Physical and Conservation Constraints and Management Components for SAT Alfisols

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Abstract

The Alfisols of the semi-arid tropics are well-drained soils but possess low water-storage capacities. They are therefore cropped only during the rainy (monsoon) season. With traditional rainfed farming the soils are both unproductive and prone to excessive runoff and erosion. Efforts to improve management of these soils for conventional cropping have succeeded in increasing crop yields over traditional management systems but effective practices for improved soil and water conservation remain to be formulated. This is primarily because of the extreme structural instability of the soils. Physical components of improved management have been subject to many investigations and many promising trends have emerged but no integrated set of practices can as yet be confidently recommended for sustaining agricultural productivity on small farms. In this background paper evidence primarily from research at ICRISAT is used as a basis for discussion of the physical constraints and the promising developments that have been made in improving the conservation and management of these soils.

Introduction

The diversity of soils in the semi-arid tropics (SAT) is clearly indicated by the fact that 8 of the 10 orders in Soil Taxonomy (USDA Soil Survey Staff 1975) are represented in this region. Table 1 shows that nearly 33% of the land area in the SAT is occupied by Alfisols (6.96 million km^2). Associated soils are primarily the Aridisols (5.20 million km^2), Entisols (2.72 million km^2), Oxisols (1.88 million km^2), and Vertisols (1.31 million km^2). The Aridisols and Entisols may be considered as related soils, particularly in the African SAT. SAT environments are identified at the suborder level within the ustic moisture regime. This term implies dryness during parts of the year, but "moisture is present at a time when conditions are suitable for plant growth" (USDA Soil Survey Staff 1975). The specific definition of ustic is based on mean annual soil temperature, and duration of the period in which the control section of the profile remains moist or dries out. By this definition, the ustic regime occurs in tropical regions, with a monsoon climate that has at least one rainy season lasting 3 months or more in a year.

Table 1. Soils of the semi-arid tropics

	Area (million km^2)			
Soil order	Africa	Latin America	Asia	Total
Alfisols	4.66	1.07	1.21	6.96
Aridisols	4.40	0.33	0.47	5.20
Entisols	2.55	0.17	-	2.72
Inceptisols	0.38	-	0.28	0.66
Mollisols	-	0.78	-	0.78
Oxisols	1.88	-	-	1.88
Ultisols	0.24	0.08	0.20	0.52
Vertisols	0.51	-	0.80	1.31
Others	-	0.70	0.23	0.93
Total	14.62	3.13	3.19	20.94

Source: Kampen and Burford 1980.

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Alfisols in the semi-arid tropics. Proceedings of the Consultants Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1-3 December 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

All the forementioned soils are used for agricultural production, and come under a wide variety of "traditional", "improved", or "developed" methods of farming These, together with general reviews of soil resources in the tropics and the SAT are given in Sanchez (1976), Swindale (1982), and Kanwar (1983) The major characteristics of several tropical soil orders, including Alfisols, are provided in a recent document on soils of variable charge (Theng 1980) These inventories, however do not specifically document the experiences that have been acquired in recent years on major constraints to productivity and optimized management of SAT Alfisols

This paper reviews recent studies on the physical constraints and the developments that have been made in soil and water management and conservation to optimize productivity of these soils under rainfed conditions

Alfisols are represented within the experimental farm of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) by the Patancheru soil series This soil, a Udic Rhodustalf, will therefore be central to the discussions that follow Its major characteristics are shown in Table 2 Available information from other locations in the SAT will be presented where relevant

Relevant Characteristics of SAT Alfisols

Alfisols possess an argillic horizon within the profile Hence the clay content of these soils increases with depth although shallow and gravelly Alfisols are also common as a result of erosion The enrichment of surface layers with coarse particles is assumed to be the result of clay migration with percolating water, termite activity, and/or selective removal of fine particles by erosion The soils may contain distinct layers of gravel and weathered rock fragments at lower depths (often called murrum) How the presence of stone in these layers effects several Alfisol properties is shown in Fig 1 Effective rooting depths of crops are restricted either by the limited soil depth imposed by the presence of such layers, or by the compact argillic horizon that may restrict root penetration Restricted root development on these soils prevents many crops from withstanding even moderate droughts Hence, poor crop yields are common

