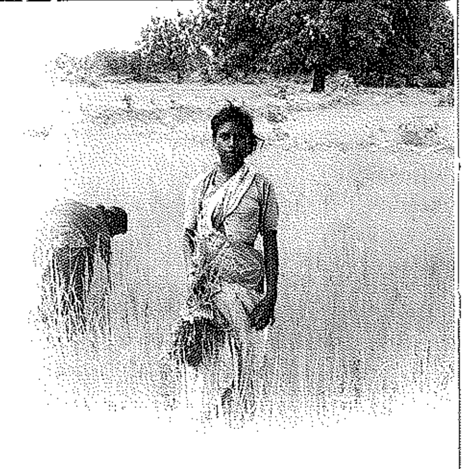

WATERSHED MANAGEMENT AS A BASIS FOR LAND DEVELOPMENT AND MANAGEMENT IN INDIA

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INTRODUCTION

Watershed management implies rational utilization of land and water resources for optimum and sustained production with the minimum of hazard to natural resources. It essentially relates to soil and water conservation in the watershed which means proper land use and the protection of land against all forms of deterioration and it also implies maintaining soil fertility, flood protection and sediment reduction and the increase of productivity from all land uses.

The problem of soil and water conservation in India is rather alarming. Recent surveys have shown that 58% of the agricultural land (80,000,000 ha.) 33% of the forest land (20,000,000 ha), 86% of the culturable waste land (15,000,000 ha), 95% of permanent pastures and other grazing lands (14,000,000 ha), 75% of the fallow lands (15,000,000 ha), 24% of land under trees and groves (1,00,000 ha) and 44% of the geographical area of India (145,000,000 ha), are subject to severe erosion (Anonymous, 1968). The degradation of the forest and pasture lands in river catchments, including 2,300,000 to 4,000,000 ha of gullied lands contribute to the disastrous floods and sediment yield that pose the greatest threats to the well-being and economy of India.

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For example, a survey of 21 reservoirs has indicated that they receive sediment at the rate of 8.51 ha m (100 $km^{-2} yr^{-1}$) as against the designed inflow of 3.02 ha m (100 $km^{-2} yr^{-1}$). This represents 282% more inflow of sediment than the designed inflow (Gupta, 1975).

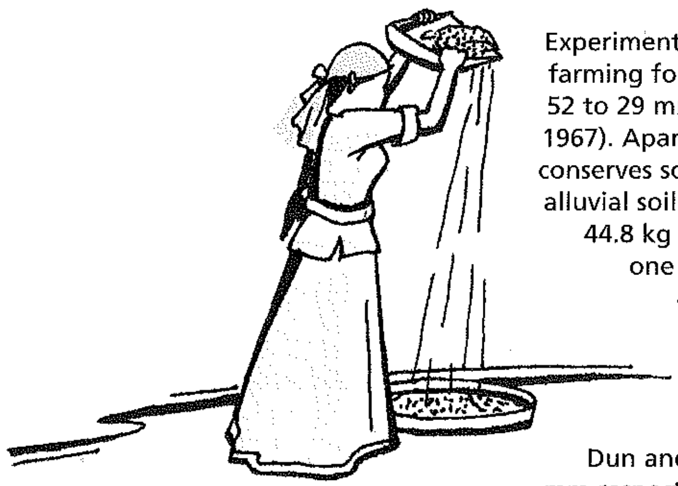
CONSERVING LAND AND WATER AND INCREASING PRODUCTION ON AGRICULTURAL LANDS

Contour cropping

It has been experimentally shown at Dehra Dun that contour cultivation reduces runoff and prevents soil erosion when compared with up and down cultivation (Tejwani, Gupta and Mathur, 1975). Contour farming is easy, simple and economical.

Table 1: Effect of contour cultivation on runoff and soil loss. Average of 4 years for Dhoolkot silty clay loam with 8% slope at Dehra Dun

	Up and down cultivation	Contour cultivation
Runoff (mm)	670	511
Runoff as percentage of rainfall	54.1	41.2
Soil loss (t ha^{-1})	28.5	19.3
Rainfall (mm)	1239 Crop - maize	



Experiments at Ootacumund have shown that by adopting contour farming for potato, cultivated on 25% slope, runoff was reduced from 52 to 29 mm and soil loss from 39.0 to 14.9 t ha^{-1} (Raghunath et al., 1967). Apart from conserving the water and soil, contour cultivation conserves soil fertility and increases crop yields. Contour cultivation on alluvial soil at 2.2% slope at Kanpur conserved 11.2 kg N, 10.2 kg P_2O_5, 44.8 kg k_2O, 557.4 kg CaO, 109.7 MgO and 74.0 kg ha^{-1} humus in one season alone. Contour cultivation also produced 440 and 4176 kg of sorghum (Sorghum vulgare) grain and stover respectively more than up and down cultivation. Thus every centimeter of rainwater conserved produced 44.8 and 422 kg of grain and stover respectively more than up and down cultivation (Bhatia and Chaudhary, 1977). Dehra Dun and Kanpur have an average annual rainfall of 1674 and 805 mm respectively, 80 to 85% of which is received in three months during southwest monsoon. It would thus appear that contour cultivation is effective both in low and high rainfall areas. However, in low rainfall areas contour cultivation not only conserves soil and moisture but the conserved soil moisture contributes to increased crop production. In high rainfall areas the major gain is reduction of soil erosion while conserved moisture may not benefit the crop, as soil moisture is not a limiting factor for crop yields.

Mechanical measures of erosion control on agricultural lands

Mechanical measures, which include contour bunded, grading bunding, and bench terracing on steep slopes are adopted to supplement the agronomical practices when the latter alone are not adequately effective.

At Dehra Dun, it has been observed that as a result of field bunding of an agricultural watershed (54.63 ha area), there was a 62% reduction in runoff amount and 40% reduction in the peak runoff rate (Rambabu et al., 1974).

At Dehra Dun, a bunded agricultural watershed of 12 ha had less runoff and peak discharge than another unbunded watershed of 2.94 ha (Bansal and Husenappa, 1977).

Table 2: Monthly rainfall, runoff, and peak discharge of agricultural watersheds at Dehra Dun

Rainfall Month, 1976	(mm)	Runoff (mm)	Peak discharge (Percentage of rainfall)	(mm/hr)
Bunded sub-catchment - (12.08 ha)				
July	527.5	90.1	17.1	39.7
August	606.5	134.1	22.1	26.2
September	131.5	1.6	1.2	1.0
Unbunded sub-catchment - (2.94 ha)				
July	527.5	144.4	27.4	47.5
August	606.5	271.4	44.8	53.1
September	131.5	20.5	15.6	23.1

Table 3: Effect of bunding on runoff, peak discharge, soil loss, and crop yield at Chandigarh. (Average of 6 years : 1972-1977)

	Unbunded	Bunded
Rainfall (mm)	764.3	764.3
Runoff (mm)	169.2	107.4
Runoff (%)	22.2	14.0
Annual peak discharge ($m^3 ha^{-1}$)	0.206	0.120
Soil loss ($t ha^{-1}$)	3.51	0.97
Maize yield ($kg ha^{-1}$)	1541	1699

Average of 5 years after excluding the yield of 1974

Similar results have been reported from Chandigarh, where bunding of agricultural land reduced runoff, peak discharge and soil loss, and on an average conserved 62 mm of rainfall and 2.34 t ha^{-1} yr^{-1} of soil (Sud et al., 1977) (Table 3).

The bunded area also gave 10.1% more yield than unbunded area.

At Agra, it was observed that field bunding of an agricultural watershed (22.3 ha) reduced the runoff by 45%. In addition to erosion control, the field bunding due to moisture conservation is reported to have increased grain and stover yields of pearl millet by 1.0 and 5.0 q ha^{-1} respectively (Anonymous, 1971 : 1978).

On steeply sloping and undulating lands, intensive farming can be practiced only with bench terracing. In rainfed areas bench terracing is recommended on slopes from 6 to 33. It is recommended for slopes of less than 6% for irrigated agriculture.

Investigations conducted in South India by Das et al. (1970) indicated that different lengths of bench terraces had no significant effect on runoff, soil loss and potato yield. However, terraces longer than 100 m had less soil moisture reserve than short length terraces. The runoff and soil loss on a 25% slope increased with an increase in the longitudinal terrace gradient from 0.15% to 0.84%. However, maximum runoff with 0.84% gradient was only 0.9% of the rainfall and soil loss was only 0.3 t ha^{-1}, both of which are negligible. The differences in potato yield from bench terraces of various grades were also not significant.

Peak rate of runoff

If appropriate measures are adopted for safe disposal of water runoff, its storage and recycling provide an opportunity for supplemental irrigation. The prediction of peak runoff rate and amount for design purposes for Ambala Siwaliks have been facilitated by the use of the modified rational formula :
q = CIA 0.73 (Erasmus and Bansal, 1965).

where q = runoff, ft^3 sec-1
C = runoff coefficient
I = rainfall intensity for duration equal to time of concentration (T_c), in hr^{-1}
A = Area of catchment, acres

The value of 'C' for different conditions in India is shown in Table 4.

Peak runoff rates are also estimated by the use of nomograms prepared on the basis of: (i) rational formula, (ii) Cook's method and (iii) Hydrologic soil cover complex method, for small watersheds up to 300 ha in area (Gupta et al., 1970). A comparison of experimental and predicted peak runoff rates has indicated that the

prediction based on the hydrological soil cover complex method was closely associated with the experimentally measured data (Gupta et al., 1969).

Runoff volume : Information on runoff volume is necessary for estimation of storage capacity and for designing structures for disposal of surplus water. Wasi Ullah and Rambabu (1970), established an empirical relation between peak runoff rate and the expected volume of runoff:

$$Q = 0.14A^{0.33}\,q$$

Where *Q* = Volume of runoff, ha m
A =Area of watershed, ha
q = Peak discharge, $m^3 s^{-1}$

Based on the hydrologic soil cover complex method, weekly yield of runoff for 15 stations located in different agro-ecological regions of India were computed for different levels of probabilities (Gupta et al., 1971). An equation and nomograph have been developed for estimation of annual runoff (cm) for the Nilgiri hills in South India for watersheds of 1 to 400 km^2, different shapes, drainage densities, relief and temperature (Das et al., 1971).

$$Q = \frac{1.911\,(P)^{1.44}}{Tm^{1.34}\,A^{0.0613}}$$

Table 4: Value of C for Rational Formula

	Land use		
	Cultivated	Pasture	Forest
General (Gupta et al., 1970) With above average infiltration rates usually sand or gravel	0.29	0.15	0.10
With average infiltration rates. No clay pans loam and similar soils	0.40	0.35	0.30
With below average infiltration rates; heavy clay soils or soils with clay pan impervious rock	0.50	0.45	0.40
Specific for Doon Valley (Gupta *et al.*, (1969) Agricultural small watersheds with benches	0.18 to 0.25 Average 0.22	–	–
Forest watersheds	–	–	0.22 to 0.28 Average 0.25
Chandigarh (Erasmus and Bansal, 1965) Unculturable hilly lands	0.70		

Where Q = Annual runoff, cm
T_m = Mean annual temperature, °C
A = Catchment area, km^2
P = Annual rainfall, cm

Runoff storage: The losses due to seepage and evaporation from the storage tanks should be minimized. Seepage losses are generally more in alluvial soils. Annual losses due to seepage and evaporation have been estimated to be 1.8 to 4.0 m of water for Dehra Dun and Chandigarh regions of northern India (Agnihotri et al., 1971; Erasmus et al., 1971; Bansal and Husenappa, 1977). Seepage losses may be slight from dugout ponds in vertisols. Simple and economical techniques for storage of water in farm ponds are not yet available. With high demand for supplemental irrigation, high investments for lining the ponds with bricks or concrete may be justified. For example, Sastri et al., (1975) observed in the semi-arid regions of Bellary that supplementary application of 5 cm of harvested water increased the sorghum grain yield from 22 to 29 t ha^{-1} and stover yield from 52 to 57 t ha^{-1}. Similar investigations for wheat in Dehra Dun showed 57% increase in grain yield (Singh and Bhusan, 1977).

Table 5: Yield (kg ha^{-1}) of wheat as influenced by supplemental irrigation at Dehra Dun(Singh and Bhushan, 1977)

	1974 - 1975		1975 - 1976		1976 - 1977		Average	
Treatment	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Supplemental irrigation								
Control	3776	7140	1249	2925	1110	5366	2045	5144
Presowing irrigation (5 cm)	4540	7061	2088	4889	2981	5741	3202	5897
Irrigation at crown root initiation (5 cm)	4671	7140	1999	4659	3039	3498	3236	5099
Presowing irrigation + irrigationat crown) root initiation (10 cm	4660	7240	2955	6940	4078	8535	3898	7572
SEm(±)	146	566	163	379	192	199		
CD at 5%	439	-	564	1309	863	688		

CONSERVING LAND AND WATER AND INCREASING PRODUCTION FROM LANDS NOT SUITED FOR AGRICULTURE

Land capability classes V, VI, VII and VIII have limitations of slope, erosion, stoniness, rockiness, shallow soils, wetness, flooding, climate, etc. which make them generally unsuited for agricultural crops and limit their use largely to pastures, forests, wildlife and cover. The importance of vegetation cover on soil and water loss is evident from the data presented in Table 6.

Table 6: Effect of vegetative cover on runoff and soil loss (Tejwani et al., 1975)

	Center		
	Dehra Dun	Agra	Kota
Soil	Inceptisol	Inceptisol	Vertisol
Slope (per cent)	8	2	1
Runoff (% of rainfall)			
Cultivated fallow	35.9	NO[a]	17.3
Grass cover	2.5	17.3	10.7
Arable rowcrop (maize/sorghum)	41.2[b]	18.7[c]	15.7[c]
Soil loss (t ha^{-1})			
Cultivated fallow	44.0	NO[a]	3.7
Grass cover	1.3	2.1	0.4
Arable rowcrop (maize/sorghum)	19.3[b]	3.1[c]	2.4[c]

[a]NO = Not observed [b] maize [c] sorghum

Trees play a multifarious role in effective utilization of precipitation. By intercepting rainfall, trees reduce the raindrop impact by dissipating the energy. Tejwani et al. (1975) reported that as much as 14 to 20% rainfall might be intercepted by Acacia spp. and Shorea robusta. Depending on the canopy structure some species may intercept even more (Table 7). For example, Acacia nilotica can intercept about 60% more rainfall than Dalbergia sissoo. The interception increases with the increase in canopy cover and with age (Singh and Prajapati, 1974).

