Assessing Effectiveness of Soil and Water Conservation Practices by EPIC model

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1.0 Introduction

Crop production in drylands is subject to the vagaries of monsoon. Agricultural droughts are common in drylands. Soils of shallow depth, low fertility, poor water holding capacity and the resultant soil moisture stress during crop growth are some of the major constraints. Integrated Watershed management is being recommended for improving the productivity of drylands. Activities aimed at conserving the natural resources, particularly soil and water, and their judicious development and utilisation form the backbone of the watershed programmes. As a part of better land management, several land treatments such as contour farming tied ridging, broad bed and furrows are being suggested for erosion control and rain water conservation. The utility of such measures in terms of soil water availability to crops will depend on a number of factors. Additional retention of water in the soil profile will depend on the antecedent soil moisture condition, amount of rainfall infiltration and seepage/percolation losses besides the water holding capacity of the soil (Padmanabhan et al, 1999). The utility of such practices will also depend on the frequency of runoff events as well as the quantum of runoff, which we are trying to control through such practices. The results of a study made earlier to understand the relative usefulness of retaining varying levels of runoff in an Alfisol watershed through simulation of hydrologic parameters, soil loss and crop yield over a period of ten years are presented.

2.0 Past Research Studies

Historically, the subject matter covering availability of soil moisture to crops has been studied mainly under two domains; i) as a study of the occurrence, distribution and probability of rainfall which supplies water to crops (rainfall and drought studies) and ii) the experimental studies with different land and water management practices aimed at improving the rainwater utilization (studies on soil and water conservation practices). Some of the salient observations by early researchers in the field are as follows:

2.1Drought Studies

- While the models based on rainfall probabilities are useful in evaluating suitability of growing dryland crops ;additional considerations of soil, crop and management aspects make the assessment more realistic and applicable both for planning and crop production purposes (Huda et.al.,1986).
- For direct application to crop planning, information on meteorological drought occurrence, if related to some crop character would enhance its practical value (Sastri, 1986).

- For agricultural purposes, the time interval in drought analysis has to be for a short period say week by week (Das, 1986; Krishnan, 1979).
- For understanding the real significance of a drought situation, it is necessary to analyse and understand the variability in surface runoff, the groundwater recharge and soil moisture conditions is also analysed and understood properly (Chitale, 1986).
- Availability of useful soil moisture to the vegetation appears to be a better index for drought analysis (Sikka, 1986).
- Depending on the soil characteristics , the rainfall efficiency can vary vastly and such information is vital in planning crop production based on soil and climatic factors (Huda,et.al., 1986).
- Development of new techniques based on parameters of climate-soil - plant interaction would be useful for accurate analysis and interpretation of drought for practical agriculture(Das, 1986).

2.2 Soil Moisture Conservation

- Beneficial effects of different inter-terrace land management practices have been reported by several workers from different dryland regions of India. These include small corrugations and vertical mulching in vertisols of Bellary; sowing flat on grade and ridging later in alfisols of Hyderabad; graded border strips in red sandy loam soils of Bangalore; and broad bed and furrow in vertisols of Akola (Padmanabhan et. al.,1992).Similarly, advantages of agronomic conservation practices such as tillage, vegetal cover and contour farming in terms of reduction in runoff and soil loss and increase in crop yields have been reported (Padmanabhan et. al.,1992). A review of literature on soil and water conservation research shows that most field experimental studies with conservation treatments generally report the effects on runoff, soil loss and crop yields. They seldom look at the soil moisture availability to crops or soil moisture in crop root zone on a continuous basis and the effects due to moisture excess (saturation) or deficit(drought) with in the season.
- Drylands are characterised by wide variations of moisture shortage and surplus both within as well as between seasons. This makes the choice of conservation treatment difficult because the desired objective may change from one season to another. In a dry area, it may be sensible to increase the surface storage to improve the crop yield in most years, but in a wet year this could cause water logging and reduce the yield. On the other hand, a drainage system may have the objective of increasing the runoff but also have the undesired effect of exaggerating the effect of drought(Hudson, 1987).

- A multitude of soil moisture accounting models have been developed by several investigators but less attention has been paid to application of these models for drought analysis and management(Sikka,1986).