Alfisols—at least those cultivated in the SAT—are characterized by lack of structural development, this results from a low content of fine (clay-sized) particles particularly in the surface horizon clay minerals of low activity (kaolins with varying but small proportions of 2 1 layer-lattice clays and sesquioxides), and—with the cropping systems prevalent in the SAT—the tendency to stabilize only minute amounts of decomposed organic matter within the soil mass The increased clay content with depth often distinguishes these soils from other "sandy" soils (e g , Entisols) However, since soils in many SAT regions have not been described according to Soil Taxonomy, it is difficult to retrieve from the literature precise global information on experiences with these soils

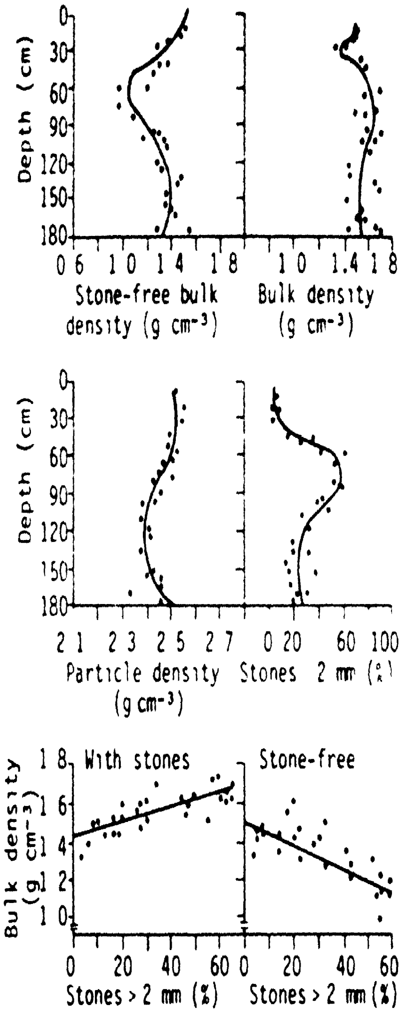

Figure 1 Bulk density, particle density, and the percentage of stones in Alfisols

A major consequence of the lack of aggregation, or unstable aggregation, is the tendency of these soils to display rapid surface-sealing following rainfall, and crusting with subsequent drying cycles This

Table 2 Major characteristics of the Patancheru soil series a Udic Rhodustalf at ICRISAT Center

Horizon	Depth (cm)	Size class and particle diameter (mm): Sand (2 0 0 02)	Silt (0 02 0 002)	Clay (< 0 002)	Coarse fragments (> 2 mm) % of whole soil	Organic carbon (%)	pH (1 2 5) H$_2$O	EC (1 2 5) suspension	Water retention 1/3 bar	15 bar
		% of 2 mm soil particle							Gravimetric %	
Ap	0-5	79.3	6.4	14.3	17	0.55	6.0	0.1	16.2	6.3
B 1	5-18	66.7	5.5	27.8	17	0.57	6.9	0.1	20.0	12.4
B 2t	18-36	41.6	6.8	51.6	36	0.63	6.9	0.1	21.9	13.9
B 2	36-71	45.0	4.4	50.6	54	0.30	6.8	0.1	24.8	17.[illegible]
B 2t	71-112	54.1	7.4	38.5	50	0.10	6.5	0.1	23.6	16.[illegible]
B 3	112-140	70.6	4.1	25.3	63	0.18	6.2	0.2	18.7	11.[illegible]

Depth (cm)	Extractable bases: Ca	Mg	Na	K	Sum	CEC NH$_4$OAC	Base saturation (%)	CEC Clay ratio	Clay fraction mineralogy[1]: Am	KK	MI	SM	QZ	Sand fraction mineralogy[2]: QZ	FDM	FE	HE	FDP	Others
	meq 100 g																		
0-5	2.6	0.5		0.4	3.5	4.8	74	0.34	11	3		1	1	35	25	10	10	5	15
5-18	3.8	0.9		0.5	5.2	8.2	64	0.29	12	32		13	14	45	20	5	5	10	15
18-36	5.8	3.8		0.6	10.2	14.8	69	0.29	14	37	1	23	13	40	30	10		10	10
36-71	7.9	3.1		0.6	11.6	14.1	82	0.28	12	38	11	20	16	30	30	5	5	15	15
71-112	5.4	2.5	0.3	0.4	8.6	9.8	88	0.25	12	44	8	18	16	40	20	5		10	25
112-140	5.7	1.9	0.5	0.3	8.4	9.1	92	0.36	10	19	8	21	16	35	25	5		15	20