Table 7: Effect of tree species and their age on interception of rainfall. These observations were made at Agra, in northern India (Singh and Prajapati, 1974)

	Rainfall Intercepted (%)	
Year	Acacia nilotica	Dalbergia sissoo
1969	26.4	11.3
1970	12.8	5.1
1972	17.4	12.9
1973	20.4	17.1
1974	28.1	19.6
Average	21.0	13.2

Closure of areas to biotic influences

Regrowth of natural flora on eroded lands constitute hardy annual and unpalatable grasses rather than the desirable climax associations that normally exist in the prevailing soil-climatic environments. For example, in the Gujarat ravines Aristida spp.I and Themeda triandra colonize the eroded lands in place of the desirable Dichanthium cemcjris association (Tejwani et al. 1961). Investigations on ravine lands of Vasad and Kota indicated that protection grazing resulted in a gradual replacement of Aristida funiculata and Themeda triandra by Apluda mutica, Erempogon faveolatus, Heteropogon contortus, Dicanthium annulatum, and Cenchrus spp. As a result, the runoff and soil loss progressively decreased with the improvement of the natural vegetation and the yield of desirable grass species increased (Tejwani et al., 1961; Singh 1971, 1972; Singh and Verma, 1971). the closure to biotic interference may also lead to regeneration of trees adapted for those environments (Table 8).

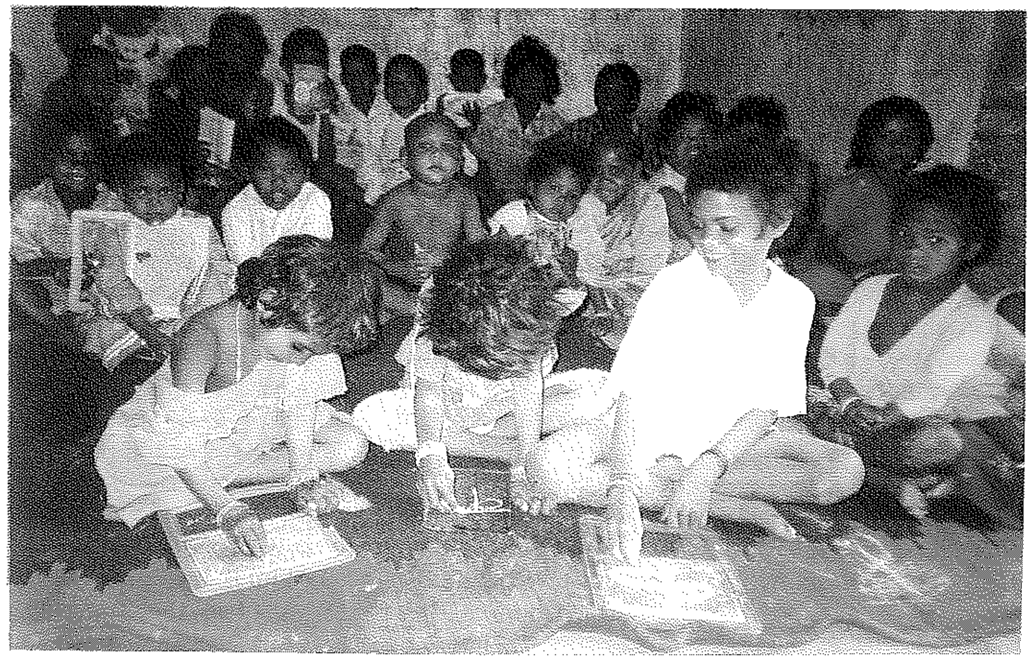


Table 8: Effect of closure on regeneration of tree species at Vasad, Gujarat (Pradhan and Vasava, 1974)

Tree species	Tree population in the year			
	1960-1961	1962-1963	1965-1966	1973-1974
Acacia nilotica	49	55	50	30
Acacia eburnea	Nil	4	20	11
Acacia senegal	23	42	81	259
Azadirachta indica	20	20	80	133
Holoptelia integrifolia	Nil	6	18	69
Prosopis spicigcra	60	74	98	88
Cassia auriculata	57	44	63	44
Cymnosporea montana	3	6	6	64
Zizyphus species	101	98	321	331
Total	313	349	737	1028
Percentage increase over 1960-1961	-	11	135	228

With closure to grazing the number of trees and shrubs increased from 1960-1961 (year of closure) to 1973-1974. Among the tree species Azadirach ta indica, prosopis spicigera, and Heloptelia integrifolia increased consistently in number. Pradhan (1977) reported that in 1973-1974 there were 6563 trees of more than 50 m girth at breast height, stocking of 80 trees ha^{-1}.

Similar results have been obtained at Agra where within a period of ten years of closure edible variety grasses increased from 44.6% to 48.5% and the non-edible decreased from 42.9 to 30.1% (Prajapati, 1974).

Fodder-Fuel Plantations

In India as in other developing countries, the fodder fuel needs are increasing rapidly. In this connection an experiment was initiated at Vasad in 1960-1961 to investigate if fodder and fuel-cum-timber trees species (*Acacia nilotica*) could be grown together without reduction in the yield of fodder.

Results presented in Table 9 indicate that there was no difference in the forage yields of Cenchrus ciliaris or Dichanthium annulatum, when grown as monoculture or in association with a tree species. Moreover, the mean forage yield increased by 101% in 1964-1965 over the yield obtained in 1960-1961. This increase was partly due to the effect of closure and protection of the area and partly due to the rejuvenation of pasture species. Fuel-cum-fodder plots that were planted to A. nilotica did not differ in forage yield from the plots of pure grass during the initial 6 years since the shading by tree species was less during this initial period. Prajapati and Joshie (1977) reported a yield potential of 2 t ha^{-1} yr^{-1} of fuel in a twenty-year-old plantation of Acacia nilotica which was grown as a protective forest on black soil in ravines in the semi-arid region of Kota. It has been observed at Dehra Dun (Mathur and Joshie, 1972) that a yield potential of about 11 t ha^{-1} yr^{-1} of grass Chrysopogon fulvus (at 0.75 m x 0.75 m) and 97 trees ha^{-1} of fuel from Dalbergia sissoo tree (at 9.14 m x 9.14 m) is attainable when grown on Class V and VI waste lands in Doon Valley. In the Siwalik hills, the estimated yield of a mixed plantation of Eucalyptus hybrid for fuel and Eulaliopis binata (a fodder and industrial grass used for rope and paper making) was standing fuel stock at 55.35 t ha^{-1} and an average air dry grass yield of 5.57 t ha^{-1} yr^{-1} was obtained in 4 yr. When Eulalipsis binata was grown alone it gave an average yield of 14.49 t ha^{-1} yr^{-1} of air dry grass in 4 years. Such high yields were obtained by planting tall plants of Eucalyptus hybrid (average initial height of seedling 2.74 m) making tie ridges 15 cm high and at intervals of 2m x 2m (Mishra and Sud, 1978).

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Table 9: Forage (green) yield (kg ha^{-1}) from fodder-fuel plantation at Vasad (Dayal, 1974)

Treatment	Year							
	1960-1961	1961-1962	1962-1963	1963-1964	1964-1965	1965-1966	1966-1967	Average
Pure grass block of Cenchxus Cillaris	2790	4190	6135	4919	6318	5192	5224	4965
Pure grass block of Dicanthium-annulatum	3948	3636	5873	4697	7277	5585	6193	5316
Fuel-cum-grass block with C. Ciliaris	3375	4378	3314	6423	6754	4887	4938	4867
Fuel-cum-grass block with D. annulatum	3227	4277	5656	5493	6505	5827	5945	5276
Average Percentage increase in yield over 1960-1961	–	28.0	68.6	72.8	101.0	61.8	68.2	

EVALUATION OF SOIL AND WATER CONSERVATION MEASURES

Peak rate of runoff and sediment control

Patil and Sohoni (1969) reported that contour bunding increased yield of crops in semi-arid tropical rainfed areas of Maharashtra state. Since the runoff losses decreased, there was a trend of increasing ground water level in wells.

Investigation conducted on a 2 ha watershed in the Shiwalik ranges of Chandigarh showed that the total runoff and peak rate of runoff were reduced by 60.4% and 61.1% respectively as a result of the following soil and water conservation measures: (i) construction of earthen debris basins, (ii) earthen poundage banks, (iii) staggered contour trenches and (iv) planting with Eucalyptus hybrid and Acacia catechu (Kaushal et al., 1975). Similar results have been reported from Dehra Dun where a reduction of 28% in runoff and 73% in peak rate of flow were achieved by reforestation of a small watershed (Mathur et al, 1976). Another series of experiments conducted at Chandigarh indicated that whereas soil and water conservation practices of contour trenching and afforestation reduced the runoff by 41%, annual burning, over-grazing and cutting of trees plus over-grazing increased runoff by 69%, 88%, and 71% respectively (Gupta et al. 1974).

Studies conducted at Chandigarh in the Siwalik region (Mishra et al. 1977) on a watershed of 20 ha showed that with appropriate soil and water conservation measures the rate of sediment was reduced from 80 t ha^{-1} yr^{-1} to 6 to 7 t ha^{-1} yr^{-1} within four years. Thereafter the rate of sediment has gradually decreased to only 2.9 t ha^{-1} yr^{-1}. Runoff was reduced from 23.5 in 1964 to about 10%. Peak rate of discharge was reduced from 0.065 in 1964 to 0.034 m^3 sec^{-1} in 1977. At Vasad, it was seen that when 1422 tons of sediment from an untreated catchment of 67 ha were delivered to a treated catchment of 72 ha, all the sediment was either contained or retained in the latter as a result of soil and water conservation measures(Nema and Kamanwar, 1976). Jalote and Malik (1974) reported complete stabilization of 270 ha of severely eroded land by afforestation in the catchment of Gomti the river.

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The results of the treatment of some of the large reservoir catchments have been very encouraging. For example, in 16 sub-watersheds of the Damodar Valley, the sediment load has been reduced from 0.30 to 0.019 ha m km^{-2}. In five major reservoir catchments (Bhakra, Machkund, Panchet, Maithon, and Hirakud), treatment resulted in a decrease in the sediment load by 16.3 to 42% (Patnaik, 1977). Pathak (1974) reported that sediment load of 0.18 ha m km-2 was reduced to 0.15 ha m km^{-2} when 770 ha (0.25% of the total area) of agricultural land were treated with soil and water conservation measures and 16,000 ha (5.2% of the total area) were afforested in the Ram Ganga catchment.

Increase in production

While sediment control and water conservation is necessary for management of reservoirs, it is essential that the production of food, fiber, fuel, timber, etc. be also sustained. The Indian experience reinforces the belief that soil and water conservation measures are economical in the long run. The beneficial effects to soil moisture conservation by construction of bunds and leveling of land have been extensively demonstrated in the alluvial plains of UP where 35%, 63 and 98% increase in crop yield was obtained by bunding, leveling, and bunding-cum-leveling respectively (Khan, 1962). Bunding increased yields of Setaria, cotton and sorghum by 18, 11, and 17% in large field trials in Madras State (Kanitkar et. al., 1960). As a result of contour bunding, Tamhane et al. (1967) reported 25% increase in crop yield in the Maharashtra state; 35.6% and 25.4% increase in yield of sorghum and pearl millet respectively in Tamilnadu; 20% increase in yield of groundnut in Tamilnadu; 21.4%, 15.0%, 19.7%, and 13.9% increase in yield of wheat, gram, maize, and pearl millet respectively in Punjab state.

Afforestation trials carried out in the ravines at Vasad have shown that Dendrocalamus strictus (bamboo), Tectonia grandis (teak), Dalbergia sissoo (shisham) and Eucalyptus camaldulensis are very promising (Table 10).

Table 10: Net annual income from various tree species at Vasad

Species	Rotation (years)	Cost of production	Gross income	Net annual income ($Rsha^{-1}$)	Remarks
Dalbergia sissoo[a]		30	3380	23356 666	
Dendrocalamus strictus[a]	30	3380	44475	1370	
Eucalyptus camaldulensis[a] (3 rotations)	24	12824	13478	444	
Tectonia gradis	15	1300	17500	1080	For poles

[a]Singh 1972; bDayal et al., 1974

Aggarwal et al., 1977, carried out an economic evaluation of 17 years old fodder-fuel plantations of Chrysopogan fulvus and Eulaliopsis binata grasses and Dalbergia sissoo and Acacia catechu trees. The results presented in Table 11 indicate that Eulaliopsis binata grass with Acacia catechu produced the highest gross income Rs. 35498 per hectare). The association of Chrosopogon fulvus grass with and without trees produced net income of Rs. 9110 (mean of 7 Chrysopogon treatments) and Rs. 11447 per hectare respectively. Similarly growing Chrysopogon fulvus with Dalbergia sissoo and Acacia catechu fetched an income of Rs. 91941 (mean of 4 D. sissoo treatments) and Rs. 8670 (mean of 3 A. catechu treatments) per hectare respectively. Spacing of the trees did not have any significant effect on the growth or yield of Chrysopogon fulvus grass. On an average Dalbergia sissoo and Acacia catechu produced an income of Rs. 4077 (men of 4 D. sissoo treatments) and Rs. 1202 (mean of 4 A. catechu treatments) and Rs. 1202 (mean of 4 A. catechu treatments) per hectare respectively. Dalbergia sissoo at 9.15 m x 9.15 m spacing and Acacia catechu at a spacing of 4.55 m x 4.55 m resulted in the maximum income of Rs. 8684 and Rs. 2652 per hectare respectively. The data indicated that for fuel purposes, trees at a closer spacing of 4.55 m x 4.55 m or 9.15 m x 9.15 m would be more profitable than when grown at wider spacing. The benefit: cost (b:c) ratio was more than unity for all treatments investigated. From these b:c ratios, it was inferred that Dalbergia sissoo at 9.15 m x 9.15 m + Chrysopogon fulvus for fuel and fodder; Chrysopogon fulvus alone for fodder, and Acacia catechu and Eulaliopsis binata for fuel and fiber requirement are economically justified to be grown in the wastelands of the Doon Valley.

