SOIL CONSERVATION AND PRODUCTIVITY

PROCEEDINGS
IV INTERNATIONAL CONFERENCE ON
SOIL CONSERVATION
MARACAY-VENEZUELA, NOVEMBER 3-9, 1985

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EDITOR

"SOIL AND WATER
CONSERVATION TO
PREVENT FOOD
SHORTAGE"

"CONSERVACION
DE SUELOS Y AGUA PARA
PREVENIR DEFICIT
DE ALIMENTOS"

This volume is based on the

IV INTERNATIONAL CONFERENCE ON SOIL CONSERVATION

held in Maracay, Venezuela - November 3-9, 1985

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SOIL CONSERVATION AND PRODUCTIVITY

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ISBN 980-265-924-X

SOIL AND WATER MANAGEMENT ALTERNATIVES FOR INCREASED PRODUCTIVITY ON SAT ALFISOLS

P. Pathak, S. Singh, and R. Sudi

Alfisols are agriculturally important soils throughout much of the semi-arid tropics (SAT) in spite of serious physical and chemical limitations. They are the third most important soil order in the world, covering 13.1% of the world area (**Buringh, 1982**) and are the most abundant soils in the **SAT**, cover nearly 16% of the tropics and 33% of the **SAT** region (**Figure 1**).

Due to aberrant weather and soil related constraints to production, crop yields on **SAT** Alfisols have remained low and unstable. In general, traditional agriculture on these soils suffers from moisture deficits, nutrient impoverishment, soil erosion, and unfavorable surface physical conditions which result in reduced infiltration and poor crop establishment. Experimental evidence however, has clearly shown that most **SAT** Alfisols do possess a much higher productivity potential than that obtained with traditional farming (200-600 kg/ha). At ICRISAT Center, an average yields of 2900 kg/ha for hybrid sorghum, 2750 kg/ha for pearl millet, 1600 kg/ha of improved castor and 1475 kg/ha for groundnut have been reported from the operational scale research on Alfisol watersheds (1978-84).

Drawing largely on ICRISAT's work, this paper discusses the results from recent studies on the physical constraints and the developments that have been made in soil and water management to optimize productivity of Alfisols under rainfed conditions. The paper also tries to highlight the feasibility of the runoff harvesting and supplemental irrigation on Alfisols.

Reprinted from Soil Conservation and Productivity.

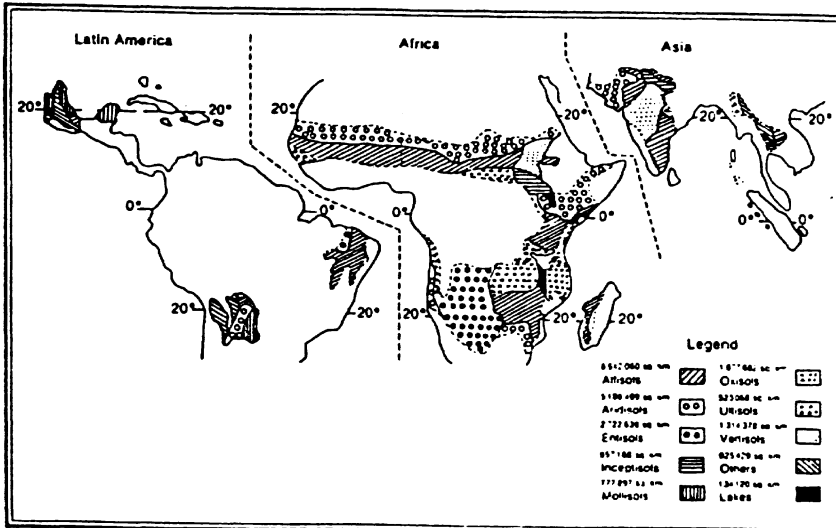

Fig. 1. Soil classification in the semi-arid tropics. Source: USDA (1975)

ALFISOLS AT ICRISAT CENTER, PATANCHERU

Alfisols are represented within the experimental farm of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Center by the Patancheru Soil series. The Patancheru Soil series consists of light reddish brown soils derived from pink granites. This soil has been classified according to USDA Soil Taxonomy as fine loamy mixed isohyperthermic family of Udic Rhodustalf. Though Alfisols display a wide degree of diversity and spatial variability, general properties are discussed below and given in table 1.