1 Clay fraction mineralogy Am Amphibole KK Kaolinite MI Mica SM Smectite QZ Quartz
2 Sand fraction mineralogy QZ Quartz FDM Feldspar microline FE Magnetite HE Haematite and FDP Feldspar plagioclase

crusting can adversely affect plant establishment (Figs 2 and 3) It often extends deeper than the immediate soil surface, resulting in consolidation of the soil profile (slumping) to a depth that is determined by several factors Apparently the particle-size distribution (and mineralogy) favors slaking, packing and compaction Thus, although the soils permit easy tillage when wet, they become hard and difficult to till when dry Tillage when the soil is too wet may result in excessive compaction Hence only a limited soil moisture range is available for producing optimum tilth El-Swaify (1983) attributes the lack of consistent success in managing these soils under rainfed conditions to several physical factors as discussed below

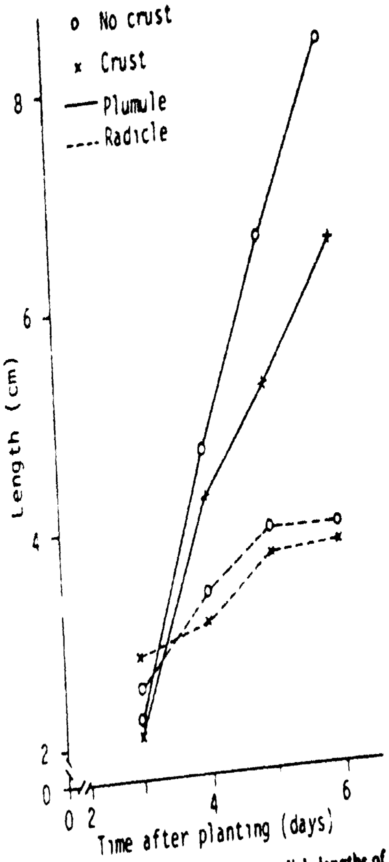

Figure 3. Changes in plumule and radicle lengths of sorghum seedlings under crust and no-crust treatments following planting.

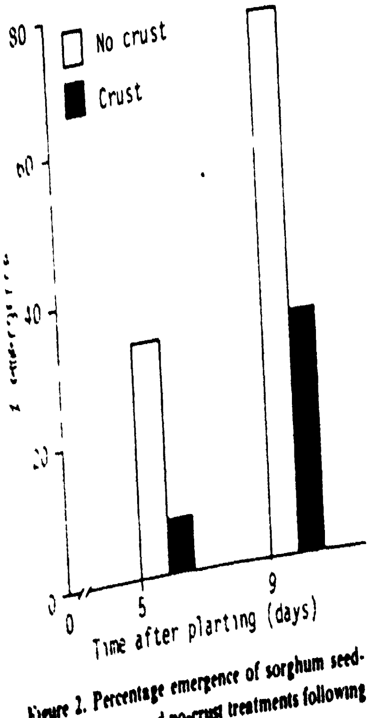

Figure 2. Percentage emergence of sorghum seedlings under crust and no-crust treatments following planting.

Alfisols generally possess inherently low water-retention characteristics because of their particle-size makeup and mineralogical composition This is often compounded by the shallow depth of the soil zone available for water storage Lack of water storage combines with mechanical impedence problems in these hardening soils to limit crop-root proliferation Improvements in medium characteristics as a result of tillage are only temporary because of the lack of structural stability The structural instability and subsequent frequent failures in land-surface configurations lead to a reduction in surface roughness (useful for maximizing infiltration) and enhancement of surface-sealing and crusting (Weststeyn 1983) These on the one hand induce excessive runoff even early in the season and, on the other, directly affect seedling emergence Direct effects on crops are more drastic with small-seeded crops such as pearl millet, finger millet (*Eleusine coracana*) and sorghum Localized droughts are also very likely in the seed environment, i e, in ridges or beds into which water entry by infiltration is restricted by surface-sealing Crusted soil surfaces are also presumed to be prone to increased evaporative water loss

Raised-land surface configurations, installed as conservation measures, lead to excessive concentrations of induced runoff in the furrows which then undergo rilling and exaggerated erosion. In many SAT Alfisols, workability in the dry state and stoniness appear to be deterrents to effective land preparation. Since the soils are generally well-drained, leaching of water-soluble fertilizers is a common occurrence with heavy rainstorms (C W Hong 1983, ICRISAT, personal communication) Such losses are particularly enhanced by the soils' low nutrient-retention capacities (cation-exchange capacity values range between 1 and 10 meq 100 g^{-1})