From the above review, the following points emerge.

i) Annual, seasonal or weekly rainfall/drought studies are inadequate to give a clear picture of the crop performance. Studies with short time periods preferably on a daily time step basis with due regard to crop stresses due to an excess or deficit of moisture is required to be carried out.

ii) The effectiveness of soil and water conservation practices is a function of the interaction between climate, soil, plant growth and management and for any realistic evaluation, it is necessary to consider all the above factors together.

Thus, modeling provides an effective tool to carry out such evaluation of complex processes. Although there may be many missing links and level of accuracy may not be to the desired extent, it can be improved with experience and availability of better data sets and information.

3.0 Simulation Studies of Soil Moisture Conservation through Modeling in Rainfed Sorghum.

3.1 About Models

A model is a simplified representation of a complex system; hydrological models (i.e., models of hydrologic system) may be classified under the following categories:

(a) Physical, such as a scaled down facsimile of the full-scale prototype;

(b) Analogue, such as the resistance-capacitance analogue of a coastal aquifer

(c) Mathematical, in which the behaviour of the system is represented by a set of equations, perhaps together with logical statements, expressing relations between variables and parameters.

A mathematical model is most useful in simulating physical systems as well as economic, social, and physical impacts. Models can be used

(i) to forecast future conditions.

(ii) to evaluate the best strategy for achieving an objective .

(iii) to demonstrate how a complex system will operate under certain imposed conditions such as a flood, a drought, or demand increases and

(iv) to examine different scenarios of water management and to improve the quality of decisions

Models are approximations of reality, not reality itself. Usually they are very crude approximations. This should be kept in mind when using a model on which to base one's decision. Yet, a crude prediction may be better than none. Models of low absolute accuracy may still correctly reflect the different tendencies of alternate courses of action. Also, by introducing conservative assumptions in to a model, worst-case scenarios can be used to find reasonable decisions even with inaccurate models.

The main merits of modeling are:

(i) increased understanding of the interaction of simultaneous processes and influences.

(ii) concise problem formulation .

(iii) focusing of interdisciplinary efforts into one goal, where the results of different disciplines may be represented by sub-models or even single parameters in a model.

(iv) ease of comparison of tendencies, if not of absolute values resulting from different courses of action, simulated in advance.

According to France and Thornley (1984),

- In a system with several components (as the one which we are discussing i.e., climate-soil-crop interactions), a model provides a way of bringing together knowledge about the parts to give a coherent view of the behaviour of the whole system.

- Modeling may lead to less ad hoc experimentation as models some times make it easier to design experiments to answer particular questions or to discriminate between alternate mechanisms.
  The predictive power of a successful model may be used in many ways. It can be used to fix priorities in research and development, management, and planning. For instance, a model can be used to indicate the answers to 'What if...' questions.

3.2 Epic Model

EPIC (Environmental Policy Integration Climate earlier known as Erosion Productivity Impact Calculator) is a physically based mathematical model, originally developed by the Scientists of the USDA headed by Dr. J.R.Williams to assess the impact of erosion on productivity. EPIC is designed to be (i) Capable of simulating the relevant biophysical processes simultaneously, as well as realistically, using readily available inputs and, where possible accepted methodologies; (ii) Capable of simulating cropping systems for hundreds of years because erosion can be a relatively slow process; (iii) applicable to a wide range of soils, climates and crops; and (iv) efficient, convenient to use and capable of simulating the particular effects of management on soil erosion and productivity in specific environments. The model uses a daily time step to simulate (i) Weather (ii) Hydrology (iii) Erosion (iv) Nutrient Cycling (v) Pesticide fate (vi) Plant growth (vii) Soil Temperature (viii) Tillage (ix) Economics (x) Crop and Soil Management. EPIC is a field scale model applicable to areas where weather, soils and management systems can be assumed to be homogeneous (USDA,--).

EPIC model has been tested for its ability to simulate yields of several crops, used to study soil degradation, input levels and management practices, response to climate and soils (USDA,----) . Arnold and Jones (1987) concluded that EPIC can be used to evaluate previously untested combinations of soil, climate and crop management, thereby reducing the amount of site specific research needed to assess improved agricultural technology.

3.3 Methodology

EPIC model (Williams, 1994) was used in this study to evaluate the performance of in-situ soil and water conservation practices by assuming varying levels of runoff retentions as represented by a 300 mm furrow dike with efficiencies of 10%(FD1), 25%(FD2), 50%(FD3), 75%(FD4) and 95%(FD5). Studies were carried out with Pattancheru series (Alfisol) considering a root zone depth of 2.0 m (default value in EPIC). The simulated crop was sorghum, the common food crop of the region, grown in kharif (June-September) season. Studies were made for ten years (1985-1994), each year representing a unique rainfall distribution. Thus, in all, 6 simulation runs were made for 6 conservation levels, each one for a period of ten years.

