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Front Cover: Rice paddies with *hasakake* ··· a traditional Japanese means for drying rice by stacking harvested stalks around a supporting pole.

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THE STORAGE AND USE OF RUNOFF WATER FOR AGRICULTURE IN THE SEMI-ARID TROPICS*

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Abstract

In arid and semi-arid parts of the world, low annual rainfall, its high variability in onset and distribution, and low retention capacity of some of the soils contribute greatly to low agricultural productivity. Rainfall intensity in these regions often exceeds the infiltration capacity of the soils, resulting in excessive runoff and erosion.

In some parts of the semi-arid tropics (SAT), particularly southern India, the excess runoff is collected, stored in small reservoirs or "tanks", and used to grow rice. In some instances, the water stored in the tank is used to supplement rainfall during prolonged drought in the cropping season to grow upland crops. Thus, the risk inherent in rainfed agriculture is reduced and crop yields stabilized. Usually the quantity of water available from these tanks for irrigation is limited because of high seepage and evaporation. Therefore, it is very important to maximize benefits accruing from this limited irrigation water by increasing the water-use efficiency through timely irrigation and efficient soil and water management practices.

Studies conducted at ICRISAT have shown clearly that crop yields, particularly on Alfisols, can be increased through timely supplemental irrigation when there is drought during the rainy season. Further, a management system that conjunctively utilizes rainfall and the limited irrigation water from the tanks not only increases crop yields but also improves the water application efficiency.

An economic evaluation, using simulation models and a survey of 32 tanks, has indicated that supplemental irrigation is a viable and attractive proposition in Madhya Pradesh state provided tank seepage is low.

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Introduction

The common problem of low crop yields in the semi-arid tropics (SAT) is caused by low annual rainfall, high variability in onset and distribution of rains, and the low water-retention capacity of some of the soils. In this region, precipitation exceeds potential evaporation for only 2 to 4.5 months (dry semi-arid) or 4.5 to 7 months (wet semi-arid) in any particular year (Troll, 1965). Usually irrigation is introduced in such areas to overcome this problem if surface water or groundwater is ailable.

In many regions of the SAT, surface water near to farmed land is scarce at the time when irrigation is needed. Also, in some cases, groundwater may be either found at great depths or brackish. Consequently, irrigation from the usual surface water sources or from groundwater sources is not feasible. Despite low annual rainfall, rain intensity often exceeds the infiltration capacity of the soils in these regions. This, and the low in situ storage capacity of the soil, result in much of the rain being lost as runoff and contributing to soil erosion. In such situations, runoff collection and storage on a relatively small scale is the only possible source of irrigation water. It offers the potential to increase and stabilize crop yields. We make a distinction here between runoff collection and water harvesting. The latter involves inducement of runoff by treating a catchment area while in the former, management practices may deliberately try to maximize in situ infiltration and storage.

Some parts of the SAT, particularly southern India, have a long history of runoff collection and storage in small tanks. The catchment area (or area contributing runoff) is left for its riginal use and excess rain is generally allowed to follow the atural drainage path into a tank created by an earthen or masonary bund or dam across a suitable section of the valley. These runoff collection systems are basically water conservation structures, aimed at regulating water flow and providing water for drinking and agricultural use. The water in the tanks is used to grow rice and, in some instances, to supplement rainfall during prolonged rainless periods in the cropping season to grow upland crops. Supplementary irrigations during prolonged rainless periods reduce the risk inherent in rainfed agriculture and help stabilize crop yields. However, because of evaporation and sometimes high seepage losses, only limited water is available from these tanks for irrigation. Therefore, it is very important to maximize benefits accruing from this limited supply of irrigation water. Increasing the water-use efficiency through timely irrigation and efficient soil and water management is essential in realizing maximum benefits.

In this paper, we review work at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) on the use of the water stored in small tanks to supplement rainfall during drought periods, a management system aimed at efficiently utilizing the impounded water and the economic evaluation of tank systems using both simulation studies and field surveys.

