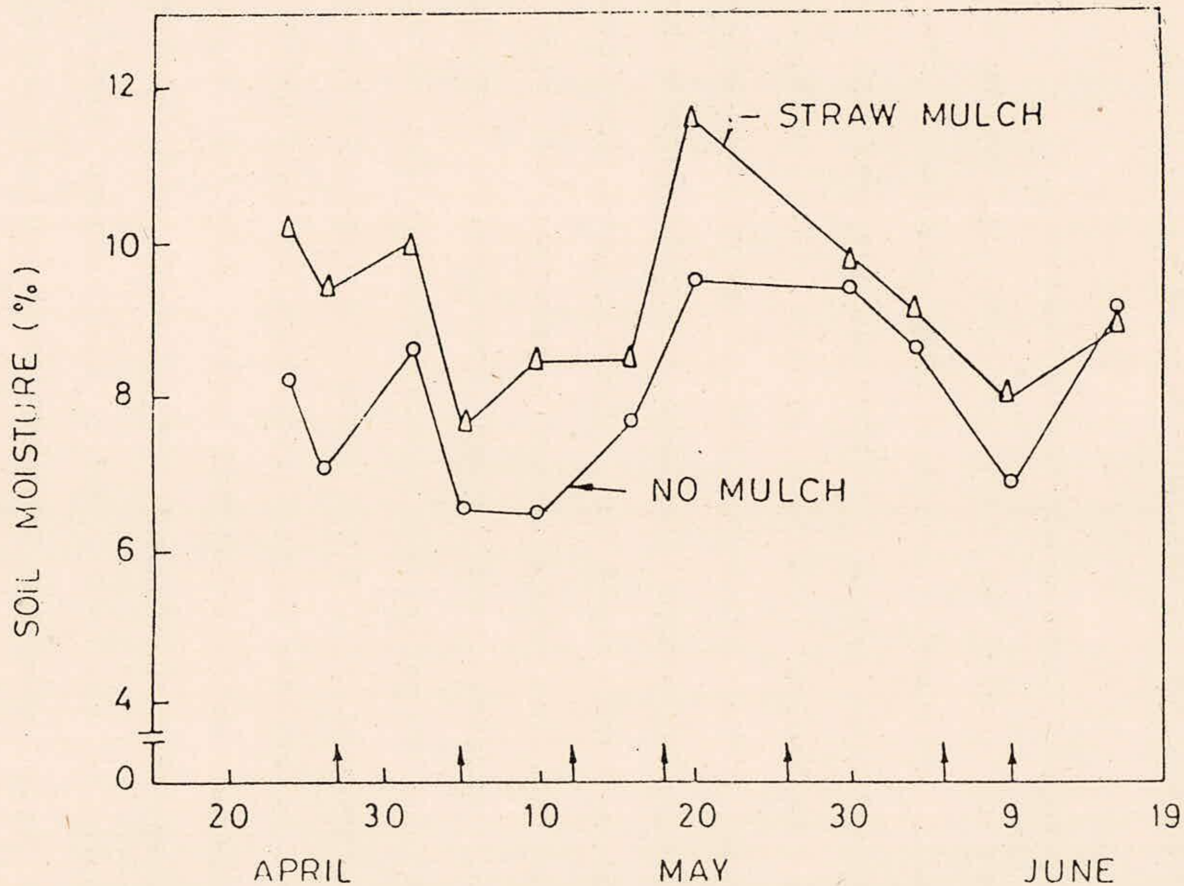

FIG: 4 PERCENT SOIL MOISTURE IN 0 - 15 cm SOIL UNDER NO MULCH AND STRAW MULCHED CROP OF MENTHA IRRIGATED ACCORDING TO IW / PAN-E = 1.00

Besides soil moisture conservation straw mulches bring the soil temperature towards the general optimal range of 25-35^{o}C. General optimal range thus creates better atmosphere for optimum growth of plants. Straw mulches also increase Nitrogen uptake by 8-55% and Phosphate uptake by 10-18% in different crops. Consequently straw mulching caused an increase of 9-25% in the yields of various crops.

4.3 Asphat, Oil Mulches and Use of Chemicals

Use of asphalt and oil mulches have been studied in desert situations for conservation of moisture. These have been found suitable for growing vegetation on water bearing sand dunes. Chemicals like Silicones, , polythylene oxides, fatty alcohols have been tested as evaporation suppressant and are still under investigation stage. Figure -5 indicates the reduction rates of evaporation from the wet soil sprayed on the surface with very thin layer of multimolecular film of mono-oxyethylene docosyl ether (short name OED-13) emulsion and OED suspension against the dosage of OED -13 dry weight (Mihara, 1962).