4.0 Research Findings

The hydrologic output parameters of EPIC simulation runs for ten years (1985-1994) with various conservation treatments in Alfisol are furnished in Table 1(a) to (f). If we look at the year wise data, the maximum possible additional retention (FD5 – FD0) ranged from 1.73 mm in 1985 to 157.6 mm in 1989 with FD5 treatment. Now let us see what has happened to this additionally conserved water.

Table 1. Effect of Conservation Practices (Different Furrow Dikes) on Simulated Hydrologic Parameters in Alfisol.

(a) RUN OFF (Q) in mm

YEAR	FD0	FD1	FD2	FD3	FD4	FD5	FD5-FD0
1985	10.51	8.53	8.78	8.78	8.78	8.78	-1.73
1986	13.44	9.64	0	0	0	0	-13.44
1987	39.3	20.61	0	0	0	0	-39.3
1988	35.4	23.5	0	0	0	0	-35.4
1989	157.6	157.88	108.1	108.12	0	0	-157.6
1990	31.25	19.81	0	0	0	0	-31.25
1991	161.98	158.1	143	106.14	54.15	54.15	-107.83
1992	53.54	38.2	37.76	0	0	0	-53.54
1993	98.57	93.52	68.1	68.1	68.1	0	-98.57
1994	5.72	0	0	0	0	0	-5.72
Mean	60.8	52.9	36.6	29.1	13.1	6.3	-54.5

(b) ROOT ZONE SOIL WATER (RZSW) in mm

YEAR	FD0	FD1	FD2	FD3	FD4	FD5	FD5-FD0
1985	46.37	46.76	46.76	46.76	46.76	46.76	0.39
1986	35.19	35.2	35.22	35.22	35.2	35.22	0.03
1987	23.39	24.43	24.4	24.4	24.4	24.4	1.01
1988	77.46	77.51	77.72	77.76	77.76	77.76	0.3
1989	67.49	67.56	67.58	67.59	67.61	67.61	0.12
1990	60.09	59.99	60.1	60.11	60.16	60.16	0.07
1991	61.04	60.92	60.97	61.13	61.15	61.15	0.11
1992	50.24	50.27	50.28	50.32	50.4	50.4	0.16
1993	79.4	79.42	79.49	79.57	79.66	79.73	0.33
1994	45.34	45.23	45.31	45.38	45.48	45.55	0.21
Mean	54.601	54.729	54.783	54.824	54.858	54.874	0.273

(c) SUB-SURFACE FLOW (SSF) in mm

YEAR	FD0	FD1	FD2	FD3	FD4	FD5	FD5-FD0
1985	2.75	2.8	2.79	2.79	2.79	2.79	0.04
1986	3.62	3.71	3.94	3.94	3.94	3.94	0.32
1987	4.42	4.84	5.33	5.33	5.33	5.33	0.91
1988	5.44	5.71	6.27	6.27	6.27	6.27	0.83
1989	7.33	7.33	8.49	8.49	11.03	11.03	3.7
1990	4.35	4.62	5.09	5.09	5.09	5.09	0.74
1991	7.97	8.06	8.42	9.29	10.52	10.52	2.55
1992	5.24	5.59	5.61	6.52	6.55	6.55	1.31
1993	5	5.1	5.7	5.7	5.71	7.31	2.31
1994	2.74	2.87	2.87	2.87	2.88	2.88	0.14
Mean	4.89	5.06	5.45	5.63	6.01	6.17	1.29

(d) PERCOLATION (PRK) in mm

YEAR	FD0	FD1	FD2	FD3	FD4	FD5	FD5-FD0
1985	59.08	59.53	59.22	59.22	59.22	59.22	0.14
1986	77.89	81.64	90.9	90.9	90.9	90.9	13.01
1987	64.34	79.49	99.48	99.48	99.48	99.48	35.14
1988	155.57	167.33	190.45	190.62	190.62	190.62	35.05
1989	244.69	244.66	292.98	293.28	398.83	398.83	154.14
1990	59.34	69.79	89.43	89.47	89.68	89.68	30.34
1991	230.03	233.16	248.39	285.39	336.58	336.58	106.55
1992	117.23	131.43	132.46	170.23	171.88	171.88	54.65
1993	128.67	132.35	157.36	157.65	158.01	224.87	96.2
1994	30.09	35.48	35.71	35.92	36.15	36.31	6.22
Mean	116.6	123.5	139.6	147.3	163.1	169.8	53.2