Table 3 Physical properties of two Alfisol profiles at ICRISAT Center

Depth (cm)	Stone content %[1]		Bulk density ($g\ cm^{-3}$)		Moisture content at[2] 15 bar		0.3 bar
	ST2	RA10	ST2	RA10	ST2	RA10	ST2
0-15	2.4 ± 0.8	10.9 ± 9.1	1.55 ± 0.22	1.57 ± 0.20	6.0	8.6	8.3
15-30	1.5 ± 0.8	7.7 ± 6.0	1.64 ± 0.15	1.72 ± 0.19	10.2	10.3	13.5
30-45	0.6 ± 0.8	2.9 ± 1.7	1.59 ± 0.07	1.67 ± 0.10	14.8	10.4	18.7
45-60	2.2 ± 4.8	1.4 ± 0.5	1.59 ± 0.12	1.63 ± 0.11	16.1	14.2	20.3
60-75	4.3 ± 10.4	2.3 ± 1.3	1.64 ± 0.04	1.71 ± 0.10	17.1	15.7	21.1
75-90	5.0 ± 13.0	11.1 ± 19.7	1.60 ± 0.04	1.79 ± 0.12	17.2	15.8	21.8
90-105	6.6 ± 10.1	16.2 ± 20.2	1.68 ± 0.10	1.83 ± 0.15	17.7	16.0	21.7
105-120	11.2 ± 13.6	30.3 ± 27.8	1.65 ± 0.09	1.85 ± 0.14	17.6	16.9	21.5
120-135	12.4 ± 14.5	21.7 ± 18.4	1.75 ± 0.10	1.81 ± 0.16	16.8	16.6	20.6
135-150	18.1 ± 17.8	26.3 ± 8.1	1.70 ± 0.09	1.86 ± 0.16	16.4	16.4	20.6
150-165	28.0 ± 14.7	33.1 ± 14.1	1.80 ± 0.11	1.86 ± 0.05	15.7	16.8	20.1
165-180	30.7 ± 10.0	31.0 ± 15.9	1.74 ± 0.08	1.83 ± 0.13	14.9	16.4	19.6
180-195	16.6 ± 14.2	35.1 ± 21.6	1.80 ± 0.14	1.89 ± 0.20	15.0	ND	19.6

[1] Mass percentage of material 2 mm

[2] On a mass basis in stone free samples

The lack of active clays in Alfisols also indicates that organic matter has an important role in controlling the soil's structural characteristics This is one important reason why management of Alfisols for sustained agricultural productivity may be comparatively easy in the humid tropics In the humid tropics, abundant and uniformly distributed rainfall allows continuous biological activity and buildup of organic matter to fairly high levels

The erodibility of Alfisols appears to vary widely The universal soil loss equation's K value has been reported to be as high as 0.4 or more, indicating that the soils are quite susceptible to erosion by water (El-Swaify and Dangler 1982)

It is important to emphasize at this point that Alfisols display wide diversity and spatial variability Therefore, Table 2 may be accepted only as representative of Udic Rhodustalfs at the precise sampling and description site Even within ICRISAT's farm, much variability is encountered in the properties of the Patancheru series Tables 3, 4a, and 4b include quantitative data for selected physical properties of various Alfisols at ICRISAT Center

Table 4a Bulk density ($g\ cm^{-3}$) of selected Alfisols at ICRISAT Center.

Depth (cm)	Location RP17	RCW20	RP1	RUS5
0-15	1.55	1.57	1.54	1.71
15-30	1.64	1.72	1.58	1.74
30-45	1.59	1.62	1.58	1.62
45-60	1.59	1.63	1.56	1.54
60-75	1.64	1.71	1.57	1.56
75-90	1.60	1.79	1.60	1.61

Table 4b. Particle size distribution of selected Alfisols at ICRISAT Center

Depth (cm)	Location RUS5			RW2C			RW3		
	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
0-15	88	6	8	88	4	8	73	10	17
15-30	69	8	23	85	6	9	55	9	36
30-45	55	6	39	76	5	19	48	10	42
45-60	47	10	43	66	6	28	45	12	43
60-75	46	9	45	59	9	32	47	9	44
75-90	48	9	43	65	8	27	46	9	45