WATERSHED MANAGEMENT BEYOND THE YEAR 2000

While it is very heartening that there is an on going and active soil and water conservation programme on watershed basis in India and a strong and stable infrastructure for executing it, if one looks at the year 2000 one feels concerned and staggered by the terrific pressures which will exerted on the land-water-plant systems by the human and cattle population in India. For example, human population, which increased from 361,000,000 in 1951 to 548,000,000 in 1971 will be 931,000,000 by the year 2000; the net area per capita which decreased from 0.9 ha in 1951 to 0.6 ha in 1971, will decrease to 0. 35 ha. Though the cultivated area increased from 119,000,000 ha in 1951 to 140,000,000 ha in 1971, yet the per capita availability of land for production of food, fiber and other needs shrank from 0.33 to 0.292 ha and this will further decrease to 0.175 ha by the year 2000 (Anonymous, 1976a; 1976b). To the growing pressure of human population on the available land resources has to be added the growing pressure of livestock population. The latter increased from 264,400,000 cattle units in 1951 to 312,200,000 cattle units in 1972. This dense population pressure on land result in cultivation of marginal lands and destruction of forests and thus aggravates the present rates of the degradation of the production base. Already 145,000,000 ha of land representing 44% of the geographical area of India are subject to severe erosion. If development costs were fixed from the sixth plan onwards and provisions were made for an increase of 3,500,000 ha in every Five Year Plan, it would be possible to implement soil and water conservation measures on some 107,000,000 ha of land by the end of the Tenth Five Year Plan in the year 2003 (Table 12).

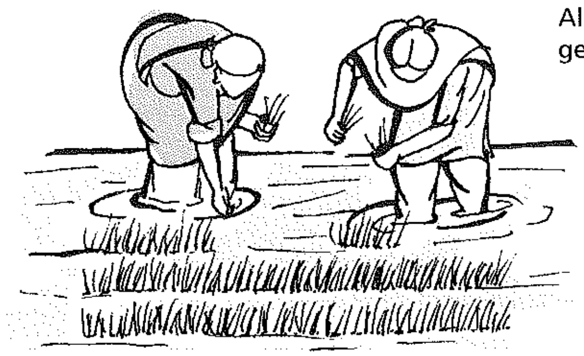

Table 12: Projection of soil and water conservation development programme

Period	Achievement of development programme (million ha)	Expenditure (million Rs)	Remarks
Total up to the end of Fifth Plan (31.3.78)	21.9	5081	
Projection of Development Programme			
Sixth plan (1978-1983)	9.9	4660	
Seventh plan (1983-1988)	13.5	6345	At the price level of the Sixth Plan
Eighth plan (1988-1993)	17.0	7990	As above
Ninth plan (1993-1998)	20.5	9635	As above
Tenth plan (1998-2003)	24.0	11280	As above
Total up to 2003	106.8	44991	

By the year 2003 about 37,000,000 ha of land which are now in need of conservation measures will still remain to be treated. Furthermore, the lands that have been and are being treated now will be in need of re-treatment. To achieve this level of development it will be necessary to train sufficient manpower for these purposes (Table 13).

Table 13: Projection of need of trained manpower

Period	Officers	Assistants
	Dehra Dun and Ootacamund Centres	Bellary, Kota, Ootacamund, and Hazaribagh Centres
Total manpower trained up to the end of fifth plan (31.378)	1076	3494
Projection of training needs		
Sixth plan (1978-1983)	2050	10250
Seventh plan (1983-1988)	2800	14000
Eighth plan (1988-1993)	3500	17500
Ninth plan (1993-1998)	4200	21000
Tenth plan (1998-2003)	4900	24500

It is essential to plan for training the manpower in advance if the programmes of soil and water conservation are to succeed.

Table 11: Economic evaluation of fodder fuel plantation at Dehra Dun (Aggarwal,et. al., 1977)

Grass	Tree	Tree	Total of establishment and maintenance cost for 17 years (Rs/ha)	Summed up value of income from grass (Rs/ha) for 17 years (Rs/ha)	Total income from trees for 17 years (Rs/ha)	Benefit : Cost ratio
C. fulvus	–		3796	11447	–	3.015
C. fulvus	D. sissoo	4.55m x 4.55m	11136	8941	2711	1.044
C. fulvus	D. sissoo	9.15m x 9.15m	6835	10089	8684	2.746
C. fulvus	D. sissoo	13.75m x 13.75m	5518	9378	2638	2.177
C. fulvus	D. sissoo	18.30m x 18.30m	4657	9355	2275	2.497
E. fulvus	A. catechu	4.55m x 4.55m	11136	35498	2652	3.425
C. fulvus	A. catechu	9.15m x 9.15m	6835	8657	1140	1.433
C. fulvus	A. catechu	13.75m x 13.75m	5518	8328	649	1.629
C. fulvus	A. catechu	18.30m x 18.30m	4657	9026	367	2.016

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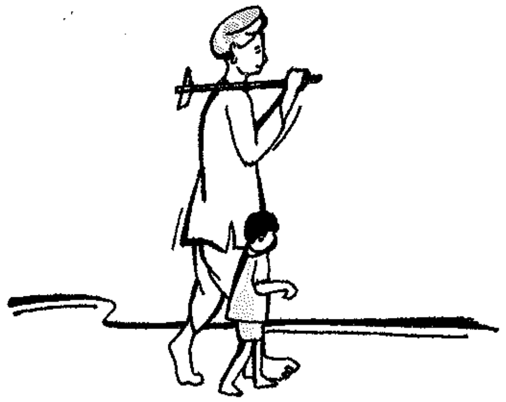
APPENDIX I: Vernacular names and their english equivalents

Jowar	Sorghum vulgare
Bajra	Pennisetum typhoides
Rabi	Crop season after south west monsoon in India; crops grown during October-April season
Kharif	Crop season during south west monsoon in India; crops grown during June-October season
Bund	Terrace
Bunding	Terracing



CATALYZING VOLUNTARY PARTICIPATION OF FARMERS – INTEGRATED WATERSHED MANAGEMENT IN A DRYLAND FARMING SYSTEMS

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INTRODUCTION

It is now universally recognised that integrated watershed management is the key to conservation and efficient utilisation of natural resources of soil and water, more so, in rainfed agriculture where water is the foremost limiting factor to upgrading productivity. Apart from moisture stress to crops, mismanagement of rainwater also entails serious land degradation, converting vast areas across the country into wastelands. It is a paradox that rainwater, the most vital resource for crop production in drylands, becomes a dominant factor (as runoff) of land degradation to the extent that once productive lands are converted into uncultivable wastes (Singh, 1997a).

RAINFED AGRO ECO-SYSTEM – THE SCENARIO

Natural resources and production system

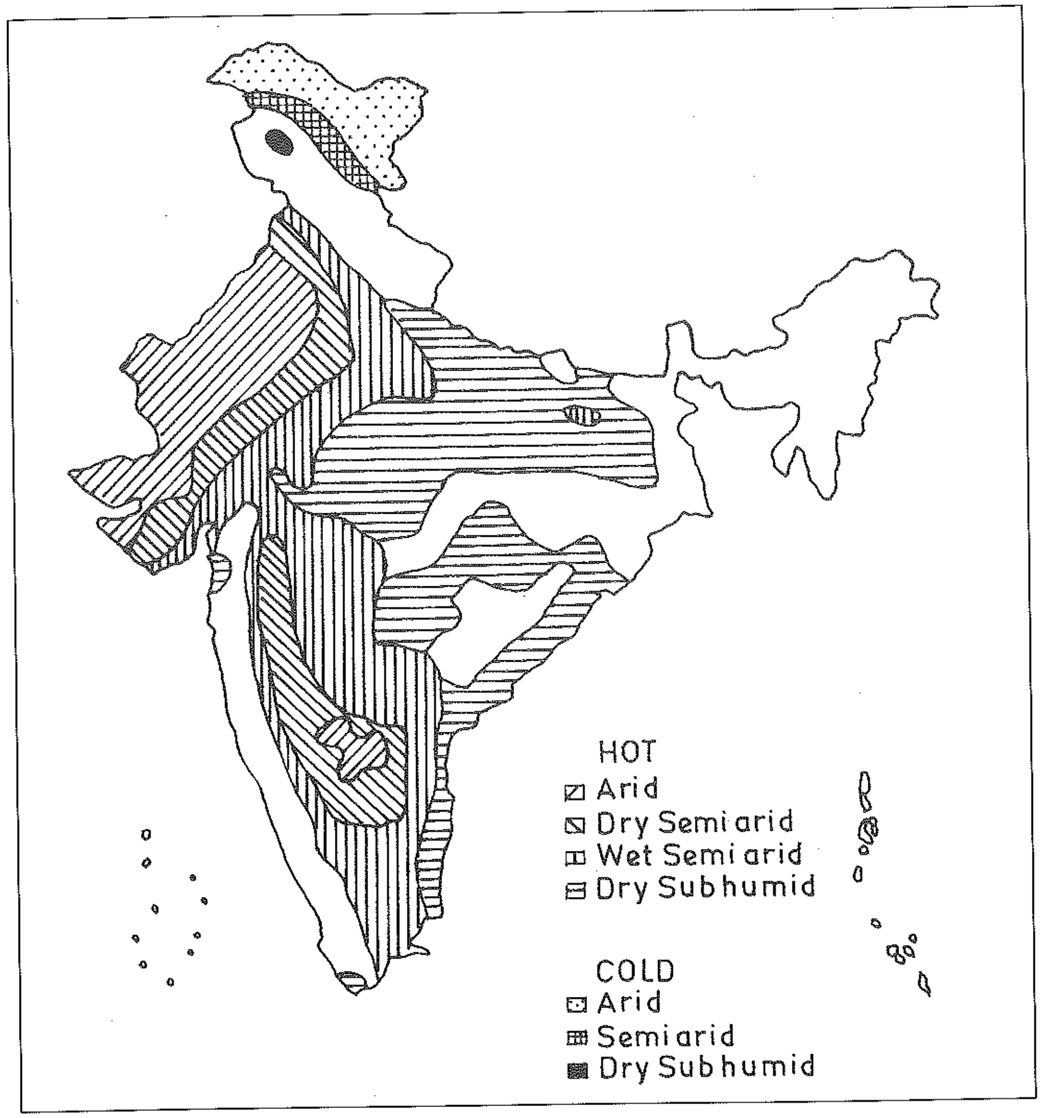
In the absence or inadequacy of water for irrigation, rainfed farming is practised in nearly 80% of the arable area of the world. The crop yields in these lands, thus, largely or entirely depend on the growing season rainfall plus water stored in the soil profile.

Rainfed agriculture in India extends over 97 million ha and constitutes nearly 67% of the net cultivated area. The National Commission on Agriculture in 1976 predicted that even when the full irrigation potential is tapped by 2013 AD, over 50% of the arable land will continue to remain rainfed in the foreseeable future. Presently 95% area under coarse cereals, 91% under pulses, 80per cent under oilseeds, 65% under cotton and 53% under rice is rainfed (GOI, 1994). Two-thirds of livestock live in these areas with small ruminants (sheep and goat) predominating.

The rainfed agricultural area in the country can be broadly classified into (i) arid, (ii) dry semi-arid, (iii) wet semi-arid, and (iv) dry sub-humid (Fig. 1). Some details are:

Climatic region	Geographical area (per cent)	Soils	Rainfall	Growing period (days)
Arid	19.6 (Sandy soils)	Aridisols	<500	75
Dry semi-arid	12.0	Light sandy loams and medium black soils (Vertic)	500-700	75-200
Wet semi-arid	25.9	Alfisols and Vertisols	700-1100	100-120
Dry sub-humid	21.0	Vertic, Vertisols and Alfisols	1100-1500	120-180 (possibility of second crop on residual moisture)

Figure 1: Geographical distribution of rainfed eco-system in India



Socio-economic issues

In the agro-ecological perspective, low and irregular rainfall and recurring droughts characterise the rainfed agro-eco system in India. In the absence of appropriate management of rainwater, low crop yields and even complete crop failures have become a recurring feature in these areas. The inhabitants, thus, are at a great disadvantage ecologically and socio-economically and are often driven to a state of despondency.

Many small holders appear to have resigned to living at or below the poverty line. The scenario has gone from bad to worse in some situations due to natural resource constraints on one hand and land abuse, on the other. People in their quest for means to meet their priorities and obligations are driven to look at what is available today disregarding the future and posterity. Extending cultivation to marginal/sub-marginal lands, overgrazing of village commons (Common Property Resources: CPRs), and indiscriminate cutting of vegetation for fodder/fuel are obviously the easiest of options. Subsistence farming has thus been in vogue to eke out livelihoods on a fragile resource base accelerating the process of land

degradation in many areas. If the cycle goes on without suitable interventions the process may no longer be reversible. The production system in vogue is thus, not sustainable (Singh, 1997a).

Cultivation of lands which should not be under plough has been one of the foremost factors of land degradation in arid and semi-arid regions. One of the many advantages of adopting watershed approach is the use of land as per land capability. The yields reduce drastically if the land is used otherwise (Table 1).

Table 1: Reduction (per cent) in yield of sorghum and pigeon pea on different lands with varying capability (mean of 3 years).

Land capability class	Reduction (per cent) from that obtained with class II land		
	Sorghum grain	Seed cotton	Pigeon pea grain
III	18	33	67
IV	35	46	86

Rainfall: 840 mm; Soil: Vertisol and associated soils.
Source: Annual Reports of AICRPDA Centre at Akola.

Over-grazing of village commons, has become a way of life. Once rich grazing lands now are a pathetic sight with hardly anything to graze on. Apart from resulting in degradation of pasture lands, uncontrolled grazing has come to stay as a formidable barrier against developing permanent vegetal resources of trees and grasses so vital not only for meeting the gap in forage supply to sustain and upgrade the livestock husbandry but also for control of land degradation and enhancement of environment. Rural communities therefore, need to be mobilised to appreciate this grave scenario and develop a new social order to ensure sustainable land use (Singh, 1997b).

The scenario described above despite the vigorous developmental efforts being pursued for the last three decades, is indeed alarming. Before discussing the strategy for R&D efforts during the next two decades, it is relevant to take stock of the past technology transfer efforts and constraints and strengths of the existing R&D scenario in the country.