Climate and Soils of the SAT

In most areas of the SAT, about 70 to 90% of the annual rainfall (which ranges from about 400 mm to 1900 mm) is received from April to October (Krishnan, 1975). The rainfall is very variable between and within the years in various SAT regions. For example, the coefficient of variation for monthly rainfall at Hyderabad (18°N, 78°E) for June is 57% (monthly mean = 107 mm); for July, 45% (mean = 165 mm); for August, 52% (mean = 147 mm); for September, 59% (mean = 163 mm); and for October, 94% (mean = 71 mm) (Krantz, 1981). The relatively high variability in rainfall is also evident from Figure 1 and Table 1. Further, a large portion of the total rainfall often occurs in a few torrential and erosive rains. As a result, the semi-arid regions generally have a high potential for water erosion, especially when the soils are bare.

Table 1. Monthly rainfall at ICRISAT Center during 1973-87 and monthly means for Hyderabad during the period 1940-70.

Year	Jan (mm)	Feb (mm)	Mar (mm)	Apr (mm)	May (mm)	Jun (mm)	Jul (mm)	Aug (mm)	Sep (mm)	Oct (mm)	Nov (mm)	Dec (mm)	Annual (mm)
1973	0	0	0	0	3	88	361	231	68	226	11	1	752
1974	0	0	0	15	15	120	88	160	186	279	4	0	868
1975	25	0	24	0	3	98	305	180	432	174	35	0	1184
1976	0	0	1	91	22	86	219	299	74	1	30	0	823
1977	0	0	0	8	36	67	304	194	60	80	28	2	819
1978	17	21	4	56	15	103	228	516	82	71	10	1	1202
1979	0	41	0	3	70	56	307	101	345	20	80	0	833
1980	0	4	9	7	10	141	127	306	153	6	0	2	773
1981	26	0	77	3	2	303	309	218	287	180	2	0	1173
1982	0	0	0	34	20	103	355	68	180	80	13	0	749
1983	0	0	12	6	47	87	311	305	287	133	1	17	1099
1984	5	1	21	31	0	93	172	140	98	88	6	0	655
1985	2	0	20	31	19	88	173	46	76	83	8	0	558
1986	83	44	6	35	0	118	331	333	87	0	37	0	712
1987	4	0	3	6	38	143	344	90	63	100	240	1	878
Mean	5.5	11.0	13.5	24.0	26.5	115.5	171.5	156.0	103.8	67.8	33.5	9.0	853.7
CV (%)	319	204	199	122	95	57	45	82	87	94	167	284	25

Source : Unpublished data (RMP-Agroclimatology, ICRISAT).

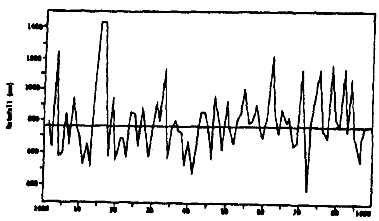

Figure 1. Annual Rainfall at Hyderabad.
Source: Unpublished data (RMP-Agroclimatology, ICRISAT).

Temperatures are high and very often exceed a mean of 18°C throughout the year. The mean annual solar radiation varies between 16 and 21 MJ m^{-1} day^{-1} (Landsberg et al, 1963; Thompson, 1965). Compared to the rainfall, the coefficient of variation for annual temperature and solar radiation is about 5%.

Seven of the 14 soil orders described by Swindale (1982) from the FAO/UNESCO Soil Map of the World, namely, Ferralsols, Luvisols, Arenosols, Acrisols, Vertisols, Nitosols, and Fluvisols occupy about 90% of the arable land area in this region. Here we consider only Alfisols (classified as Luvisols in the FAO/UNESCO Soil Map of the World) and Vertisols. Alfisols cover 32% of Africa, 34% of Latin America, and 38% of Asia. Alfisols and Vertisols cover 39% of the global SAT and 63% of the Asian SAT (Kampen and Burford, 1980; Krantz, 1981). Both soils are represented within the ICRISAT experimental farm at Patancheru.