Table 1. Selected physical properties of the experimental site (Alfisols) at ICRISAT Center

Depth	Horizon	Particle size distribution (mm)			Coarse fagments 2 mm (% of whole soil)	Organic carbon	pH 1:1 H_2O Suspension	Bulk density oven dry (g/cc)	Water content (gravimetric %)	
		Clay (.002)	Silt (0.02-0.05)	Sand (.05-2)					1/3 bar	15 bar
0-12	AP	16.0	11.8	72.2	4	0.62	6.8	1.52	9.2	5.7
12-29	B 21	40.2	9.7	50.1	4	0.66	6.4	1.68	20.0	13.8
29-56	B 22T	41.1	9.3	49.6	19	0.53	6.6	1.49	25.2	13.9
56-81	2 B23T	37.1	10.2	52.7	18	0.41	6.6	1.55	21.4	11.0
81-118	2 B 24T	30.8	16.0	53.2	10	0.30	7.0	1.63	20.4	12.1

Alfisols at ICRISAT Center are medium deep, well drained, sandy loam to sandy clay loam at the surface occurring on nearly level to gently sloping uplands. They have 5-12 cm thick Ap horizon underlain by hard argillic horizons (there is an increase in clay content from A to B horizons). The soil clays are predominantly Kaolinitic with varying but small proportions of 2:1 clays and sesquioxides. The soils may contain well defined gravel and weathered rock fragments at lower depths. The top soils are friable, nonsticky when wet but hard when dry. The particle size distribution and mineralogy is such that easy slaking, packing, and compaction are favored. The soils possess inherently low water retention characteristics.

The Problem of Alfisols as a Resource for Crop Production

The following are some of the main problems to crop production in Alfisols.

1. Poor crop stand due to:

   a) Crusting
   b) Rapid drying of surface soil
   c) High soil temperature

2. Poor crop growth due to:

   a) Unreliable soil moisture supply

      i) Low soil moisture storage capacity
      ii) Low infiltration due to crusting, sealing, and consolidation
      iii) Drought spells during the crop growing season

   b) Low soil fertility

      i) Inadequate nutrient supply
      ii) Leaching of fertilizer

   c) Soil workability problems

   d) Compact sub-soil layer (argillic horizon)

3. Declining land productivity resulting from high soil loss due to:

   a) Poor crop canopy

   b) Crusting, sealing and consolidation

Poor crop stand:

On heavy textured Alfisols crusting is one of the primary causes of poor crop stands because it reduces germination by creating mechanical impedence to emerging seedlings. Its effects on small seeded crops such as pearl millet, finger millet, and sorghum are more drastic. On Alfisols good crop establishment is also jeopardized by a high risk of rapid surface soil drying due to erratic rainfall and very high radiation early in the rainy season. On light textured soils, temperature of this dry zone causes injury to emerging seedlings (**Sinclair, 1983; McCown, 1983**). Rapid surface drying combined with crusting (restricts water infiltration) can also result in localized droughts in the seed zone.

Poor crop growth:

The effects of unreliability of rainfall, especially early in the rainy season are accentuated by the low moisture holding capacity of Alfisols. Reliability of moisture supply for growth is further reduced by impaired infiltration caused by crusting and sealing. Moisture deficits is probably the most predominant factor for poor crop growth in the SAT Alfisols.

Alfisols are generally low in fertility (**Kanwar, 1983; El-Swaify et al., 1985**). Nitrogen is the most limiting nutrient for cropping SAT Alfisols. The sandy surface texture, low cation exchange capacity and inherently low concentrations of organic matter and rapid leaching act to keep nitrogen supply low. Phosphorus is the other limiting nutrient in the SAT Alfisols. The total amount of phosphorus in Alfisols is generally very low (less than 200 ppm), and while they do not fix or absorb large amounts of phosphorus (**McCown, 1983**) as they are not well buffered against removal of phosphorus from the system. While long periods of bush fallow tended to replenish nutrients, increased cropping intensity has resulted in widespread mining of nutrients of these soils, with drastic loss of productivity (**Ruthenberg, 1980**).

Workability of the Alfisols, is yet another problem which contributes to poor crop growth. These soils generally permit easy tillage when wet, but they become hard and difficult to till when dry. Tillage when the soil is too wet may result in excessive compaction. The high level of stoniness occasionally deter effective land preparation.

Characteristically, Alfisols possess an argillic horizon within the profile. Effective rooting depths of crops are many times limited by this compact argillic horizon which may restrict root penetration. Restricted root development on these soils prevents many crops from withstanding even moderate droughts; resulting in low yields.