CONSTRAINTS AND OPPORTUNITIES IN THE ADOPTION OF TECHNOLOGIES FOR WATERSHED MANAGEMENT IN RAINFED AREAS

Past technology transfer efforts

The extension model successfully applied (beginning of the 1960s) in irrigated areas of India was essentially based on a demonstration approach. The National Demonstration Programme coupled with the Training and Visiting System (T&V) produced dramatic results: the instant adoption of the technology package over large areas in high-capacity irrigated regions. This model, however, failed to produce encouraging results in risk-prone and resource-poor dryland areas. Pilot projects in dryland farming were initiated in the early 70s together with the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in many locations. Later in the 80s and early 90s, 46 model watersheds were developed by AICRPDA and Central Soil and Water Conservation Research and Training Institute (CSWCR&TI), Dehradun. During the project period the impact was substantial and crop yields increased dramatically (Table 2).

Table 2: Productivity of dryland crops in some model watersheds

Crop	Yield (q ha-1)				
	1983-84	1984-85	1985-86	1986-87	1987-88
Sorghum (10)	6.63	6.83	9.09	10.08	17.08
Greengram (11)	5.80	2.62	5.74	4.07	5.17
Groundnut (10)	4.14	5.07	9.81	9.81	11.94

Figures in parenthesis indicate number of watersheds for calculating the yield.

Subsequently both these major interventions (barring 3-4 efforts) have failed to make any discernible impact on adoption of technologies by the farmers even in the adjoining villages. Farmers were interested in receiving free inputs and reverted to their former practices once the programme was withdrawn.

Even the benefits of simple techniques that do not need cash input have not been effectively demonstrated to the farmers through on-farm research. A couple of cases in point are:

- Loppings of plants like Glyricidia and Leucaena when spread between the crop rows after planting as land cover can reduce runoff, improve water intake, suppress weed growth and control evaporation. Incorporation of this material in soil after 30-50 DAS (Days after Sowing) depending upon canopy cover, can build up soil organic matter. Leucaena can be raised on field boundaries or in other agroforestry systems and on wastelands. Thus, a multitude of benefits accrue from a single technology, yet the adoption is negligible (Singh and Subba Reddy, 1998).
- Composting is an old practice being recommended in India since the 60s. Yet it has not been widely adopted. Results reporting use of FYM @ 10-15 t/ha for maintaining soil fertility and increasing crop yields are frequently appearing in scientific literature. Is it feasible for dryland farmers to apply such large quantities of FYM? This question has not been looked into by the researchers. But this gap can be bridged. Composting of organic wastes (including animal unpalatable weeds) with animal excreta in 4:1 or 5:1 ratio can solve this limitation. In this manner, 1 tonne of FYM is converted into 5 tonnes of compost which a dryland farmer can afford to apply. Moreover, such composting is a novel approach to put in place residue and waste recycling, so much warranted for maintenance and upgrading soil quality for plant production (Singh et al., 1998) in drylands.

The setbacks described above are analysed as follows:

Limitations and constraints

A. Bio-physical

- **Degraded natural resource base**
  - Erosion hazards and reservoir siltation
  - Flooding and waterlogging
  - Alkalinity and salinity
  - Mine-spoils
  - Shifting cultivation and cropping
  - Cultivation on marginal lands
  - Uncontrolled grazing

The soil loss from the sub-continent was estimated at 5333 million tons per annum. Out of this 1600 million tonnes was permanently lost in the sea. The average soil loss was estimated as 16 t/ha both from mild and higher slopes. Along with soil, plant nutrients to the extent of 8.4 million tons of NPK are also lost each year.

- **Inherent poor soil fertility**
  Soils are very poor in organic matter due to temperature mediated fast oxidation rate. Mostly, areas are monocropped and virtually negligible or no amount of residue is recycled back to the soil. Inappropriate tillage practices further aggravate the oxidation of organic matter.
- **Low and erratic rainfall, droughts**
  Rainfall is erratic and in many areas it is low. About 80% of the rainfall is received during the south-west monsoon period (June to September/October) in most parts of India. The mid season intermittent dry spells occur mostly during the month of August when the crops are in their critical stages of growth. The prediction of rainfall with high reliability is still a limitation.
- **Shallow soils and low water holding capacity**
  Water holding capacity in many areas is limited both by soil depth and texture.
- **Sparse vegetal cover**
  Due to low rainfall and biotic interference, the land cover is sparse limiting the opportunities for nutrient recycling on one hand and conservation of soil (against degradation), on the other.
- **Poor rainwater management**
  Many a times droughts and floods occur in different parts of the country simultaneously. Efficient watershed management can help resolve this paradox to a large extent.

B. Socio-economic and infrastructural

- **Poor socio-economic status of people**
  Farmers in rainfed areas are very poor and live virtually below the economic threshold level. This results in low purchasing power. Consequently, they cannot afford to use the desired inputs.
- **Low literacy levels and resistance to change from traditional system**
  Because of low literacy level, it is difficult to motivate the farmers for adopting new technology and change their mind set.
- **Remote locations**
  Due to vastness of the rainfed region, some areas are very remotely located and hence accessibility is difficult. This limits the technology transfer process.
- **Socio-political conflicts**
  Socio-political and revenue related conflicts among different sections of the rural community brings about another set of problems that come in the way of adoption of improved technologies.
- **Inadequate credit facilities**
  Despite great strides in the banking systems, co-operatives and other credit related financial institutions, the role of village moneylenders still prevails. In addition, due to poor risk bearing ability, lack of knowledge and complicated administrative procedures, the farmers still hesitate to apply for agricultural credit. The initiative for establishment of Lead/Rural banks could not benefit this target group to the desired extent.

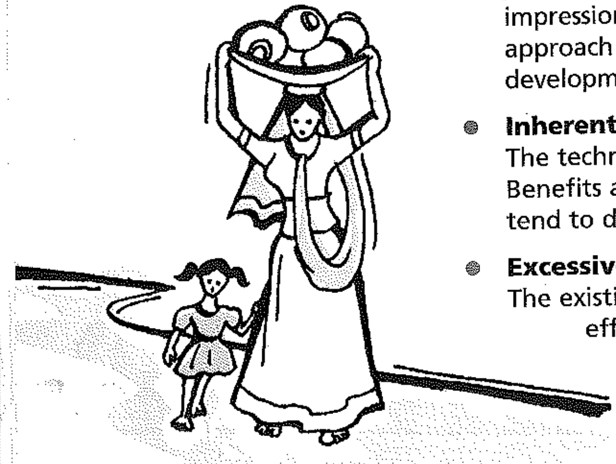
- **Subsistence orientation: lack of will in the farming community to upgrade production, particularly in remote areas**
  In remote areas, farmers satisfaction level is very low. They are satisfied with whatever produce they get with the minimum level of management. Such an attitude does not motivate them to go in for higher production.
- **Inadequate marketing facilities**
  Besides low price levels, except for some commodities, the marketing infrastructure in rainfed areas is very poor.

Natural resources such as harvested water, social forestry, common lands etc. can be shared on equity basis, if appropriate legal provisions are made. At present, such provisions do not exist

- **Migration of the younger generation to urban areas**
  Subsistence agriculture as a livelihood does not promote education. Poor education and lack of rural employment opportunities frustrate the younger generation and force them to migrate to cities for jobs.
- **Continuous reduction in farm size due to division of properties, absentee landlordism**
  The population is increasing geometrically whereas land resource is constant. An end of the joint family system has resulted in division of land into smaller units. Economic viability of the holding is thus affected. Absentee landlordism is another reason for low productivity. The tenant farmer cannot spend on conservation measures.
- **Inadequate grain storage facilities**
  Irrespective of irrigated and rainfed agriculture, technologies related to storage and post-harvest processing are not quite satisfactory. Adequate storage facilities do not exist to preserve the produce for longer periods to wait for better prices in the market.
- **Lack of proper infrastructural facilities like roads, telecommunications, transport, etc.**
  Inadequate infrastructural facilities like roads, telecommunications, transport, etc. are hurdles that stall the progress in rainfed areas.
- **Lack of legal mechanism for sharing of natural resources on equity basis**
  Natural resources such as harvested water, social forestry, common lands etc. can be shared on equity basis, if appropriate legal provisions are made. At present, such provisions do not exist.

C. Extension and technology related

- **Top down approach**
  Most of the development programmes are planned at higher levels. End users are just asked to implement these as told by the extension workers. They develop an impression that the programme launched is the necessity of the Government. This approach needs to be reversed to bottom up participatory technology development and application by involving the clientele at the planning stage itself.
- **Inherent weakness of resource management technologies**
  The technologies for management of soil and rainwater are of long gestation. Benefits are spread over a long time. Immediate visible gains are thus few and tend to disinterest the farmers.
- **Excessive emphasis on commodity research**
  The existing technology modules are mostly based on crops and varieties. Specific efforts on resource upgradation and developing a systems approach in the farming systems mode have been lacking. Commodity approach for technology generation that was successful in irrigated areas is not appropriate for rainfed areas.



Farmers participation - An essential input for successful crop strategy in watersheds

- **Low level of mechanisation**
  Adequate attention has not been paid to introduce appropriate level of mechanisation in rainfed farming (except in some areas like the arid zone) where timeliness in field operations is so crucial.
- **Weather dependence of technologies**
  Despite current understanding of the climate and crop production relationships, the progress towards evolving drought proofing technologies has been slow.
- **Lack of integration of livestock research**
  Considerable family income in rainfed areas comes from animal husbandry. Yet, the scientific integration of arable farming with livestock has not been adequately pursued.
- **Bias to irrigated areas**
  Most of the development programmes are attracted by high capacity irrigated areas. These areas have since reached an yield plateau. Besides, new problems such as water logging, salinity etc. have been coming to the fore that lead to a contention whether more areas vulnerable to these hazards, should be brought under irrigation.
- **Lack of appreciation for on-farm participatory research**
  In rainfed lands, on-farm participatory research is absolutely necessary for developing technological options suited to different categories of farmers. It is only then that sustainable farming systems can be evolved.
- **Adhocism in development efforts**
  Most of the developmental activities are taken as ad hoc schemes of some duration. Such programmes are terminated without achieving the logical ends.
- **Bias to short term gains**
  Sometimes activities are planned for short term gains which do not have long lasting effects from the view point of sustainable development.
- **Single technology approach, lack of options (to choose from) for solving a given problem**
  In many cases only a single technology for solving a given problem is available. If there are practical problems in implementing this technology or it is beyond the

farmers economic capacity, alternatives are not available. Thus, it becomes difficult to motivate/enthuse the farmers for adoption of such technology.

- **Lack of appreciation for indigenous technical knowledge and its utilisation in technology development, inadequate research – extension – client linkage**
  The technology development process passes through the stages of identifying research problems, conducting research, field verification of the research results and refinements. In this whole sequence, available indigenous technical knowledge is not considered.

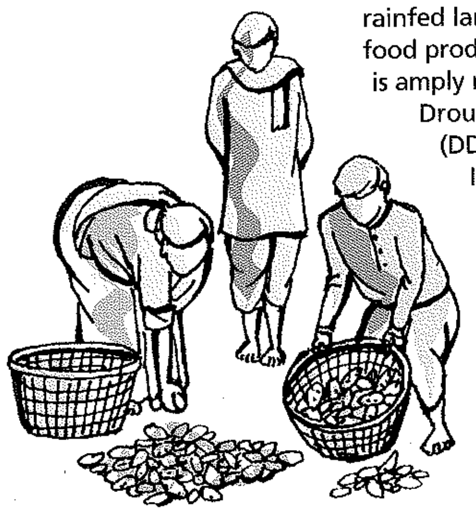
- **Lack of co-ordination between research institutes and development agencies (Government departments and NGOs)**
  As mentioned earlier, despite a good extension network, desired results are not achieved. This is basically due to lack of co-ordination between research institutes and development agencies including NGOs.

- **Poor extension services**
  The extension services in rainfed areas are inadequate as compared to irrigated areas. The technology diffusion process has thus been slow and ineffective.

The constraints listed ts indeed reflect a bleak scenario. Yet there are emerging opportunities that need to be capitalised upon to make a breakthrough in the adoption of integrated watershed management programmes in rainfed areas.

Opportunities

- **National awareness**
  There is a growing realisation across the world that production in rainfed areas must be enhanced. This stems not only from the consideration of social equity, but also for improving the food production, commensurate with the requirements of continuous population growth. In India it is no more possible to tap further irrigation water resources due to prohibitive costs involved and environmental considerations. Furthermore, in many irrigated areas the yields have reached such a plateau that further enhancement in productivity is difficult unless a breakthrough is made in upgrading the existing plant types with biotechnological and genetic engineering tools. Besides, in many irrigated areas due to faulty management, land degradation (water logging, soil-salination-alkalinization) has started taking place in an alarming manner.
  Hence, integrated watershed management for upgrading the productivity of rainfed lands must be addressed with real seriousness if the national goals set for food production during the next decade have to be adequately met. This realisation is amply reflected in the national allocation of as high as Rs. 16,000 million to Drought Prone Areas Programme (DPAP), Desert Development Programme (DDP) and Watershed Development Programmes during the Ninth Plan, in India. Besides DPAP and DDP Jawahar Rozgar Yojna (JRY) programmes (upto 50%) are also to be carried out on watershed basis. Further, new guidelines for watershed management projects focused on peoples participation have been developed and are being implemented by the District Rural Development Agencies since 1996.



- **Good research network**
  Extensive research network involving research institutes and agricultural universities exists specifically addressing the problems of rainfed areas.

Water harvesting and recycling through dug out ponds: A key component of watershed technology

- **NGO network**
  World-wide growth in the NGO sector in an organised manner and with commitment to work at grass roots in the rural areas is a new strength.

- **Multi-Institutional partnership**
  With increasing involvement of Government and Non-Government Organisations in watershed development, excellent opportunities are emerging for achieving goals through mutual cooperation among research and development organisations.

- **New paradigms in the development efforts**
  Involvement of Panchayati Raj Institutions and Non-Government organisations offers much greater scope for introduction of improved technologies particularly on watershed basis than the "take or leave" approach followed earlier.

- **Rainwater resource**
  India receives 400 million ha m of rainwater annually. Out of this 24 million ha m equivalent is available for harvesting in small scale water harvesting structures. Estimated harvestable runoff potential in regions upto 1000 mm of rainfall which constitute the bulk of rainfed region in the country is 6.32 million ha m. Efficient watershed management can translate this potential into reality.

- **Local wisdom**
  Across the world, farmers have acquired and inherited many indigenous technologies based on generations of experiences and practical knowledge of location specific situations. Hence, there is tremendous scope to refine these technologies based on modern scientific principles. Apparently, such innovations will be more readily acceptable to the farming community in the first instance..