The Alfisols discussed in this paper are red, reddish-brown, or yellowish brown. They usually have a loam or sandy loam surface horizon overlying a heavier textured (argillic) B horizon. They are fine kaolinitic, isohyperthermic members of the family of Udic Rhodustalfs (USDA, 1975). Slope is commonly 1-3%. The Vertisols (Usterts) referred to in this paper are fine calcareous, smectitic, isohyperthermic members of the family of Typic Pellusterts. They are high in smectitic clay (30-60%), develop large cracks upon drying, and with wetting and drying the surface self-mulches.

Runoff Collection and Reuse

Assuming negligible amounts of (a) depression storage on the soil surface, and (b) interception of rainfall by plants, surface runoff rate (overland flow) is the difference between the intensity of rainfall and the infiltration rate of the soil. Therefore, the two major determinants of surface runoff rate are the rainfall characteristics and the infiltration behavior of the soil. We have indicated that a large portion of the total rainfall in the SAT often occurs in torrential and erosive rains. The terminal infiltration rates found for Alfisols at ICRISAT range from 6-60 mm/hr, but the mean for Vertisols was only 0.21 mm/hr. The high terminal infiltration rate of Alfisols is often reduced during the initial period of the rainy season to about 3-4 mm/hr by surface sealing and crusting, caused by the impact of rain drops on bare soil (Mensah Bonsu, unpublished data). As a consequence, runoff and soil erosion are greatly increased. In contrast, Vertisols have gross cracks at the end of the dry season and there is very little runoff until the soil water deficit is recharged.

In SAT India, excess runoff is traditionally collected and stored in small reservoirs, which are usually constructed and maintained by Irrigation Departments (>40 ha command area) and Panchayat Unions (village councils). The major problems encountered in the traditional water collection and storage in tanks include soil erosion, leading to siltation of tanks, and gully formation, resulting in taking land out of cultivation. Farmers are responsible for water distribution and management below the outlet. Most of these reservoirs are shallow with the result that evaporation losses are high. A number of reservoirs have been constructed at ICRISAT Center on both the Alfisol and the Vertisol watersheds. These are excavated tanks, which differ markedly from the conventional reservoir design. Figure 2 shows a detailed sketch of the experimental reservoir. This design has greater depth and offers a relatively smaller water surface area for evaporation than the conventional tanks. Because of the greater depth of the reservoirs at ICPISAT Center, water is normally pumped to irrigate the fields below. Seepage is also quite low. For example, the average seepage rate from a tank located on a Vertisol at ICRISAT Center in 1974 was 1.2 mm/day for October 10-19, and 2.2 mm/day for the period November 13-December 2 (ICRISAT, 1973/74). It has been found that tanks on Vertisols in Central India can supply the amount of water required for supplemental irrigation of a soybean/pigeonpea intercrop, provided the average seepage rate is below 10 mm/day (Pandey, 1986).

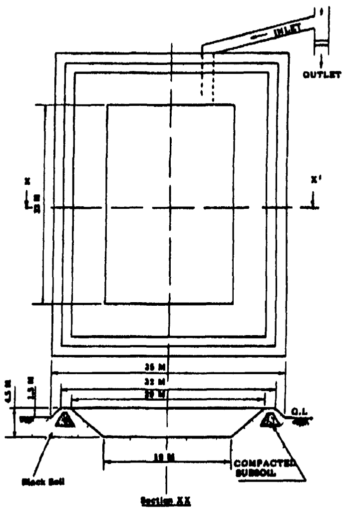

Fig. 3 Details of experimental tank.

On Alfisols the potential quantities of water available for tank or groundwater storage are relatively high because, even with improved cropping systems, 55-70% runs off or percolates to deeper layers of the soil profile; both can be captured for supplemental irrigation (Sachan and Smith, 1987). However, high seepage rates can be a problem in some Alfisols.