(e) EVAPO-TRANSPIRATION (ET) in mm

YEAR	FD0	FD1	FD2	FD3	FD4	FD5	FD5-FD0
1985	260.91	260.9	260.92	260.92	260.92	260.92	0.01
1986	359.93	359.93	360.05	360.05	360.05	360.05	0.12
1987	349.4	349.59	349.6	349.6	349.6	349.6	0.2
1988	294.74	294.68	294.6	294.54	294.54	294.54	-0.2
1989	338.2	338.16	338.77	338.69	338.68	338.68	0.48
1990	287.16	287.93	287.62	287.59	287.38	287.38	0.22
1991	324.73	325.48	325.33	324.38	324.13	324.13	-0.6
1992	323.16	323.76	323.7	323.52	323.08	323.08	-0.08
1993	354.96	356.21	356.03	355.76	355.4	355	0.04
1994	401.12	401.44	401.35	401.25	401.17	401.1	-0.02
Mean	329.431	329.808	329.797	329.63	329.495	329.448	0.017

f) SOIL LOSS (MUSS) in t ha^{-1}

YEAR	FD0	FD1	FD2	FD3	FD4	FD5	FD5-FD0
1985	0.34	0.32	0.33	0.33	0.33	0.33	-0.01
1986	0.1	0.07	0	0	0	0	-0.1
1987	0.25	0.15	0	0	0	0	-0.25
1988	0.25	0.17	0	0	0	0	-0.25
1989	2.18	2.35	1.38	1.38	0	0	-2.18
1990	0.3	0.2	0	0	0	0	-0.3
1991	3.18	3.11	3	1.54	0.69	0.69	-2.49
1992	0.45	0.3	0.3	0	0	0	-0.45
1993	0.74	0.72	0.56	0.56	0.56	0	-0.74
1994	0.03	0	0	0	0	0	-0.03
Mean	0.77	0.73	0.56	0.38	0.15	0.1	-0.67
PRCP	491.7	491.7	491.7	491.7	491.7	491.7	0
DAYP	44.2	44.2	44.2	44.2	44.2	44.2	0
DAYQ	4.9	2	0.8	0.6	0.3	0.2	-4.7

It can be observed from the sub-surface flows (Table 1c) and the percolation values (Table 1d) that most of the additionally held runoff water was lost in these two ways. For example, the conservation treatment 300 mm dike with 95% efficiency (FD5), which increase retention of rainwater by an average 54.5 mm, lost 53.2 mm through percolation and another 1.28 mm by way of sub-surface flow. There was negligible increase of 0.017 mm in simulated evapo-transpiration (Table 1e).

Different treatments did not show much change in the evapo-transpiration values. Ten year mean values varied from 329.44 to 329.80 mm with different treatments compared to the value of 329.43 mm for no treatment (FD0) which means an increase in ET ranging from 0.01 to 0.37 mm. (Table 1e). Individual years' values show that in some years, there were initially marginal increase in ET, but with additional conservation they dropped below the values for control. Similar was the case with root zone soil water; the treatmental effects with any amount of conservation did not show significant advantage (Table 1b). While the ten-year mean root zone soil water for control was 54.6 mm, the increase in mean root zone soil water was only to the tune of 0.12 mm and 0.27 mm i.e., a root zone soil water of 54.72 mm and 54.87 mm for 300 mm furrow dikes with 10% (FD1) and 95% (FD5) efficiencies respectively. Across years, the highest and the lowest increase (FD5-FD0) were 1.01 mm in 1987 and 0.03 mm in 1986. However, all the years recorded marginal increase in root zone soil water. The ten-year mean rainfall (PRCP) in mm, mean number of rainy days (DAYP), and the number of days with runoff (DAYQ), are given at the end of the table. While the mean rainfall and the mean number of rainy days remain same for the experimental period, the number of days in which runoff occurred vary according to the runoff retention (FD0 to FD5) within the field.

Table 2. Effect of Conservation Practices (Different Furrow Dikes) on Water Stress, Air Stress, Available Water and Crop Yield in Alfisol.