- **Value added products in niche areas**
  With the opening up of global trade, opportunities are emerging to grow high value medicinal, aromatic, and dye yielding plants in niche areas.

- **Private sector R&D initiatives**
  There is a growing realisation in the industry (Fertiliser, Plant Protection Chemicals and Seed, etc.) that they have to join the public sector R&D efforts to obtain the fullest benefits of the fast coming up liberalisation scenario and IPR regime.

The given scenario clearly brings out that apart from infrastructural constraints, the following gaps in the R&D approach have been primarily responsible for poor participation of farmers in watershed management programmes in dryland areas.

- Lack of involvement of farmers in programme planning. Apparently, the bias has been towards the condition of natural resources with little attention to socio-economic issues.
- Lack of participatory technology development through OFR (On-farm research). Development of technological options to provide choice to different categories of farmers has been missing.
- Limited increase in productivity from technologies in isolation, which failed to enthuse and motivate the farmers for adoption.

These shortfalls call for a new approach to obtain the voluntary participation of farmers in watershed management programmes to be undertaken in the country in the coming decades.

STRATEGY TO CATALYZE FARMERS' PARTICIPATION

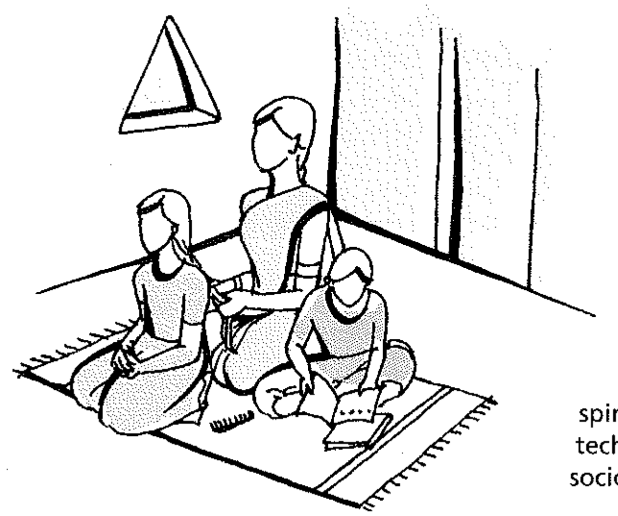
Involvement of farmers

The following methodology has been found effective in obtaining people's participation in programme planning and implementation.

- Participatory resource appraisal
- Demonstration of land degradation processes (water and soil loss) through tools like a portable rainfall simulator
- Focus group interactions to clearly obtain (i) farmers perceptions on land degradation issues, (ii) "what is watershed and how relevant?", and (iii) sustainability of dryland farming
- Identification and listing of indigenous technical knowledge.

On-farm research

On-farm research has been in vogue in India since the mid-70s. However, these efforts were primarily directed at demonstration are at best testing the research results emanating from the research Institutes/Agricultural Universities under farmers' situations. In many instances, the participation of scientists responsible for generating the research information was negligible and the programme was implemented by the extension personnel. Virtually there was no effort to tailor these research results into appropriate technologies with the full involvement of farmers. Obviously, therefore, once the projects were completed and intervention withdrawn the farmers reverted to their original ways and means as stated earlier. This has happened to a multitude of pilot projects including many of the 46 model watersheds implemented in various agro-ecological situations of the country during the 80s. Hence, unless on-farm research both in letter and spirit is carried out by the scientists themselves, appropriate technologies considering both the natural resources and farmer socio-economic circumstances, cannot be developed.



Enhancement of productivity to a level that may interest the farmers – The farming systems perspective

The task: As stated above, extension and development programmes have failed to inspire farmers to adopt technology in rainfed areas of India and many other developing countries. Besides lacking a farmer participatory approach as stated earlier, these failures partly stem from the inherent difficulty of the task. Of late, it has been increasingly recognised how difficult it is to develop sustainable technology for heterogeneous agroecological and socio-economic conditions of smallholders in arid and semi-arid regions, as opposed to those in irrigated areas (von der Osten et al., 1989). The problems are complex, characterised by a host of environmental and socio-economic issues. Addressing only a component of the farming system, e.g. crop variety, fertiliser use, or even crop husbandry per se, is not expected to dramatically increase the productivity as witnessed in irrigated areas. Mixed farming, consisting of crop production and animal husbandry for risk aversion, has been the mainstay of subsistence for such farmers. The farming systems perspective, therefore, can be the proper management strategy for such regions (Chambers, 1991).

Strict prescriptions of component technologies developed at the research stations should be avoided. Needed adjustments can be incorporated to offer a basket of options suited to client requirements and priorities based on the output of PRA and Focus Group Interaction

Methodology: Planning on-farm Farming Systems Research (FSR) requires a perfect understanding of what farmers are already doing. Three sets of information are needed to initiate farming systems research (Singh, 1997b) in real field situations: i) socio-economic conditions of people, their perceptions, priorities, requirements and indigenous technical knowledge (ITK); ii) resource conditions; and iii) technology (research information) developed at the research stations.

These data are collected and then carefully analysed to balance resource conditions and farmers' requirements for selecting technologies to apply and test as treatments. To begin with, more emphasis should be placed on indigenous technical knowledge-based refinements. Strict prescriptions of component technologies developed at the research stations should be avoided. Needed adjustments can be incorporated to offer a basket of options suited to client requirements and priorities based on the output of PRA and Focus Group Interactions.

Sustainability issues: Sustainability of rainfed agriculture in India is likely to be one of the most crucial problems of the next two decades. In the Indian context by sustainable agriculture, we mean a farming system which on a continuous basis enhances the productivity and economic returns, protects the environment, conserves the natural resources and finally leads to improved quality of life of people (Singh, 1995).

The burgeoning human and livestock population regime in India demands a continuous increase in productivity to meet the increasing requirements. Economic growth associated with development further adds to it. The fragile resource base in these regions is, therefore, required to be balanced with production activities in such a way that it continuously responds to the increased requirements without compromising on quality: a challenging and uphill task indeed! (Singh, 1995).

Synergy among farming systems components: In irrigated areas the synergy among components of the recommended technology - high yielding variety, water management, fertiliser use and plant protection - resulted in a quantum jump in productivity, as stated earlier. Farmers got impressed and readily accepted the technology, which led to the green revolution.

In drylands, such synergy could at best operate at a very low level. Water, the most important input, is uncertain. Moreover, farmers are poor and cannot cope with the risk factor. Inputs like fertilisers are thus seldom used. In this setting, how do we get farmers interested in improved technology as willing participants? We cannot do so until productivity substantially increases. For this reason farmers in dryland areas have not accepted technologies (in isolation) despite vigorous extension efforts throughout India during the last two decades.

Crops alone cannot meet the formidable task of sustainable dryland farming. We, therefore, have to look into the whole production/farming system for synergy among its components, e.g. arable cropping, livestock management, alternative land use systems and management of village commons/degraded lands. With such a synergistic integration the farming systems approach can meet the objective of productivity increase to the desired extent in drylands. Some examples of such synergy are as follows (Singh, 1998):

- Agroforestry is our best bet for controlling desertification in rainfed areas. But farmers will readily accept agroforestry only if the product of the system is directly useful to them. The best use is for fodder, but livestock quality must be upgraded to readily respond to the increased fodder availability. Therefore, agroforestry and animal husbandry together should constitute the central strategy for sustainably managing the rainfed lands.
- Upgrading animal husbandry to a commercially viable level will increase the area under grasses and trees, which, with the introduction of suitable medicinal and horticultural crops, will eventually lead to a reduced area under arable crops. Smaller cropped areas thus can be managed more efficiently.
- Upgrading the quality of animals over time may lead to controlled grazing and stall feeding. The present large, poor quality herds (particularly cattle) unattended for grazing may eventually be replaced by small, high quality herds that may pave the way for attended grazing and stall feeding. This indeed may eventually prove to be a positive way to eliminate the practice of free grazing, which has seriously impeded the implementation of developmental programmes in such socio-ecological regions.
- Greater availability of manure through better livestock and organic wastes can help boost productivity when applied to the reduced areas under arable crops.
- Weeds, if used for composting, may encourage farmers to apply timely weed control in their crop fields.
- Pastures established for use of marginal lands, soil conservation and meeting livestock forage requirements, when rotated every 4th or 5th year with crop lands (ley farming) can enhance the soil quality substantially.
- Planting trees on field boundaries, apart from contributing to soil conservation and the generation of forage and wood, can also upgrade field microclimate for better performance of arable crops in the long run.
- Planting of multipurpose tree species (MPTS) on field boundaries, by augmenting forage production, may eventually reduce dependence on stubble grazing, thus paving the way for residue recycling so much warranted for managing rainfed lands.
- Planting fuel trees such as Prosopis juliflora on degraded lands and using solar-driven appliances may help discourage the use of dung as fuel, allowing more manure to upgrade and maintain soil fertility and reduce the dependence on chemical fertilisers.

Diversification of production in rainfed areas as suggested above, constitutes a trade-off between increasing farmers income along with control of land degradation and national food security. Apparently, since `sustainability' of production in rainfed areas may perhaps be a bigger issue than `national food security' (though

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debatable), diversification is warranted (Singh, 1998). Household food security is not threatened by diversification for the farmers will not risk it and continue to grow food crops to the extent that it meets the food requirement of the family. In so far as introduction of diversification without jeopardising the national food security is concerned, the underlying argument is that the productivity in high rainfall areas and new irrigation commands must be upgraded.

CONCLUSIONS

In India, sustainability issues demand both conservation of resources and enhancement of productivity on a continuous basis in rainfed areas. Increased production from these areas is the only way of bridging the gap between current level of production and demand in the next two decades on one hand and social equity between irrigated and rainfed areas, on the other. Integrated watershed management is the proven approach to reach this goal. But it cannot be put in place unless dovetailed with participatory technology development in a farming systems perspective through vigorous efforts directed to on-farm location specific research in different agro-ecological situations obtainable in the country.

The National Agricultural Technology Project (NATP) is a fresh national initiative launched in the above mentioned mode to realise the sustainability of rainfed agricultural production system in India.

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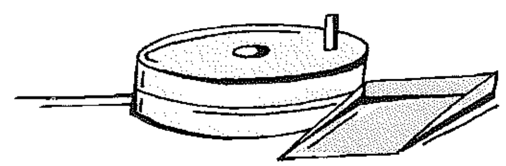


APPROPRIATE TECHNOLOGIES FOR SOIL AND WATER CONSERVATION

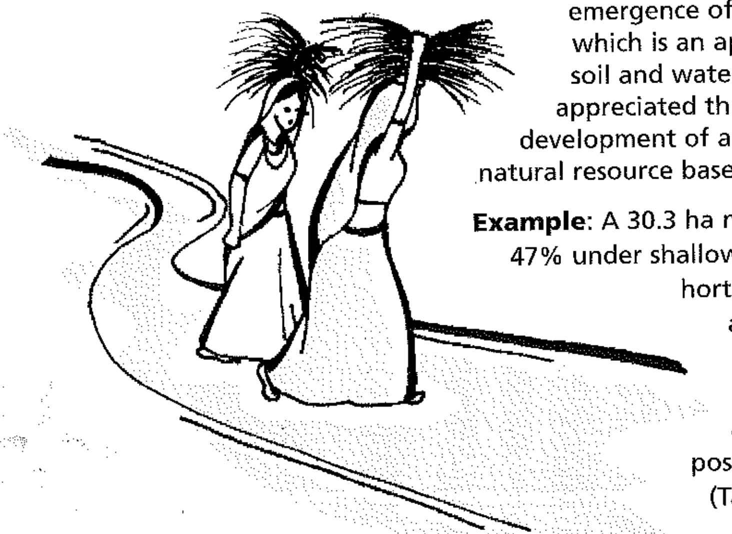
A. Singh • Water Technology Centre • IARI • New Delhi

INTRODUCTION

The dictionary meaning of "technology" is systematic treatment or the science of the practical or industrial art. The term "technology" has also been defined as applied science. The term "soil conservation" has been defined as the art of good land use. The term "appropriate" is generally used in reference to fitness of the technology to a particular situation. In the field of soil and water conservation, it has been well recognized that technologies are highly site specific. Considering all these points, the author would wish to define appropriate technology for soil and water conservation as one, which is acceptable to the users, fits well to the purpose for which it is used and is local natural resource-based. If we go by the concept "Soil Conservation as an art of good land use" then appropriate technologies for soil and water conservation can well be defined by the term "Watershed Management" which essentially is a site specific package. This package consists of numerous technologies such as bunding, terracing, water harvesting, farming systems, afforestation, etc. In this chapter, an attempt has been made to discuss experience-based technological developments for management of natural resource base through the path of watershed management.

APPROPRIATE TECHNOLOGY CONCEPT

On the land surface, vegetation plays an important role in the process of in-situ retention of rainfall. In recent times deforestation and increasing biotic activities for producing more and more food have adversely affected the process of in-situ retention of rainfall. Run-off from the land surface has increased with harmful effects of soil erosion and poor ground water recharge. Mechanical measures such as tillage, bunds, terraces, trenches and ponds have emerged as alternatives to the roles played by vegetation for in-situ retention of rainfall. Such measures with appropriate standards and specification for different purposes exist in every locality and region of the country and need to be identified and chosen with a scientific angle for specific use. Developments in this field have led to the emergence of the concept of micro-watershed based management which is an appropriate package for biomass production while adopting soil and water conservation technologies. The concept can well be appreciated through an example where systematic treatment and development of a micro watershed, induced reversal in the process of natural resource base degradation (Singh et al 1976).



Example: A 30.3 ha micro-watershed with 52% area as slopy eroding land and 47% under shallow, medium and deep gullies was developed for agriculture, horticulture and forestry with the support of appropriate soil and water conservation measures (Tejwani and Dhrunarayana 1960). This piece of land after 14 years of development was found to have retained the entire amount of annual rainfall (816 mm) within it and showed positive trends in annual growth rates of biomass production (Table 1).