Spectacular benefits have been reported from supplemental irrigation using water stored by tanks on Alfisols at ICRISAT Center (El-Swaify et al., 1985; Srivastava et al., 1985; Pathak et al., 1986). The crop yield responses obtained in both rainy and postrainy seasons are shown in Table 2. Higher irrigation-use efficiencies were observed for all crops during the postrainy season as compared to the rainy season. In a sorghum/pigeonpea intercrop, two 40 mm irrigations gave an additional gross return of 2747 Rs ha^{-1} (one US$ = Rs 14.50). The highest additional gross return from supplemental irrigation was obtained by growing tomatoes (7870 Rs ha^{-1}). The irrigation-use efficiency (IUE) in Rs mm^{-1} ha^{-1} was 11 for pearl millet, 18 for sorghum, 26 for pigeonpea, and 93 for tomatoes, indicating that on Alfisols substantial returns can be obtained from relatively small quantities of supplemental water on rainy and postrainy season

Table 2. Additional gross returns (Rs) due to supplemental irrigation and irrigation-use efficiency (IUE)* on an Alfisol watershed, ICRISAT Center (1981-84)

	Grain yield, kg ha^{-1}									
	Intercropping system									
	Sorghum				Pigeonpea					
Year	Control	One irrigation of 40 mm	Increase	IUE Rs mm^{-1} ha^{-1}	Control	Two irrigations of 40 mm each	Increase	IUE Rs mm^{-1} ha^{-1}	Combined additional gross returns due to supplemental irrigation**	Combined IUE Rs mm^{-1} ha^{-1}
1981-82	2820	3220	400	12	660	1120	460	23	2220	19
1983-84	2300	3090	790	24	710	1320	610	29	3268	27
Average	2560	3155	595	18	685	1220	535	26	2747	23
	Sequential cropping system									
	Pearl millet				Tomato					
1981-82	2100	2710	610	18	9600	23200	13600	85	7532	63
1982-83	1630	1720	90	3	13100	29300	16200	101	8208	68
Average	1865	2215	350	11	11350	26250	14900	93	7870	66

*Irrigation-Use Efficiency (IUE) = $\frac{\text{Addl gross returns due to irrigation}}{\text{Depth of irrigation}}$

**One US$ = Rs 14.50

Source: Pathak et al (1985)

On Vertisols where double cropping is practiced, there will be relatively less water available for tank storage. However, about 50 to 65% of the water collected in the tank could be used for irrigation. The remainder is usually lost as evaporation and seepage. Srivastava et al. (1985) found in a study conducted on a Vertisol watershed at ICRISAT that average additional gross returns due to supplemental irrigation were about 630 Rs ha^{-1} for safflower, 1680 Rs ha^{-1} for chickpea, and 2110 Rs ha^{-1} for chillies (Table 3). The IUE was satisfactory for chillies (26 Rs/mm/ha) and chickpea (21 Rs/mm/ha), but it was low for safflower (8 Rs/mm/ha).

A System for Efficient Utilization of Water from Tanks

As a result of seepage and evaporation, generally only limited irrigation water supplies are available from small reservoirs. Also, the rapidly escalating cost of energy used for pumping water is of concern. Furthermore, the unpredictability of the timing and amount of rainfall makes efficient use of water from these tanks difficult. Therefore, a management system for the conjunctive use of rainfall and a limited amount of irrigation water, CURLI (Stewart et al. 1981) was adapted and tested for rainy-season sorghum on Alfisols during 1984-86 at ICRISAT Center. This involved essentially the division of a 60 m irrigable field (under a ridge-and-furrow system) along its slope into three 20 m sections. The upper section was conventionally irrigated, the middle received the tail-end water from irrigation of the upper section, and the lower section was managed as dryland but it received irrigation and rainfall runoff from the upstream section as well as the normal rainfall in the area. These three sections had different plant densities and fertilizer rates. The CURLI management system allowed (i) a small amount of water in the tanks to be applied in such a way that very little or no water left the field, and (ii) conjunctive use of rainfall by eliminating or reducing runoff even when rain fell soon after an irrigation.