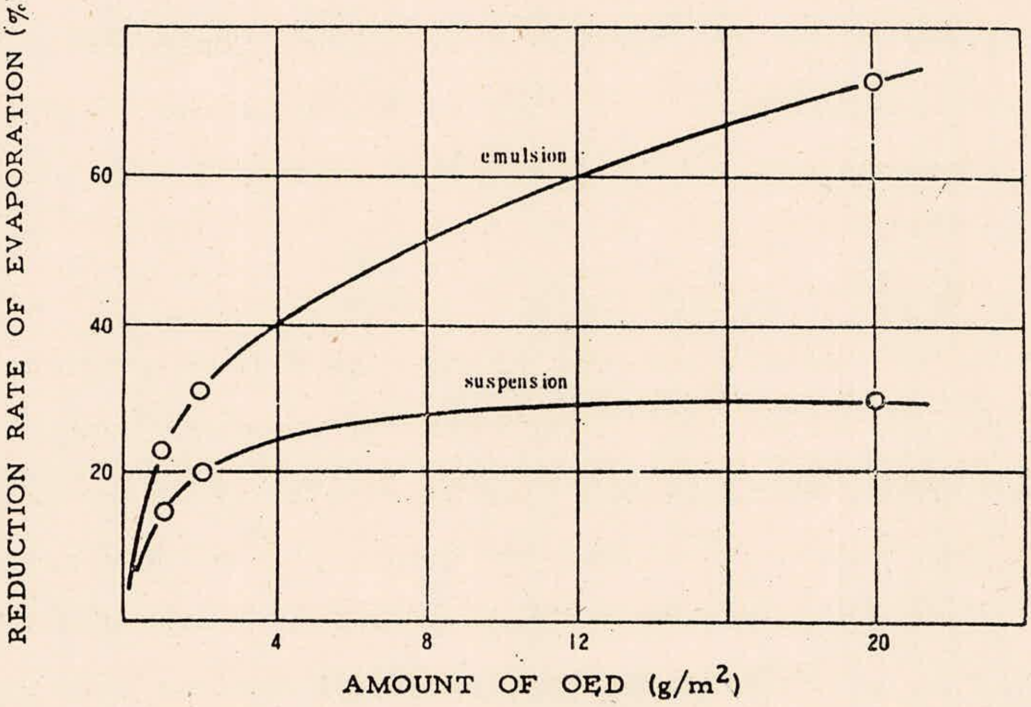

Fig. 5 Rate of reducing evaporation from the wet soil by the emulsion and suspension of OED

5.0 CONCLUSIONS AND RECOMMENDATIONS

The saving of water loss by evaporation has an important consideration in planning and design of drought alleviation strategies. The field trials on evaporation reduction through chemicals in the country have shown a substantial saving in evaporation reduction of about 10-35 percent. The cost of saving evaporation is found to vary from Rs.0.4 to 0.6 per thousand litres of water which is cheaper than other alternative modes of providing drinking water by rail and road transport. In addition vegetation belt with less evapotranspiration must be encouraged around water bodies to achieve more saving through reducing the evaporative effects of wind and its velocity towards water body and improve environment also. The effects of evaporation retardants on animal life needs to be studied for various species. Sand filled dams (artificial aquifers) can be built only where the geology permits. The use of mulches to conserve soil moisture has been successfully tested in various experiments. The main limitation with plant residues as mulches is their relatively short life time. The use of straw mulches are found to be cheap and effective in enhancing crop yield by increasing nitrogen and by optimising soil temperature. The use of plastic mulches and other kind of mulches is an expensive affair. The large scale use of non-porous mulches such as plastic paper, oil, asphalt etc. is to be studied for their economic viability. The use of covers which reflect incoming solar radiation is yet to be practicised. However, studies conducted abroad indicated that evaporation losses can be reduced upto 36% to 84% by using energy reducing materials as floating covers. The state of art of evaporation reduction is still incomplete especially in reference to efficiency of various methods in arid regions of the world.

Keeping in view of discussions in the report following recommendations are made for further research and development:

i) Economical methods need to be investigated for reducing evaporation from large multipurpose reservoirs.

ii) In case of extreme circumstances such as famine and drought the cost of equipment and chemicals should not be taken into account for economic viability.

iii) Research efforts are required to be strengthened for developing chemicals which will produce films to resist effects of wind, wave and currents.

iv) Selection of wind breaks with less evapotranspiration loss is required to have a net gain in saving water.

v) Dams and reservoirs should be located at high altitudes to the extent possible and should be designed for lower area/volume ratio.

vi) Floating covers of foamed wax blocks, continuous wax, and foamed rubber should be used as they can stand with high winds and reduce evaporation losses 36% -84%.

vii) Straw mulches that optimise the temperature of soil and increase the crop yields (9-25%) by reducing evaporation losses and also by enhancing root proliferation and nitrification rate need further investigations.

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