Table 1: Land use details and results of a degraded micro watershed developed through appropriate soil and water conservation treatment for biomass production

Particulars	1960	1961-73	Remarks
Watershed area (ha)	30.3	30.3	Conservation measures viz. contour/peripheral bunds (2635 m); composite check dams (8 Nos.); gully plugs (52 Nos.) pipe outlets (10 nos.); terracing of side slopes and gully beds (4.13 ha) at a cost of Rs. 1810 per ha (196) price level) were used
Slope of the watershed (%)	1.4	1.4	
a) Agriculture	53.0	29.0	
b) Horticulture	-	7.0	
c) Forest	-	57.0	
d) Road/Building	-	7.0	
e) Waste	47.0	-	
Annual Run-off (ha m.)	6.7	Nil	
Ground water recharge (ha m.)	4.2	6.5	
Ground water drawn for irrigation (ha m.)	-	8.6	
Annual growth rates (%)-			
f) horticultural crops		13.6 to 15.5	
g) cereal crops		1.2 to 7.9	
h) grasses as fodder from bunds		1.6 to 25.6	

Annual rainfall 816 mm

The treated area has the provision of tube well for irrigation purposes and the water use was 33% more than the estimated ground water recharge (Singh and Dayal 1975). This imbalance of extracting more ground water than the recharge in such a well managed system needs to be adjusted through improving irrigation water use efficiencies or effecting changes in cropping patterns followed in the area. On the economic front a simple method of resource gain assessment considering only the cost parameter was appropriately developed for planning and developing ravine lands.

The method involves analyzing the value of land before and after the development. With simple techniques, a quick check can be made of the gains at the project planning stage itself for economic feasibility. The judging tool is presented as follows (Singh 1976):

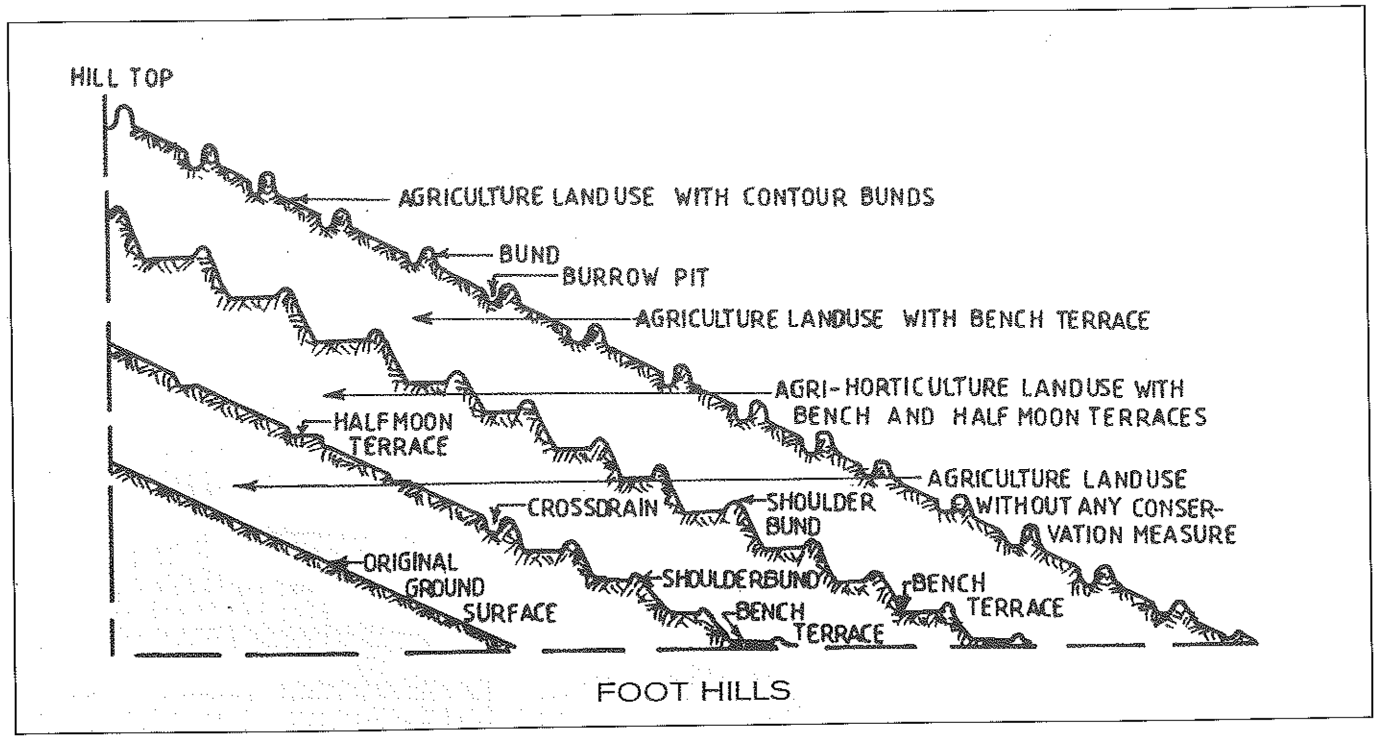
$$RG = VTL - (VUTL + CT) \quad (1)$$

where,

RG = Resource gain
VTL = Value of treated land (Rs. /ha)
VUTL = Value of untreated land (Rs. /ha)
CT = Cost of treatment

Resource gain with positive value is considered as acceptable investment, whereas, negative gains reflect on the need for changing the land use at planning stage itself. The gains judged in the above example were found positive (Singh 1976). Experience with this micro watershed based management revealed the possibility of managing soil erosion problems with the use of local natural resources.

Figure 1: Schematic views of ground surface profile treated with appropriate soil and water conservation measures under various land use systems in hilly micro-watersheds



(source: Singh et al 1981)

Watershed-based management

The experience with micro watershed-based development and management discussed with the example cited, provided insight and led to further exploration of appropriate soil and water conservation technologies while integrating land use aspects simultaneously. In fact the experience led to the development of a concept and hypothesis on the efficacy of micro watershed base for in-situ retention of rainfall, and management of land and water with local resource based conservation measures. The hypothesis was tested at two different locations in the Eastern Himalayas where hill slopes suffered from the serious problem of soil erosion due to the practice of shifting cultivation (Singh and Singh 1978). Details of the locations, micro watersheds and land uses are presented in Table 2. A schematic view of ground surface profile in micro hilly watersheds having appropriate soil and water conservation measures is shown in Figure 1.

Figure 2: A view of micro-watersheds under alternate land use systems treated with local natural resource based appropriate soil and water conservation measures

Alternate land use systems in micro watersheds on hill slopes located at Barapani are shown in Figure 2. The hypothesis on the efficacy of micro watershed based management did prove workable at both the locations as 80 to 100% of annual rainfall was absorbed within the micro watersheds (Table 3). Surface run-off and soil losses from alternate land uses were similar to forestry land use in the watersheds having the

support of local resource based conservation measures. These studies lead us to conclude that (i) soil and water conservation measures developed with the use of local natural resources are adequate to meet the conservation needs and (ii) if agriculture is to be practiced on steep slopes, technology is available to do so without fear of degrading the land (Singh 1995).

Table 2: Details of experimental micro watersheds located in the Eastern Himalayas for testing the hypothesis on local resource based soil and water conservation measures

Particulars	Location/Details	
	Burnihat (Meghalaya)	Barapani (Meghalaya)
Latitude	25° - 80'	25° - 40'
Longitude	91° - 78'	91° - 58'
Elevation (m)	100	1000
Land type	hills	hills
Land uses	Agriculture Horticulture Forestry Mixed	Agriculture Horticulture Forestry Mixed
Nos. of micro-watersheds	6	7
Area (ha)	0.0.09 - 0.15	0.52 to 3.89
Mean slope (%)	40 - 50	32 - 52
Soil type	Sandy loam	Silty clay loam
Period of study	1976 - 83	1983 - 90
Annual rainfall (mm)	1600	2352
Soil and water conservation measures	Bench terrace contour bunds half moon terrace grassed water ways	Bench terrace contour bunds half moon terrace grassed water ways

Soil and water conservation measures used in different land use systems were of the appropriate types (indigenous origin). Some of the popular measures are discussed as follows:

Contour bunds

Bunds are mechanical barriers created across the slope. The purpose is to divert the excess run-off during rains to the grassed waterways and retain eroded soil with the bund. With slow process of silt deposition with bunds, the area between two bunds get leveled up and takes the shape of a terrace in the course of 4 to 8 years. These bunds on steep slopes (30 to 55%) are created by way of excavating parabolic shaped channels (0.3 m top and 0.2 m deep) on contours and keeping the dug-out soil in the form of a bund at the lower edge of the channel (Figure 1). These bunds require care in maintenance during the first two years and subsequently become manageable as a part of farming activity. The vertical interval of the bunds may vary from 0.5 to 1 m depending on the soil depth and land slope.

Table 3: In-situ retention of rainfall and soil losses from micro watershed based land uses

Land use	Mean slope (%)	Soil and water conservation measures	Percentage annual rainfall retained (%)	Soil loss t/ha
Burnihat (1976 -1983)				
Bamboo forest	45	–	99.55 - 99.98	0.04 - 0.52
Agriculture (S)	40	–	90.27 - 98.94	5.10 - 83.30
Agriculture (C)	42	Bench terrace	95.03 - 100.00	0.00 - 7.70
Agriculture (C)	43	Contour bunds	80.74 - 99.79	0.60 - 68.20
Agriculture (C)	44	Contour bunds	97.08 - 99.66	0.88 - 15.28
Agri + horti	44	Bench terrace+ contour bund+ half moon terrace	93.37 - 99.98	0.44 - 10.10
Barapani (1983 - 1990)				
Natural fallow	36	–	98.4 - 100.00	0.00 - 0.05
Agriculture (F)	32	Contour trench	98.68 - 100.00	0.00 - 0.16
Agriculture (C)	32	Contour bunds+ bench terrace	98.53 - 99.77	Trace -0.33
Agri - horti	42			
Silvi pastoral		Contour bund+ bench terrace+ half moon terrace	96.18 - 99.75	Trace - 1.22
Horticulture	53	– do –	96.18 - 99.75	Trace - 4.37
Agro-forestry	32	–	96.83 - 99.52	Trace - 0.39
Forestry	39	–	92.79 - 98.27	Trace - 7.80

S - Shifting cultivation;C- Cereal crops, F - Fodder crops

Bench terraces

Bench terraces are flat beds constructed across the slope. Spaces between two contours are leveled by cut and fill method. In micro-watersheds involving steep slopes, experience shows that only at the foothills, a few benches may be constructed to produce food crops through intensive cropping. For operational convenience, the vertical interval of such terraces may not exceed 1 m. In case, the entire hill slope is to be converted into benches, the construction should start from the foothill.

Half moon terrace

These are level circular beds having 1 to 1.5m diameter cut into half moon shape on the hill slopes. These beds are used for planting and maintaining saplings of fruit and fodder trees in horticulture/agro-forestry land uses.

Grassed waterways

These are the channels laid out preferably on natural drainage lines in the watershed. As far as possible, natural water courses should be used without much disturbance for draining out the excess run-off. At appropriate locations stilling basins (water pools) should be created with the use of earthen and boulders pitched bunds for temporary detention of runoff water.

Water harvesting ponds

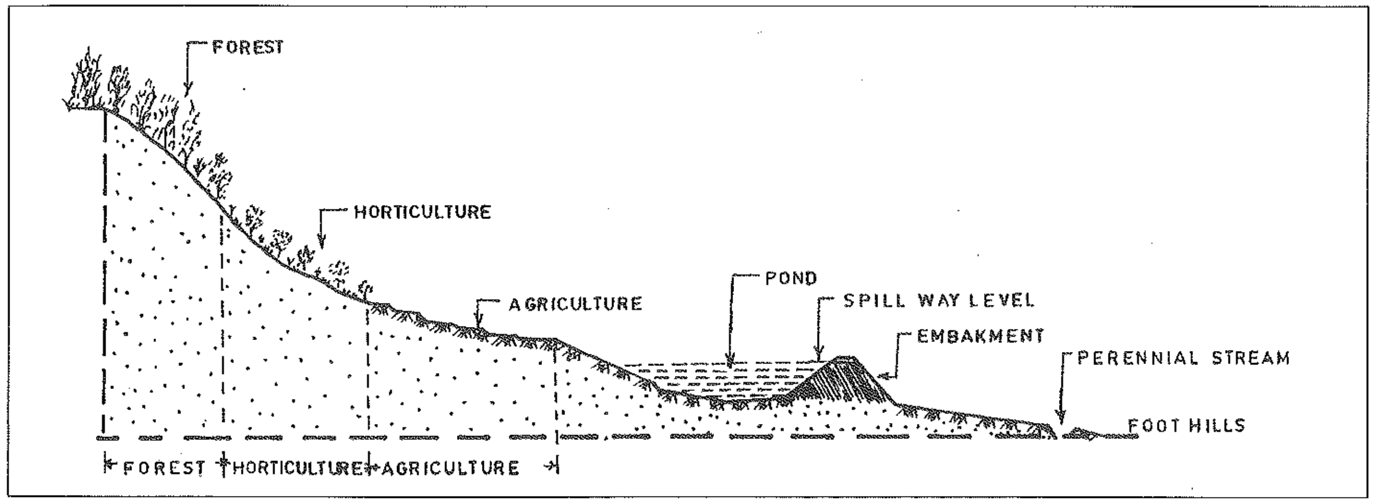
Dugout-cum-embankment types of water harvesting structures are used for creating seasonal and perennial ponds at the lower point of the micro-watershed.

Water harvesting

Generally the term "water harvesting" implies the storage of runoff water in ponds. But in hilly regions the problem is of depletion in availability of water during off season (after withdrawal of monsoon). Phenomenon of drying up of springs and streams is common which has set in. In-situ retention of rainfall and gradual release of water through springs and streams had been the unique character of hilly areas.

With the passage of time, increasing biotic interference has adversely affected the dynamics of water with the result a need for conservation has arisen. Water harvesting in ponds is one activity but the solution for conservation of water demands consideration in a broader perspective. In fact, in hilly regions in-situ retention of rainfall is an important act of water harvesting. Appropriate soil and water conservation measures in land use combination are capable of creating similar hydrological situations on hill slopes as is found under natural vegetation. Schematic view of surface profile of a hilly micro watershed of 11.1 ha area under mixed land use system having support of local resource based conservation measures is shown in Figure. 3. Hydrological behavior of the watershed (Figure 2) during the first five years of its life is presented in Table 4 (Singh 1990).