Declining land productivity:

In the long term, the most serious problem of Alfisols is soil erosion (**Sanchez, 1976**). Multiple, diversified sloping topography and the unstable nature of the surface structure resulting in low depression storage, surface slaking, compaction, crusting, sealing and consolidation of soil profile causes greater runoff and soil loss from Alfisols. This is exhibited by the presence of low crop cover due to poor crop growth.

In summary the problems of crop production on Alfisols in the SAT are numerous and complex. However, most of the problems are related to the physical and chemical characteristics of the soils.

Developments in Improved Management for Optimized Productivity on Alfisols

The crop yields under the traditional management on Alfisols are very low (200 to 600 kg/ha). The traditional use and management which exists on the SAT Alfisols are discussed in detail by **Sanghi and Rao (1982)**, and **El-Swaify et al. (1985)**. The latter expressed serious concern about the excessive runoff and soil loss which are recorded from the traditional system of farming. Hydrologic studies of the traditional system at the ICRISAT Center have shown that, of the total rainfall potentially available, an average of about 26% is lost through runoff, 34% through deep percolation, and only the balance 40% is utilized for evapotranspiration by crops (**Table** 2). On average a high soil loss of 3.84 t/ha was recorded from the traditional system.

Table 2. Estimated water balance components and soil loss observed for the traditional cultivation system [a/] on Alfisols, ICRISAT Center (1978-83).

Year	Rainfall (mm)	Runoff (mm)	Evapo-transpi-ration (mm)	Deep percola-tion (mm)	Soil loss (t/ha)
1978	1060	391	395	274	5.19
1979	671	113	335	223	1.83
1980	765	149	345	271	1.62
1981	1130	292	415	423	5.61
1982	765	181	310	274	3.69
1983	990	276	375	339	5.07
1978-83 [b/]	100	26	40	34	3.84 [c/]

a/ Traditional varities of sorghum as sole crop and sorghum/pigeonpea as intercrop were grown.

b/ In percentage of rainfall

c/ Average annual soil loss

Experimental evidence however showed that these soils are capable of producing more food with improved technology. The results of research on physical components that were found to be promising for improving productivity are discussed below.

Land Management Systems

For lands having slopes less than 1.5%, the flat on grade system is found to be the most effective in reducing runoff and soil loss and in increasing crop yields (**Table 3**). Raised land configurations (broadbed and furrow, and narrow ridge and furrow) offered no particular advantages in terms of runoff, soil loss, and yield over the flat on grade system. They also posed problems resulting from low stability and complications in accomodating certain crop combinations. In raised land configurations, the expected benefits of high infiltration rates in the planting zone, and reduced velocity of overland flow were counteracated by the extremely low surface-depression storage and other problems resulting from turning the soil and exposure of the compact argillic horizon in the furrow zone (**Pathak et al., 1983**). Thus in Alfisols with moderate slopes unless furrow irrigation is required, the flat on grade configuration is probably the most effective. In Alfisols where supplemental irrigation is an essential part of the system, the narrow ridge and furrow configuration is the most appropriate one. It is because this system has been found to be the most efficient in application of the irrigation water. It is also the second best land configuration for Alfisols with respect to crop yields (**Table 3**).

Table 3. Effect of alternative land surface configurations on crop yield, runoff, and soil loss on Alfisols, ICRISAT Center (1981-84).

Land treatment	Crop yield (kg/ha) Intercropping system*		Runoff (mm)	Soil loss (t/ha)
	Sorghum	Pigeonpea		
Broadbed and furrow at 0.4%	2740	825	315	3.79
Narrow ridge and furrow at 0.4%	2910	870	282	3.02
Flat on grade at 0.4%	2960	875	172	2.05
Flat on grade at 0.4% plus ridging up later	2880	840	180	2.78
S E ±	121	65	15.8	0.144

For Alfisols having slopes more than 1.5%, a modified contour bund system is found to be the most promising (**Figure 2**). The contour bunding is widely practised system in the SAT, particularly on rainfed Alfisols in India. Results from this system showed that well designed and maintained contour bunds on Alfisols conserve soil and water effectively; for this specific purpose contour bunds are more efficient than graded and field bunds (**Pathak et al., 1983**). However, the system has disadvantages that include, water stagnation and restricted drainage in sizeable areas with in the fields during rainy season (**Figure 2**). In most years crop yields are reduced in areas where water is impounded. In modified contour bund system the original system is modified by installing gated outlets in the lower field sections, land smoothing, and planting on grade instead of on contour, which allow runoff water to be stored above the bund for a certain period and then released at the desired rate through the gated outlet. Most of the erosional sediments are deposited so that relatively sediment-free water drains through the outlet and releasing excess water considerably reduces water logging. This system when compared with alternative land management systems on watersheds at ICRISAT Center during 1981-84, consistently produced the highest crop yields, while still providing adequate control on runoff and soil loss (**Table 4**).