Table 3. Additional gross returns due to supplemental irrigation* and irrigation-use efficiency** (IUE) on a Vertisol watershed.

Cropping system	Year	Yield, kg ha^{-1} Control	Supplemental irrigation	Increase due to irrigation	Additional gross returns due to supplemental irrigation, Rs/ha	IUE Rs/mm
				Chickpea		
1. Maize + Chickpea sequential	1981-82	1160	1470	310	1170	15
	1982-83	1050	1480	430	1634	30
	1983-84	1300	1830	530	2090	36
	1984-85	900	1300	400	1634	33
				Average	1690	31
				Chillies		
2. Mung + Chillies sequential	1981-82	1020	1340	320	3000	36
	1982-83	1140	1490	350	2275	38
	1983-84	840	1120	280	1820	23
	1984-85	1030	1380	350	2275	28
				Average	2113	26
				Safflower		
3. Maize + Safflower sequential	1981-82	970	1160	190	722	9
	1982-83	1030	1200	170	648	8
	1983-84	1250	1400	150	578	7
	1984-85	1050	1200	150	627	6
				Average	641	8

*One irrigation of 50 mm was applied at flowering stage of crops.

$$\text{**Irrigation-use efficiency (IUE)} = \frac{\text{Addl. gross returns due to irrigation}}{\text{Depth of irrigation}}$$

Source: Srivastava et al. 1985, unpublished paper, presented at the National Seminar on Soil Conservation and Watershed Management, New Delhi, 17-18 September, 1985.

Table 4 presents the results of 3 irrigation regimes on grain yield of 2 sorghum cultivars grown at population densities of 6, 12, and 18 plants/m^2 with 3 levels of added fertilizer (55N:20P; 120N:30P; 200N:50P kg/ha) on an Alfisol in 1984. Only 435 mm rain fell between sowing and harvest. No rain fell for 30 days (10 August to 10 September) and so the dryland section did not receive any rainfall during that period. Of the 255 mm water supplied in 5 irrigations to the upper section, 167 mm reached the downstream sections. As expected for a season with prolonged midseason drought, this irrigation management system markedly increased sorghum grain yield (Table 4). The grain yield for all 3 population densities of cultivar SPH 221 for two higher fertilizer levels exceeded 4000 kg/ha in the upper section (ICRISAT, 1984). The cultivar SPV 351 yielded less and responded less to fertilizer. Response to fertilizer was lower in the middle section of the field than the irrigated section and there was statistically no significant difference in response to fertilizer levels for the dryland section (ICRISAT, 1984).

Table 4. Effect of three irrigation regimes on grain yield (kg ha^{-1}) of two sorghum cultivars grown at the three population densities with three levels of added fertilizer. Alfisol, ICRISAT Center, rainy season 1984.

Irrigation regime	Fertilizer level[1]	SPV351 Population (10^3 ha^{-1}) 60	120	180		SPH221 Population (10^3 ha^{-1}) 60	120	180
Irrigated	F_1	2500	2530	2710		2480	3220	3700
	F_2	3300	3540	3700		4200	4310	4700
	F_3	4400	3130	3260		4090	4620	5110
SE					±237			
Tail-end water from upper section	F_1	[illegible]	1930	3300		3000	3100	4030
	F_2	3660	3070	3640		3920	4580	4740
	F_3	3070	3200	3260		3760	4340	4390
SE					±322			
Dryland	F_1	2140	2570	2440		2700	2930	3090
	F_2	2260	2750	2700		3260	3310	3340
	F_3	2230	3040	2830		3140	2470	3440
SE					±392			

1. F_1 = 80 kg N and 20 kg P ha^{-1}.
F_2 = 120 kg N and 30 kg P ha^{-1}.
F_3 = 200 kg N and 50 kg P ha^{-1}.

Source: ICRISAT (1984).