Figure 3: Profile of hill slope under watershed based mixed land use system



Rainfall retained in the hill slopes through good land use method, moved as a subsurface flow. The path of base flow at the foothills is obstructed through dug out cum embankment type of water storage structure helped in accumulation of water in the pond

Rainfall retained in the hill slopes through good land use method, moved as a subsurface flow. The path of base flow at the foothills is obstructed through dug out cum embankment type of water storage structure helped in accumulation of water in the pond. As is seen from Table 4 the pond on an average received 3.7 ha m of water yield through runoff (3.2%), base flow (80.0%) and direct rainfall (16.8%). The water stored in the pond was utilized for fish production during the limited period of storage. LDPE lining against seepage losses tried in the pond was found ineffective due to site conditions and owing to the pattern of base flow in pond bed/sides (Singh et al 1991). Threshold rainfall is crucial which is likely to increase with time as the land use in the watershed develops towards maturity and stability and may have adverse effect on water accumulation in ponds. Nevertheless, ground water as an alternative will be available to meet the water supply within the watershed.

These are some of the appropriate soil and water conservation methods experimented with, which have local resource use bearing. These results do show the potential and possibility of efficient land management through appropriate soil and water conservation technologies.

Table 4: Water yield to a dug-out-cum embankment type of pond from a well developed hilly micro watershed

Particulars	Year					Mean
	1984	1985	1986	1987	1988	
Rainfall (mm)	1194.6	2234.3	2230.1	2705.8	3323.8	2537.6
Water yield (ha m)	1.2	1.2	2.6	5.2	8.6	3.7
-as runoff (%)	2.3	3.8	1.9	0.6	7.5	3.1
-as base flow (%)	75.3	77.4	82.8	85.0	78.5	80.0
-as direct rain (%)	24.4	18.8	14.4	14.4	13.0	16.8
Threshold rainfall (mm)*	2613.4	1560.11	136.8	773.1	511.3	1118.9
Life of water storage (days)	120	181	69	055	225	163
Over flow (ha m.)	0.0	0.0	1.1	3.1	5.9	2.0

*accumulated rainfall during the year after which water storage in the pond begins

TRADITIONAL SOIL AND WATER CONSERVATION TECHNOLOGIES

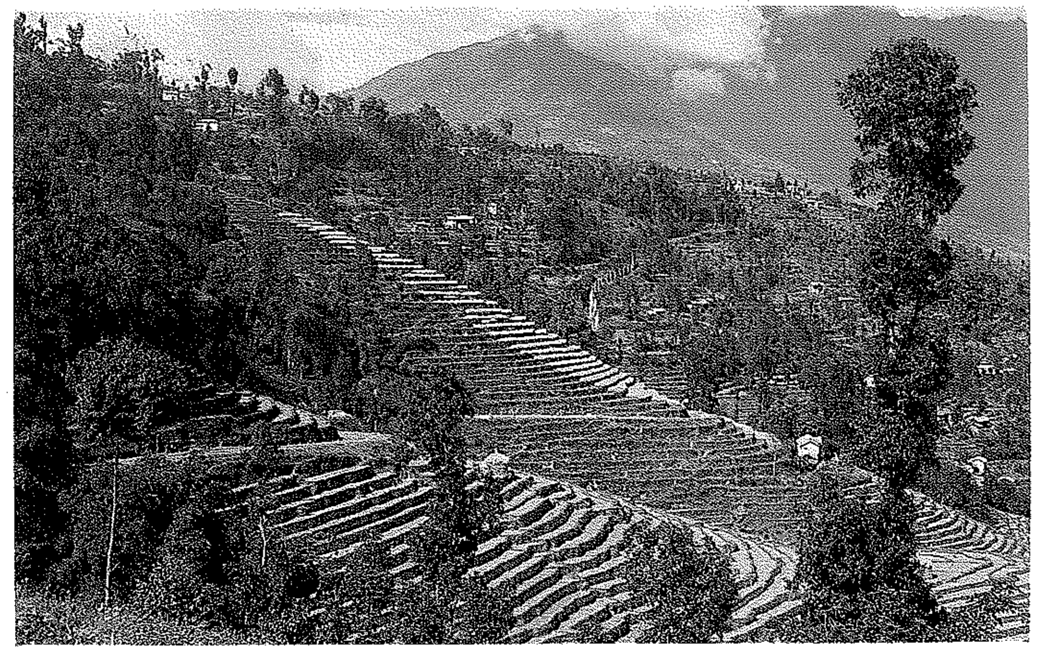
Hydrology, the science of water and its application to the solutions of land and water management was comparatively well developed in ancient India (Anonymous 1990). One can appreciate this information, if one reads the book "Dying Wisdom" published on traditional water harvesting systems of India (Agarwal and Narain 1997). The application of traditional hydrological knowledge was based on holistic considerations where environmental issues were an integral part. The author had an opportunity to study a few of them in the Eastern Himalayas which are still in use and unique to the situation. The process of evolution and ingenuity of the people were the key factors in traditional wisdom. When we talk of the appropriateness of any soil and water conservation technology the people's involvement is most crucial and has to be linked with it. Some of the systems practiced even today are discussed as follows:

Bench terrace based landuse

When we talk of the appropriateness of any soil and water conservation technology the people's involvement is most crucial and has to be linked with it

Terrace-based agriculture is widely practiced in hills the world over. A wide range of variations exist in their specifications. What is most confusing and misleading in perceptions today on bench terracing, is about the slope limit, method of construction, area lost, soil fertility problems and requirement of financial resources for terrace construction. If we look at the Indian experience there is no room for such confusion (Singh and Rai, 1978). Soil and water conservation technologies being site specific, a large variation in terrace specification exists. Site conditions and use of animate energy source in practicing appropriate farming systems are the main reasons for the wide range of variations. One gets thrilled to see extensive sites with terrace width and steepness of slopes in the states of Manipur and Sikkim where 0.4m terrace width and more than 100% hill slopes are cultivated successfully (Figure 4). This makes one reflect upon the processes of development such as how these terraces were constructed, what kind of resources were used, what was the cost of development. The existence of the system over centuries does prove its potential in terms of stability to agricultural systems in the region. Exploration on construction aspects reveals a unique system adopted where not the money but use of human resource and ingenuity were the major inputs in the making of these terraces. The following methods were adopted for terrace construction in the state of Sikkim.

Figure 4: A view of agricultural land use on steep hill slope having the support of bench terraces built with ingenuity of local people



Parma method

This was community-based work exchange method. Two members from each family were pooled and the work schedule was decided in village meetings. After completing work of at one participant's site, the next was taken up in a similar fashion.

Temporary settlement method

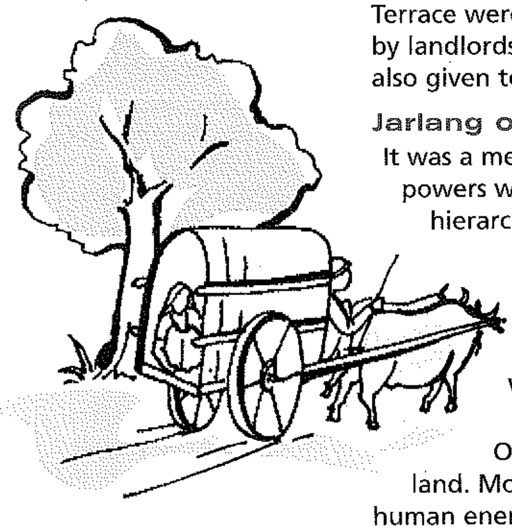
Landlords (Bhutia) offered a good piece of land for temporary settlement to Nepali migrants who worked for them. About 0.4 ha land was given for cropping to each family in lieu of work, which they did for the landlords. Once they completed the development of site with terrace making, it was taken away and the next site was allotted to them. The site selection was done by the Nepalese who were experts in terrace making.

Barter method

Bhutia landlords requested landless people to prepare terraces in lieu of some gift (rice, maize, kodo etc.).

Dhamkey method

Terrace were built through organizing picnics for village youth of 8-20 years of age by landlords. During picnics, terrace construction was done. Sometimes gifts were also given to the participants.



Jarlang or Kazi method

It was a method of compulsion. Each family was involved in terrace making. Judicial powers were with kazis who acted at their will and mobilized people for work. The hierarchical system - Dharam Raja - Mandal - Workers was followed. Dharm Raja was king of entire state. Kazis were like his governors and landlords, Mandals were next to the Kazis and responsible for development of a particular area. Villagers were compelled to develop terraces. If any one refused, he was boycotted and ousted from the village.

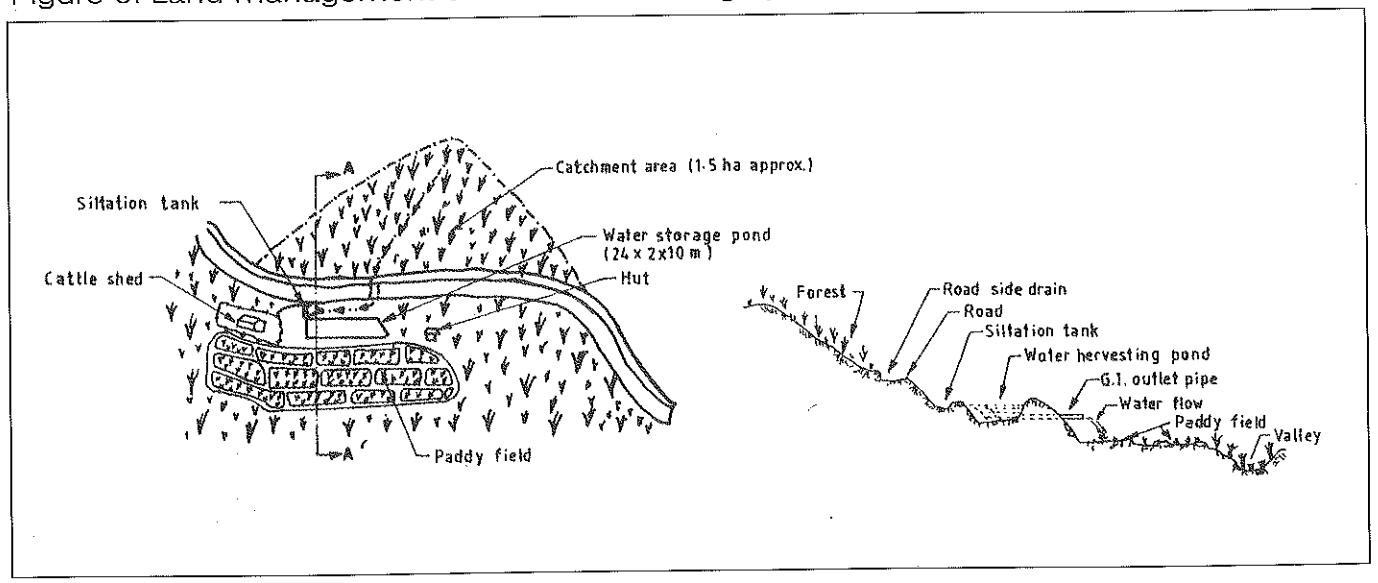
With these processes, slopes between 20-80% were converted into terraces having width from 0 to 7m and vertical interval, 0.29 to 4.0 m. One hundred and forty man days were required to develop one ha of land. Most of the communities in hills must have had different methods where human energy was the major input.

Zabo land use system

Zabo is an indigenous farming system practiced in the state of Nagaland with the appropriate soil and water conservation technology. Forestry, agriculture and animal husbandry with a well-founded conservation base are taken up in an integrated manner for water resource development, management, protection of environment and production. The good aspect of the system is that each and every farmer takes appropriate care of his land with the use of local resources (Sonwal et al 1989).

The term "Zabo" means "Impounding water". Farmers of Kikruma village located at an elevation of 1270 m, in Phek district of Nagaland have developed integrated farming system to take advantage of 1633 mm annual rainfall. The soil is silty clay loam and acidic in nature. The system comprises of protected forest on hilltops, well planned water harvesting tanks at the middle slope and cattle yards just above the paddy fields near the foot hills. Where suitable sites for water harvesting are not available, the run-off water is diverted and stored in paddy fields. The special technique of puddling with paddy husk is used to control seepage through shoulder bunds. The system is shown in Figure 5.

Figure 5: Land management under zabo farming system



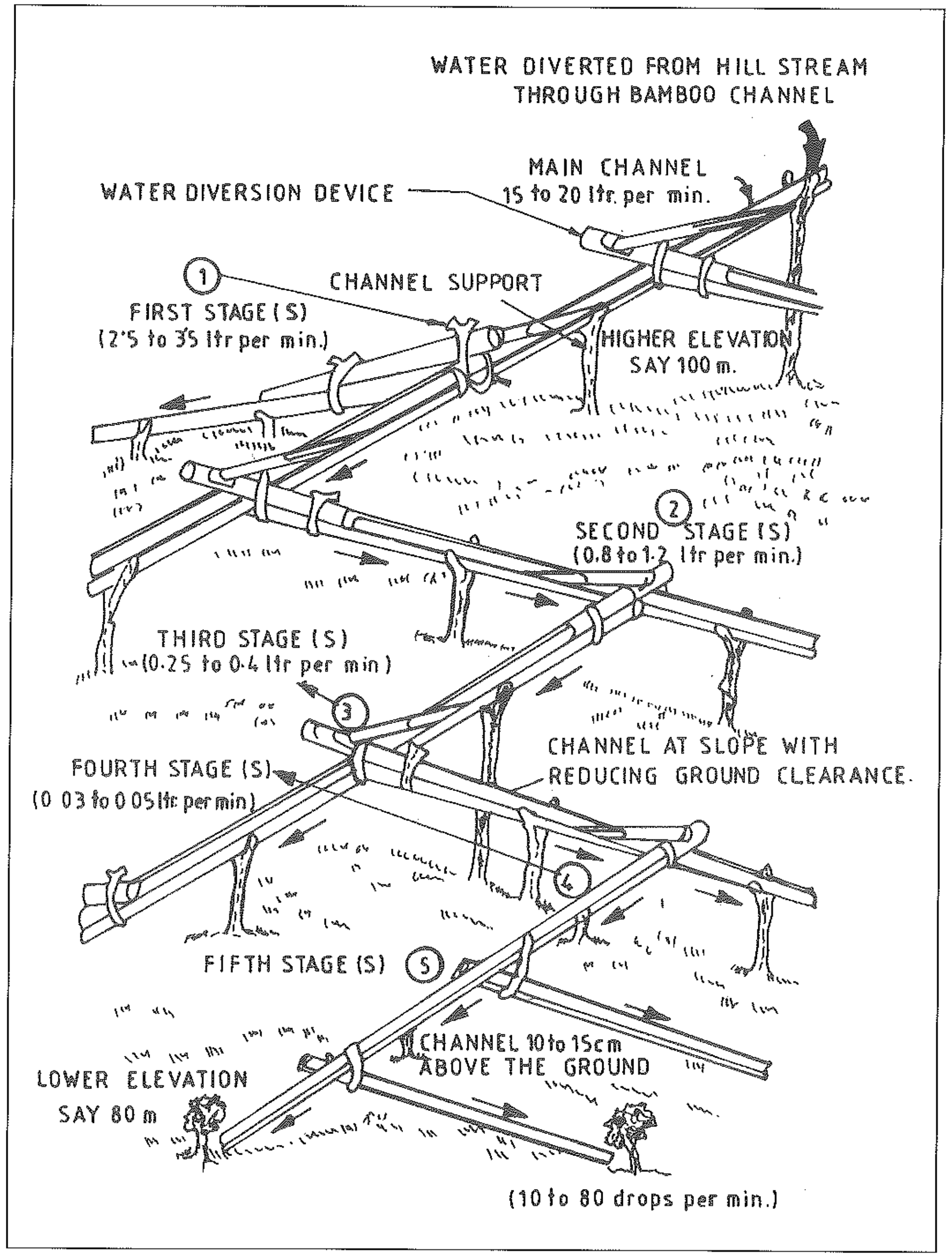
At the individual farmer's level, about 1.5 ha land use system is common in the area on steep hill slopes. About 1.5 ha area on the hill top is left undisturbed for natural forest. Cattle, pigs, poultry are occasionally let loose in forest area. A pond of 24 x 10 x 2m size with silt retention tank at run-off water entry point is constructed. Considerable efforts are made for compacting the pond bed and sides for checking water losses through seepage. Open cattle yard, fenced with local material at a lower elevation than the pond is created for cattle. Washing from the yard is taken to the paddy fields. Only one crop of paddy (a tall variety) is grown which have potential of 3 to 4t/ha in 180 days. Paddy and fish culture is common practice, which yield 50-60 kg, per ha.