Table 4. Grain yield, runoff, and soil loss from different land-management systems, Alfisol watersheds, ICRISAT Center (1981-84).

Land-management System	Crop	Grain yield (kg/ha)	Runoff (mm)	Soil loss (t/ha)
Broadbed and furrow	Sorghum/	2740		
	pigeonpea	800		
			289	3.61
	Pearl millet/	2400		
	pigeonpea	920		
Contour bund	Sorghum/	2520		
	pigeonpea	920		
			75	0.97
	Pearl millet/	2230		
	pigeonpea	730		
Modified contour bund with gated outlet	Sorghum/	3020		
	pigeonpea	970		
			160	0.92
	Pearl millet/	2730		
	pigeonpea	1010		
Traditional flat with field bunds	Sorghum/	380		
	pigeonpea	220		
			256	4.79
	Pearl millet/	470		
		210		

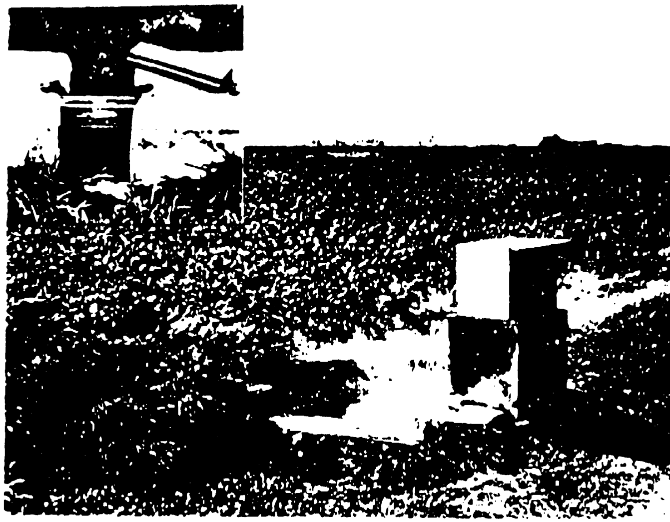

Figure 2. Contour bunding and gated outlets in the low section of the field.

Tillage

Primary tillage: Intensive primary tillage was generally found to be necessary for creating a favorable root proliferation zone and for enhancing rainfall acceptance on Alfisols. In SAT where residue management represents only a minor part of the cropping system, minimum tillage concepts are clearly at a disadvantage in dryland cropping of Alfisols (**El-Swaify et al., 1985**). At ICRISAT Center, **Klaij (1983)** reported promising results from the "split strip plowing" (an intensive tillage system). In a normal rainfall year this system increased pearl millet yield from 1503 kg/ha to 1841 kg/ha. The bulk density of the upper 20 cm soil layer was reduced to 1.48 g/cc from 1.55 g/cc in the control with normal tillage system. Clear benefits from deep tillage (cross chiseling) were recorded from a more systematic tillage experiment, conducted at ICRISAT Center. In addition to the higher crop yields, deep tillage was also effective in reducing runoff and soil loss (Table 5). There are also indications that the effects of deep tillage could last for 2 to 5 years depending upon the soil texture and rainfall.

Table 5. Effect of normal and deep primary tillage on sorghum yield, runoff, and soil loss on Alfisols at ICRISAT Center (1983).

Tillage	Sorghum yield (kg/ha)	Runoff (mm)	Soil loss (t/ha)
Normal tillage (mold board plowing 12 cm deep)	2160	285	3.27
Deep tillage (cross chiseling 25 cm deep)	2720	195	2.86
S E ±	130	15.0	0.234

Off-season tillage: On Alfisols the off-season tillage should be done whenever feasible. It has been found to be helpful in increasing the rain water infiltration and in decreasing weeds problems. It minimises stored-water evaporation by a "Mulching" effect and allows the acceleration of planting operations (which must be done at the onset of the rainy season) thereby permitting earlier sowing and extension of the growing season (El-Swaify et al., 1984). Experiments at ICRISAT Center during 1981-83 have shown that in most of the years off-season tillage alone can increase the crop yields by 7-9% over the control. In 1981 runoff from the first two storms were also reduced by 36% by the off-season tillage compared to no off-season tillage.