Dryland Management Options for SAT Alfisols

Traditional uses and management

In contrast to Vertisols, rainfed cultivation of Alfisols in the semi-arid tropics is practiced only during the rainy season The growth period for sequential cropping is extended into the postrainy season where water is available for supplemental irrigation For certain rainfed intercropping combinations, the season extends to the end of the long-duration crop (e g , castor) The main traditional crops include sorghum, pearl millet, finger millet, groundnut, pigeonpea, cotton, castor, green gram (mung bean) and black gram (*Vigna mungo*) These are grown as sole crops, in discrete mixtures or as intercrops Farmers prefer mixtures or intercropping especially in low-rainfall regions because such combinations reduce the risk associated with variable and unpredictable moisture situations, and allow taking maximum advantage of both good and poor rainfall years Intercropping of cereals with pulses or oilseeds is most common the farmer requires these for food and cash purposes (Jodha 1980) In the Indian SAT, supplemental irrigation from tanks (small, surface reservoirs) or wells is common on Alfisols In such cases, farmers prefer paddy rice, sugarcane, tobacco, groundnut, and maize as the main crops

With their poor water-retention characteristics, rainfed cropping of Alfisols faces the constant threat of deficient soil moisture even during relatively short dry spells Common crop failures discourage farmers from making substantial investments for improved management (Kampen 1980) Therefore they generally plant traditional crop varieties with little or no chemical fertilizer Even in dependable-rainfall regions, the average yields are very low Village-level surveys of some Alfisol areas in India (Rastogi et al 1982, Sanghi and Rao 1982) have revealed the following average yields for major crops

Sorghum	300-500 kg ha^{-1}
Pearl millet	300-450 kg ha^{-1}
Castor	300-550 kg ha^{-1}
Pigeonpea	200-300 kg ha^{-1}
Groundnut	400-600 kg ha^{-1}

Since dry soils are quite difficult to handle before the monsoon, all agricultural operations are conducted following the onset of the rainy season Often therefore, the fields are relatively bare when the monsoon begins Further, the nonstable structure of these soils enhances their tendency to develop surface seals that reduce infiltration and profile recharge, even when rains are moderate These seals harden into crusts during intermittent dry periods Such conditions deter the establishment of adequate protective crop cover early in the season As a consequence, the traditional system of farming induces excessive runoff and soil loss Later in the growing season, poor crop establishment, coupled with continued poor growth, result in very low rainfall utilization

Hydrologic studies conducted at ICRISAT on the traditional farming system have shown that, of the total rainfall potentially available, an average of about 26% is lost through runoff, 33% through deep percolation, and only the balance 41% is utilized for evapotranspiration by crops (Table 5) For cropped Alfisols—whose physical and fertility status are generally marginal, and the profile often shallow—excessive runoff and soil losses represent further degradation of the resource b[illegible] and lead to a further decline in productivity

Table 5 Estimated water-balance components and soil loss observed for the traditional cultivation system[1] on Alfisols at ICRISAT Center

Year	Rainfall (mm)	Runoff (mm)	Evapotranspiration (mm)	Deep percolation (mm)	Soil loss (t ha^{-1})
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
1978-81[2]	100	26	41	33	3 71[3]

1 Traditional varieties of sorghum as sole crop and sorghum pigeonpea as intercrop were grown

2 In percentage of rainfall

3 Average annual soil loss

Developments in improved management for optimized productivity

Our present knowledge about Alfisols—in contrast to that about Vertisols, on which the broadbed-and-furrow (BBF) technology is proving quite promising for optimized management (Kampen 1982)—does not provide a clear and tested approach in management that can be recommended as part of a "technological package" for optimizing the productivity of Alfisols under rainfed conditions In particular, land- and soil-management techniques that are effective in reducing runoff and erosion imparting structural stability to the soil, improving water-storage characteristics, and reducing sealing and crusting are yet to be defined

There are clear indications, however, that most SAT Alfisols do possess a much higher productivity potential than that indicated by yields obtained through traditional farming (shown earlier) Randhawa and Venkateswarlu (1980) report yields of 3500 kg ha^{-1} for hybrid sorghum, 1500 kg ha^{-1} for improved castor, and 2700 kg ha^{-1} for finger millet on Rhodustalfs in southern India The results of research on physical components that were found promising for improving productivity are discussed below