Bamboo drip irrigation system

Water application on slopes for irrigation of plantation crops poses a serious problem of soil erosion. Tribal farmers in the Jaintia Hills district of Meghalaya have evolved an indigenous technique of bamboo drip irrigation. Betel leaf crop planted with arecanut is irrigated, with this system in which water trickles drop by drop. In this system, water from natural streams located at higher elevations is conveyed with

the use of bamboo channels supported on ground surface by wooden or bamboo supports to the site of the orchard through gravity flow. Water distribution in the system is done with the use of bamboo channels, channel supports, water diversion pipes and bamboo strips. The whole system enables the distribution of 15-25 litres of water per minute entering the main channel to 10-80 drops per minute at the site of water application without any leakage at any point. A diagrammatic presentation of a five stage bamboo drip irrigation system is shown in Fig. 6. The system is laid out in such a way that ground clearance of channels reduces from a few meter to 10-15cm (main to last stage channel) which is done with the use of reducing height of channel support (Singh 1979). The system when put into operation works round the clock without having leakage at any point.

Figure 6: Principle of water distribution in bamboo drip irrigation system



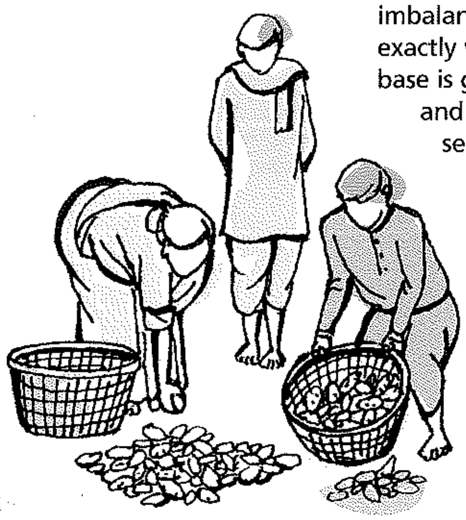
Valley land management

Generally in hilly regions, valley lands are well maintained for raising one or two crops of paddy and land use systems are well perfected for land and water management. Techniques of land and water management evolved by the Apatani tribe in Subansiri district of Arunachal Pradesh at an elevation of 1600m is unique (Figure 7). About 2000 ha of plateau land with gentle slopes have been utilized for agriculture except the areas occupied under house sites, roads and water courses. Bamboo and wood log pipes of various sizes are used as prefabricated water management structures. These aids are used as conduits for water inlets, waste weirs and energy dissipaters (Singh and Singh 1981).

Figure 7:
A view of valley land developed for agriculture land use at Apatani Plateau in Arunachal Pradesh

Need for research

Indian agriculture is a conglomeration of various types of farming systems. It comprises several components, namely crops, trees, livestock and other subsidiary enterprises. The components are often interdependent. Sectoral approach of improvement or development of one component ignoring the other complementary enterprises creates imbalance in the farming system and results in resource base degradation. This is exactly what has been happening and the problem of degradation of natural resource base is getting aggravated everyday. Despite concerted efforts in research, extension and development, it has not been possible so far to identify any alternative to sectoral approach. Watershed based development efforts are emerging as potential alternative approaches for sustainable agriculture, though it is still in the evolutionary stage.

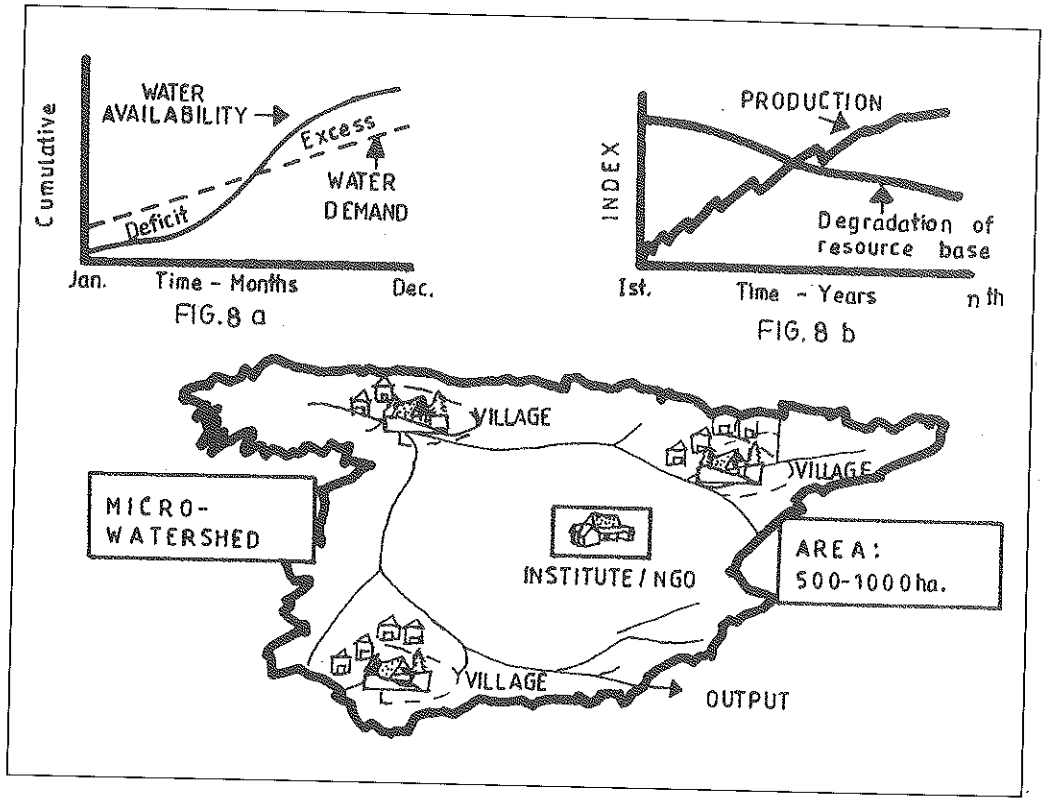


It cannot be denied that the degradation of land, water and environment is the cumulative effect of human action. Therefore, the reversal of the degradation process has to come through the contributions from each and every member of the society. The prime question is how to organize the developmental activities involving people in the unique scenario of India's socio-economic setup. During the last few years, an attempt has been made at the water Technology Center (WTC), Indian Agricultural Research Institute (IARI), New Delhi to conceive a holistic and integrated approach for developing sustainable agriculture . The essence of the approach is as follows:

Research institutes or NGOs intending to take up work on sustainable agricultural development may take the responsibility for holistic development of 500 to 1000 hectare watersheds in which they are located and work for overall development of the area with the in-built monitoring and data base building mechanism and aim at achieving an increasing trend in overall biomass production with decreasing trend of resource base degradation.

A conceptual approach for the above mode of development involving research and extension in a single capsule is shown in Figure 8.

Figure 8:
Conceptual diagram for sustainable agricultural development through micowatershed as a base



Efforts should be made to construct water scenario diagram as depicted in Figure 8a to meet the water requirements during the water deficit period from the surplus in the period of excess availability of water through the adoption of appropriate water conservation technologies. Similarly, on the production front, it will be necessary to translate the concept shown in Figure 8b into reality. Systematic monitoring and analysis of the outcome of the activities towards fulfilling the stated development concept will generate the information base which is scarce in the country (Sarkar and Singh, 1996). The approach being suggested will promote the application of science for the development and management of natural resource base i.e., land and water which are inseparable for agricultural development processes. A working structure to be adopted at watershed/village level with people's participation is shown in Figure 9. The activities, their purposes and the participants in the structure have been further elaborated in Table 5.

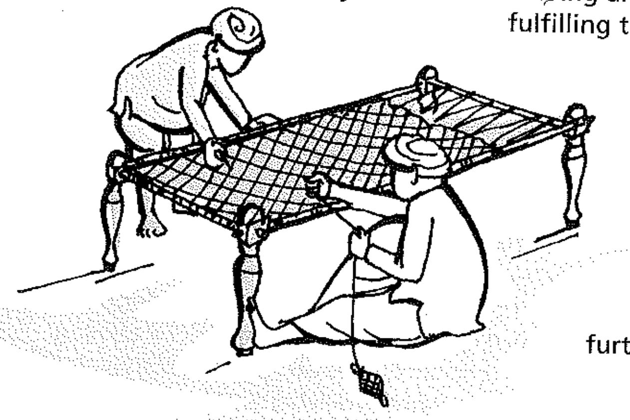
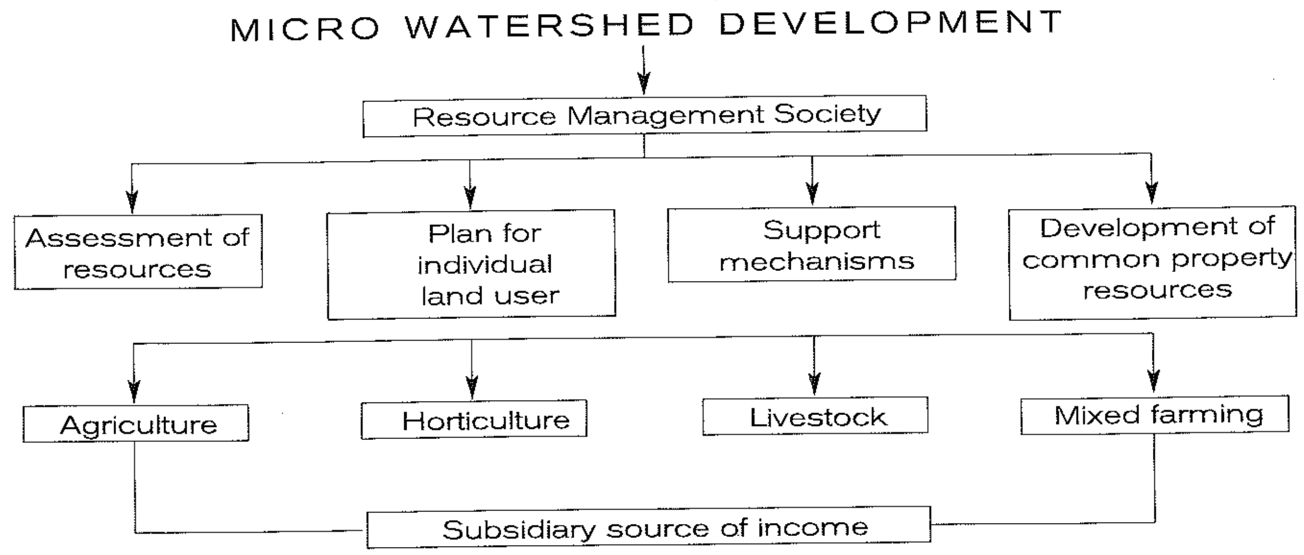


Figure 9: Working structure of sustainable micro-watershed based development.



The working structure proposed in Figure 9 and Table 5 would require the involvement of scientists, research scholars, students from the neighboring universities and the people of the area in job training, harnessing of the available resources from various state sector schemes and systematic monitoring and analysis of the activities. The proposed exercise, in fact, integrates research, extension and development activities, and aims at evolving a sustainable development process (Singh, 1997, Singh and Bhattacharya, 1998).

Table 5: Elaboration of the activities proposed for sustainable water resource development through watershed based management.

Activities	Purpose	Participants
Assessment of resources	To quantify and monitor the resource base.	Trainees and volunteers from the area.
Developing plan for individual land users.	Improvement in existing farming systems/ vocation or alternatives.	Farmers and coordinating institution.
Development of common property resources.	Opening of new areas of production and creating employment opportunities.	Local people and coordinating institution.
Support mechanism.	Organizing of cooperatives forinput and produce management.	People of the area.

The major research issues which need to be addressed are (i) Methodology for assessing biomass production through one index, (ii) Appropriate tools for indexing the overall degradation of natural resource base in the watersheds, (iii) Models and tools for assessment of water requirement in the micro watersheds (iv), Analysis of existing farming systems and their development in reference to environmental sustainability, (v) Irrigation systems analysis with reference to water availability potential and its

management, (vi) Energy management through systems analysis approach and mechanization, (vii) Impact of use of inorganic fertilizers, insecticides, pesticides and imported water on natural resource base and environment. and, (viii) Development of methods for indexing socio-economic status of the inhabitants of the watersheds.

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