Crust and Seal Management

On Alfisols soil crust and seal formation are serious constraints to seedling emergence and soil and water conservation. One way to reduce the problem of crusting and sealing is by reducing the content of clay and silt particles in the surface layer. This is because, there is a positive relationship between the occurrence and strength of crusts with the content of clay and silt in surface soil. This implies that for Alfisols a non-turning tillage system, which in the long term will result in a relatively sandy soil surface is better suited than tillage with turning plows (inversion brings soil from argillic horizon which contains much higher clay and silt). In a small plot experiment at ICRISAT Center a 6 cm layer of sandy soil was spread on the soil surface to simulate a surface layer which is enriched in sand by avoiding turning. This resulted in increasing crop yields and reducing runoff and soil loss (**Table 6**). Lower penetration resistance was recorded in this surface than in the surface of the control treatment. Although the formation of sandy surface may take long time, the initial experimental indications show that it is possible to achieve such layer by using non-turning tillage.

Table 6. Effect of different levels of clay and silt content of surface soil (6 cm) on crop yield, runoff, and soil loss on Alfisols, ICRISAT Center (1982-84).

Treatment	Crop yield (kg/ha) Intercropping system		Runoff (mm)	Soil loss (t/ha)
	Pearl millet	Pigeonpea		
Soil I				
(Simulating soil surface for normal tillage)	2340	1070	310	4.52
Soil II				
(Sandy soil surface simulating nonturning tillage)	2780	1290	180	2.57
S E ±	132	97	19.1	0.353

Texture of soil I: Clay 16%, silt 5%, fine sand 27%, coarse sand 47%, and gravel 5%.

Texture of soil II: Clay 4%, silt 3%, fine sand 23%, coarse sand 64%, and gravel 6%.

On Alfisols the problems of crusting and sealing are encountered more during the early part of the crop growing season when the crop canopy is not yet fully developed. During this period considerable runoff was observed even when the soils were very dry. At ICRISAT Center the shallow tillage imposed as additional intercultivations has been found to be effective in breaking up the crust and improving infiltration. It was found that additional shallow tillage effectively reduced runoff and soil loss. In some years it was also effective in reducing moisture losses through evaporation by creating a dust mulch. However, significant increase in crop yields due to additional shallow intercultivations was obtained only in normal and low rainfall years.

Crop Residue Management

In long term, a 'farming systems' design which assures the generation and maintenance of favorable structural conditions would be critical to the successful use of Alfisols. The incorporation of beneficial organic matter can be a likely means of achieving favorable soil organic matter contents and in turn a better structure in the SAT Alfisols. However, in an experiment at ICRISAT Center when undecomposed crop residue (5 t/ha) were incorporated into the soil, it created several serious problems (nitrogen deficiencies, etc.). The crop yields were drastically reduced. This suggests that under semi-arid environment the large amount of undecomposed crop residue should not be incorporated into the soil.

The use of organic matter as surface mulch and incorporation into the soil in subsequent years has been useful for achieving favorable rainfall infiltration, reduced soil erosion, and structural stability. At ICRISAT Center this system is found to be very effective in reducing runoff and soil loss and increasing crop yields (**Table 7**). Since 1981-82 was the first year of the experiments the effects seen in that year were of surface mulching alone. Where as in 1983-84 the effects shown in the table 7 were due to combination of surface mulching and improvement in soil structure. During 1981-82, the mulch rate of 10 t/ha reduced the seasonal runoff by 74% and soil loss by 80% compared with no-mulch. In the same year this rate increased the sorghum yield by 9% and the pigeonpea by 35% above the no-mulch treatment. It may be worth noting the differences in effectiveness of 5 t/ha and 10 t/ha treatments during

1981-82 and 1983-84. During 1981-82 the differences are quite significant. However, during 1983-84 the differences are very marginal. This was mainly due to the improvement in soil structure suggesting that in latter years the mulch rates can be gradually reduced.

Table 7. Effect of different levels of organic mulch on crop yield, runoff, and soil loss on Alfisols, ICRISAT Center (1981-84).