Results of CURLI were compared with other management systems where the field is either fully irrigated, given supplemental irrigation, or managed as dryland. They showed an increase in grain yield of 61% in 1985 and 12% in 1986 for the CURLI compared with the dryland management system, whereas increase in grain yield (compared only in 1986) was 4% for supplemental irrigation (Sachan and Smith 1987). The water application efficiency (WAE) (Table 5) for CURLI was 9.2 kg mm^{-1} ha^{-1} in 1986, compared to 5.2 kg mm^{-1} ha^{-1} for supplemental irrigation. For the full irrigation management system, WAE was around 7 kg mm^{-1} ha^{-1} (Sachan and Smith 1987). Clearly the management system where limited application of irrigation water supports rainfall has advantages under the uncertain and uneven rainfall conditions that prevail in the SAT.

Table 5. Effect of irrigation on sorghum (CSH 6) yield (kg ha^{-1}) on different sections of the slope, Alfisols, rainy season, ICRISAT Center, 1985-86.

	Upper section[a] 0-20 m 1985	1986	Middle section 20-40 m 1985	1986	Lower section 40-60 m 1985	1986	Average 1985	1986	WAE[d] 1985	1986
Rainfed	1980	2230	1610	2110	1720	2140	1650	2150	-	-
Full irrigation[a]	3770	3400	3510	3300	2960	3450	3390	3383	6.9	7.5
Supplemental[b] irrigation	-	2400	-	2400	-	2200	-	2360	-	5.2
CURLI	3413	3000	2600	2710	2600	2110	2871	2636	12.1	9.2

[a] 5 irrigations, totaling 250 mm, were applied during 1985 and 4 irrigations, totaling 130 mm, during 1986 on the full irrigation and the CURLI upper section of the CURLI treatments.

[b] Supplemental irrigation treatment was included during 1986 only. One irrigation of 40 mm was applied.

[c] Upper section (130 kg N ha^{-1}, 10 plants m^{-2}); lower and middle section (80 kg N ha^{-1}, 8 plants m^{-2}).

[d] Water application efficiency = $\frac{\text{Increase in yield due to irrigation}}{\text{Depth of irrigation}}$

Source: Sachan and Smith (1987).

A.6

Economic Evaluation of Tank Irrigation Systems

The economic evaluation of tank irrigation has been carried out at ICRISAT, using a simulation model and a survey of 32 tanks and farms from two states (Andhra Pradesh and Maharashtra) in India. The simulation model consisted of several component modules for rainfall, runoff, soil-water-balance, yield response to irrigation, and tank-water-balance. In the model, it was assumed that a soybean-wheat double cropping sequence would be followed every year (Pandey, 1986). Simulations were run for three different seepage rates (0, 10, and 20 mm day^{-1}) for a test site on a Vertisol in Central India (Madhya Pradesh) where the long-term average annual rainfall is 1300 mm (ICRISAT 1984). Results obtained from the simulation, shown in Figure 3 as response surfaces approximated by quadratic polynomials, indicate that as seepage rate increases, optimal tank size increases while optimal size of the command area decreases. This is to be expected because an increase in catchment area and/or increase in tank size is required for storing a certain quantity of water as the seepage rate increases. The output of the simulation run at the seepage rate of 10 mm day^{-1} indicated that the response to change in the command area is determined by the average production of irrigated wheat. Since an increase in command area results in a reduction in the catchment area and hence a reduction in the amount of runoff generated, there will be a large reduction in the area irrigated in years of low rainfall. Therefore, the variability in area irrigated every year is likely to increase with increase in command area. For tank sizes of less than 200 ha mm, the response of economic returns to increasing tank size was steep for command areas up to 4.5 ha (Fig. 3). As the size of the tank increases, other factors, such as runoff volume and availability of irrigable land, become constraints (Pandey, 1986).