(a) WATER STRESS (WS) in days

YEAR	FD0	FD1	FD2	FD3	FD4	FD5	FD5-FD0
1985	30.3	30.3	30.3	30.3	30.3	30.3	0
1986	7.4	7.4	7.4	7.4	7.4	7.4	0
1987	14.1	14.1	14.1	14.1	14.1	14.1	0
1988	2	2	2	2	2	2	0
1989	1	1	1	1	1	1	0
1990	7.3	7.3	7.3	7.3	7.3	7.3	0
1991	1	1	1	1	1	1	0
1992	6	6	6	5.9	5.9	5.9	-0.1
1993	1	1	1	1	1	1	0
1994	4.1	4.1	4.1	4.1	4.1	4.1	0
Mean	7.42	7.42	7.42	7.41	7.41	7.41	-0.01

(b) AIR STRESS (AS) in days

YEAR	FD0	FD1	FD2	FD3	FD4	FD5	FD5-FD0
1985	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0
Mean	0	0	0	0	0	0	0

(c) CROP AVAILABLE WATER (CAW) in mm

YEAR	FD0	FD1	FD2	FD3	FD4	FD5	FD5-FD0
1985	49	49	49	49	49	49	0
1986	93	93	93	93	93	93	0
1987	128	128	128	128	128	128	0
1988	83	83	82	82	82	82	-1
1989	79	76	72	72	71	71	-8
1990	52	52	51	51	51	51	-1
1991	48	48	48	44	44	44	-4
1992	50	50	50	50	50	50	0
1993	51	51	51	51	51	50	-1
1994	51	51	51	51	51	51	0
Mean	68.4	68.1	67.5	67.1	67	66.9	-1.5

(d) CROP YIELD (Y) in t ha^{-1}

YEAR	FD0	FD1	FD2	FD3	FD4	FD5	FD5-FD0
1985	2.4	2.4	2.4	2.4	2.4	2.4	0
1986	4.7	4.7	4.7	4.7	4.7	4.7	0
1987	6.4	6.4	6.4	6.4	6.4	6.4	0
1988	4.2	4.2	4.2	4.2	4.2	4.2	0
1989	4.1	4	3.9	3.9	3.9	3.9	-0.2
1990	3	3	2.9	2.9	2.9	2.9	-0.1
1991	2.8	2.8	2.8	2.6	2.6	2.6	-0.2
1992	2.8	2.8	2.8	2.8	2.8	2.8	0
1993	3	3	3	3	3	2.9	-0.1
1994	3.1	3.1	3.1	3.1	3.1	3.1	0
Mean	3.65	3.64	3.62	3.6	3.6	3.59	-0.06

Thus the ten-year mean number of days of runoff varied from 4.9 for FD0 to 0.2 for FD5, a reduction of 4.7 days. The simulated water stress days are given in Table 2a. The number of water stress days varied from 1 to 30.3 in different years. It was surprising to note that in spite of retaining all the runoff in eight out of ten years (Table 1a), the number of water stress days did not decrease in any of these years. No air stress was simulated (Table 2b), as profile drainage is not a problem in Alfisol.

4.4 Summary

A review of literature on drought studies, soil moisture conservation and modeling bring out the need for more critical evaluation of soil and water conservation practices integrating all the above factors using the modelling approach. Accordingly, simulation studies have been carried out to find out the hydrological changes with six levels of runoff retention through simulated furrow dikes having different efficiencies. The crop was sorghum. The results showed that runoff and soil loss was reduced substantially with runoff retention. Sub-surface flow increased with runoff retention and high percolation was observed. Soil water increased marginally. Similar was the case with evapo-transpiration. Water stress reduction was observed to a marginal extent. No air stress was simulated. Crop available water and crop yield did not show much increase with runoff retention.

4.5 Conclusion

Soil and water conservation practices are believed to hold the key to successful dryland agriculture. However their effectiveness will depend upon the rainfall distribution, soils, crop and crop management. From the results of the study reported it may be concluded that in-situ conservation practices alone cannot guarantee an assured crop in the event of extended periods of drought. The results also point to the need for suitable cropping systems and water harvesting and utilisation structures. For example, deep rooted crops can be selected in Alfisols in order to tap the soil water from deeper layers. High percolation in Alfisol can be taken advantage of by having ground water recharge systems such as percolation tanks.

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