Land smoothing and installation of field drains are essential for improved management of Alfisols Landscapes common in farmers' fields are generally quite uneven, with many depressions of various sizes Small, surface depressions that are obliterated through normal tillage operations are not subject to waterlogging But large depressions are generally more stable and act as receiving basins for erosional sediments Once these sediments are deposited, waterlogging often results Crop yields from such areas were 10-35% less than that from other areas Pathak 1981, unpublished report, ICRISAT) Uneven land surfaces also create problems in arrying out various agricultural operations, e g , illage or planting, at the proper depth Higher ermination percentages were recorded for pearl millet and sorghum in fields with proper smoothing s compared to those without (Pathak 1981, npublished report, ICRISAT) To alleviate the influence of such depressions, it is necessary to smoothen the land surface, and this is done most efficiently in the direction of planned cultivation

Since high runoff is frequent on Alfisols, provision must be made for early and safe removal of excess runoff during the growing (rainy) season The urgency to reduce runoff must be tempered by the need to improve surface drainage during wet periods, in view of the fact that the profile's capacity for water storage is often very limited Also, the need to reduce or enhance runoff must be assessed, keeping in view a predetermined strategy for water-resource development and use Should surface storage of excess runoff water for supplemental irrigation be determined as the feasible alternative, the system should be designed to yield and store sufficient runoff for this purpose Conversely, maximum water entry into the soil should be facilitated through various ponding techniques when accessible subsurface water storage is possible

Tied ridging (installation of furrow-dams) has been extensively tried in the African SAT as an in situ soil- and water-conservation system Under certain circumstances, the system not only helped reduce runoff and soil loss but also increased crop yields (Lawes 1961 and 1963, and Dagg and Macartney 1968) However, during high rainfall years, or in years when relatively long periods within the rainy season were very wet, significantly lower yields were reported from systems using tied ridges than from graded systems that disallowed surface ponding of water (Lawes 1963, Dagg and Macartney 1968) Under such conditions, tied-ridging enhanced waterlogging, development of anaerobic conditions in the rooting zone, excessive fertilizer leaching, and rise of the water table in lower-slope areas (Kowal 1970)

Hudson (1971) expresses serious concern about overtopping of tied ridges, and emphasizes that these systems should be designed so that the ties are lower than the ridges, which should themselves be graded so that excessive runoff is released along the furrow and not down the slope Further, a support system of conventional contour terraces must be installed to cope with runoff from exceptional storms Lawes (1961, 1963, and 1966) compared the performance of alternative designs with open free-draining furrows, alternate cross-tied furrows, all furrows cross-tied, and all furrows cross-tied with mulch His results showed that tying alternate furrows alone, or tying all furrows in combination with mulching, significantly improved yields of cotton compared with open furrows and tied unmulched furrows in both dry and wet seasons (889 mm and 1303 mm rainfall) With groundnut and sorghum, the effects of treatment were less prominent

The comparative advantages of other land configurations for effective soil and water conservation have been the subject of many investigations (Pathak et al 1985) In significant contrast to Vertisols, Alfisol watersheds under the BBF system generated decisively more runoff and soil loss than various flat culture designs tested Table 6 shows the superiority of the flat systems with contour or graded bunds, over BBF and traditional methods These trends were confirmed for both low- and high-rainfall years (Table 7) These results were attributed to the tendency of BBF-shaped fields to undergo surface smoothing along the slope resulting in low surface depression, and exposure of soil layers with low infiltration rates (e g the argillic horizon) while constructing furrows In the BBF system nearly one-third of the land area is in furrows, with initial infiltration rates about one-third of those on undisturbed soil Alfisols differ from Vertisols in yet another way small and moderate storms (arbitrarily defined as those with <90 mm rainfall) contribute a major share of seasonal runoff (34-69%) and soil loss (45-75%) on BBF For large storms, there was little difference between the various land configurations (Pathak et al 1985)

The flat-on-grade system was not only most effective in reducing runoff and soil loss but also produced slightly higher crop yield than the other land configurations (Table 8) Raised land configurations (broadbed-and-furrow narrow-ridge-and-furrow and wave-type broadbed-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, seemed to be counteracted by the extremely low surface-depression storage and by other problems resulting from turning the soil and exposure of the compact argillic horizon in the furrow zone Thus, in Alfisols, unless furrow irrigation is required, the flat-on-grade configuration is probably the most effective

Table 6 Effects of alternative land-management systems on annual runoff, soil loss, and peak runoff rates from Alfisol watersheds (average annual values, 1975-79).