Mulch rate (t/ha)	Crop yield (kg/ha) Intercrop system		Runoff (mm)	Soil loss (t/ha)
	Sorghum	Pigeonpea		
	1981-82			
No mulc	2790	1340	391	5.93
2.5	2800	1390	295	3.44
5.0	2980	1500	208	2.40
10.0	3040	1810	101	1.19
SE ±	116	99	4.9	0.221
	1983-84			
No mulch	2320	720	307	4.2
2.5	2670	810	123	2.3
5.0	2890	980	27	0.8
10.0	3040	1070	18	0.4
SE ±	132	66	12.0	0.150

Water Harvesting for Supplemental Irrigation

There is considerable evidence that runoff water could be used to optimize the production on SAT Alfisols. On Alfisols, the potential for delivering excess rain water to runoff storage structure is extremely good since even improved system of farming results in the loss 15-35% of the seasonal rainfall as runoff. The high runoff produced by Alfisols during the early part of the rainy season (**Pathak et al., 1983**) provides a dependable surface water source for most of the season. An analysis of six years data collected from three tanks on Alfisol watershed at ICRISAT Center showed that these tanks held sufficient water for supplemental irrigation during the dry spells. Even in the least runoff producing year, more than 35 mm of water (on catchment area basis) was present in the tanks during periods when the probability of drought was high.

Tank storage in these soils is often hampered by high seepage rates. A long term analysis using the runoff model developed by **Pathak et al. (1984)** has shown that on Alfisols tank can supply the water needed for supplemental irrigation only when the average seepage rate is below 15 mm/day. The low cost sealing techniques for storage tanks are yet to be developed. Among the various lining materials tried on Alfisols, cement with sand in a ratio of 1:8 has been effective in reducing percolation loss (**Hegde et al., 1981; Maheshwari, 1981**). Natural siltation of tanks greatly reduces the seepage losses. This aspect certainly needs more study. Studies on two tanks at ICRISAT Center have shown that in 4 years the average seepage rate was reduced from 26 mm/day to 11 mm/day through natural siltation.

On Alfisols, striking benefits have been reported from supplemental irrigation at ICRISAT (**El-Swaify et al., 1985; Srivastava et al., 1985**) and else where (**Hegde et al., 1981**). Good yield responses, were obtained in both rainy and post rainy season (**Table 8**). In sorghum/pigeonpea intercrop two irrigations of 40 mm each have given an additional gross return of 2750 Rs/ha. The highest additional gross return from supplemental irrigation were obtained by growing the tomato (7870 Rs/ha). The irrigation water use efficiency for pearl millet, sorghum, cowpea, pigeonpea, and tomato were found to be 12, 18, 20, 23, and 93 Rs/mm/ha respectively. These results indicate that on SAT Alfisols significant returns can be gained from relatively small quantities of supplemental water on rainy and post-rainy season crops of for example sorghum, pearl millet, pigeonpea, cowpea and high value products such as tomato and other vegetables.

The above discussion shows that on Alfisols improved water management, land development and soil conservation practices combined with efficient cropping systems can contribute significantly toward greater productivity with less uncertainity. With the improved practices the crop productivity of SAT Alfisols could be increased by five to six times and the losses of soil and water could be reduced by 80% and 50% respectively compared to the traditional systems.

Table 8. Additional gross returns due to Suplemental Irrigation and Irrigation Use Efficiency (IUE)[1/] on an Alfisol watershed, ICRISAT Center.

Cropping system	Grain yield (kg/ha) Control	One irrigation of 40 mm	Two irrigations of 40 mm each	IUE (Rs/mm/ha)	Combined IUE (Rs/mm/ha)	Combined additional gross returns due to supplemental irrigation (Rs/ha)
Pearl millet/[2/]	1950	2353	-	12	17	2093
Pigeonpea	773	-	1197	20		
Sorghum/[3/]	2560	3155	-	18	23	2747
Pigeonpea	685	-	1220	26		
Pearl millet +[2/]	2170	2577	-	12	18	2104
cowpea	310	-	735	20		
Pearl millet +[3/]	1865	2215	-	11	66	7870
Tomato	11350	-	26250	93		

1/ Irrigation Use Efficiency (IUE) = Addl.gross returns due to irrigation / Depth of irrigation

2/ Average of 3 years (1981-84)

3/ Average of 2 years (1981-82 and 1983-84)

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