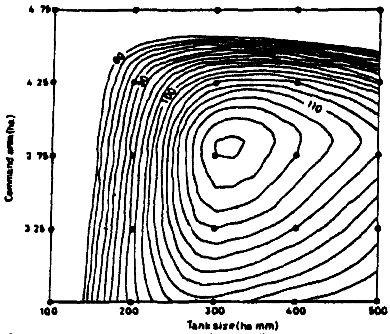

Figure 3 Economic return contours evaluated at the seepage rate of 10 mm day^{-1} Dots indicate experimental data, Figures on isoquant indicate '000 (i.e. thousand) Rupees

(Source: Pandey, S 1986 Ph D thesis University of New England, Armidale, NSW, Australia)

Assuming a rainy-season fallow followed by postrainy-season wheat as the baseline cropping pattern (used by the majority of farmers in the study areas), Pandey (1986) found that tanks are quite attractive for the soybean/wheat cropping pattern even at seepage rates as high as 20 mm day^{-1}. With the soybean/pigeonpea intercrop, the tank is attractive at seepage rates less than 10 mm day^{-1}. The seepage water would contribute to groundwater supplies but the extent of benefits is unknown.

The cost-benefit comparisons of various types of seepage controls (Pandey, 1986) indicated that although the benefits from seepage control are high, cost effective methods for controlling seepage are seemingly unavailable. Seepage control with currently available methods like sodium carbonate (0.4 kg/m^2) plus straw (0.2 kg/m^2), soil with cement (10:1) lining 15 cm thick silt and sodium carbonate (0.4 kg/m^2), or asphalt (4 l/m^2) were found in this study to be viable only if the seepage rate in the uncontrolled situation was greater than 20 mm day^{-1}.

From a survey of 32 tanks and farm data of two states (Andhra Pradesh and Maharashtra) in India, von Oppen and Rao (1987) have assessed the economic performance of irrigation tanks in SAT India. The districts selected for the survey in Andhra Pradesh are characterized by medium rainfall (about 700-800 mm) red soils (Alfisols), while most of the districts (e.g., Akola, Sholapur) chosen in Maharashtra have medium to low rainfall (600-700 mm) and deep and medium deep black soils (Vertisols). Rice is the main crop cultivated in most of the irrigable areas. In their study, it appears that the spatial distribution of tank irrigation is determined primarily by physical conditions, such as hard rock substratum, average humidity, postmonsoon rainfall, total rainfall, and low soil moisture-holding capacity. In some of the districts, rainfall significantly determines the percentage utilization of the command area actually irrigated. This study also indicates that tanks generally generate higher profits in Alfisol than in Vertisol areas. Furthermore, land values under tank irrigation are about 2.5 to 4 times those of drylands in the Alfisol areas, while there is not much difference in values of dryland and tank irrigated land in Vertisol areas.

Conclusion

We have presented in this paper the traditional tank irrigation system of SAT India and a system for runoff collection, storage, and use on Alfisol and Vertisol watersheds at ICRISAT Center. Research at ICRISAT has indicated that runoff collection and utilization is a profitable proposition, particularly on Alfisols. Further, conjunctive use of rainfall and limited irrigation, using water stored in tanks, has been found to be a good management practice to improve water-use efficiency in the region. Lastly, there is a need to develop cost-efficient seepage control techniques, especially for areas and soils having a moderate to large runoff potential. Simulation studies show that by comparison with a standard system using rainy-season fallow followed by postrainy-season wheat, tank irrigation of a cropping pattern of soybean and wheat is worthwhile even at seepage rates as high as 20 mm day^{-1}. For a soybean/pigeonpea intercrop system, tank irrigation may not be profitable at seepage rates greater than 10 mm day^{-1}.

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