Treatments	Rainfall (mm)	Runoff (mm)	Runoff % of seasonal rainfall	Peak runoff rate[1] (m^3 s^{-1} ha^{-1})	Soil loss (t ha^{-1})
Flat with graded bunds at 0 6% slope	837	135	16 1	0 14	1 87
BBF at 0 6% slope	831	238	28 6	0 25	3 40
Flat with contour bunds	836	110	13 2	0 10	0 85
Traditional flat with farmers' field bunds[2]	790	165	20 9	0 15	2 52

1 Maximum peak runoff rate 1975-79

2 Watershed monitored from 1976 to 1979 Values reported are based on these 4 years

Source Pathak et al 1985

Table 7 Annual rainfall, runoff, soil loss, and peak runoff rate for an Alfisol in a flat, graded-bunds system and a BBF system (1975-79)

	Flat with graded bunds at 0 6% slope				BBF at 0 6% slope			
Year	Rain-fall (mm)	Runoff % of seasonal rainfall	Peak runoff rate (m^3 s^{-1} ha^{-1})	Soil loss (t ha^{-1})	Rain fall (mm)	Runoff % of seasonal rainfall	Peak runoff rate (m^3 s^{-1} ha^{-1})	Soil loss (t ha^{-1})
1975	1103	15 0	0 13	2 10	1104	27 9	0 20	4 20
1976	662	21 2	0 14	2 00	684	27 9	0 25	2 81
1977	549	5 3	0 06	0 56	563	14 2	0 10	1 13
1978	1048	19 8	0 13	2 81	1060	33 6	0 17	5 00

Source Pathak et al 1985

Table 8 Effects of land management on runoff, erosion, and crop yields on Alfisols (Average of 1981-82 and 1982-83)[1]

Land treatments	Crop yield: Sorghum (kg ha^{-1})	Crop yield: Pigeonpea (kg ha^{-1})	Runoff (mm)	Soil loss (t ha^{-1})
Broadbed-and-furrow at 0 4%	2545	775	272	3 56
Narrow ridge-and-furrow at 0 4%	2560	785	296	3 20
Flat-on-grade at 0 4%	2710	825	186	2 10
Flat-on-grade plus ridging-up later at 0 4%	2690	820	215	2 61

1 Total rainfall = 921 mm Source Pathak 1984

Operational-scale research at ICRISAT, over a period of 6 years, has confirmed that clear benefits to soil and water conservation, and substantial increases in crop yield, can be obtained by using a number of improved management practices (Pathak 1984) Among these, the modified contour-bund system that includes gated outlets, involves land-smoothing and planting on grade instead of on contour, is the most promising (Table 9) In addition to a low annual runoff of 162 mm and soil loss of 1 38 t ha^{-1}, this system has been found to increase pearl millet yield by 19% and that of pigeonpea by 16%, compared with the BBF system (pearl millet yield, 1920 kg ha^{-1}, pigeonpea yield, 940 kg ha^{-1})

Table 9 Effects of different systems of farming on runoff and soil loss on Alfisol watersheds, 1981

Treatment	Runoff (mm)	Soil loss (t ha^{-1})
Traditional system	248	4 68
Contour bund system	92	1 01
Modified contour bund system	162	1 38
Broadbed-and-furrow system	298	4 12

Total rainfall = 1094 mm Source Pathak 1984

There is considerable evidence to show that the tillage operations (particularly primary tillage) selected should be appropriate if continuous cropping of SAT Alfisols is to be successful This is in contrast to the humid tropics where considerable success has been reported with minimum tillage (Lal 1977 and 1980) Intensive primary tillage of SAT Alfisols was generally found necessary for creating a favorable zone for root proliferation, and for enhancing rainfall acceptance by the soil Secondary tillage operations are necessary for seedbed preparation, and for weed control because herbicide use is still limited in the SAT Since these soils generally undergo severe hardening during the dry season, cultivation is difficult before the rainy season When powerful implements are utilized to permit plowing in dry conditions, the results are generally undesirable as large hard clods are created that necessitate further intensive tillage to produce a suitable seedbed (Rawitz et al 1981) When cultivation must await the moistening of the topsoil, the effective length of the growing season is appreciably reduced and the farmer has to conduct all the required operations within a short period Plowing at the end of the cropping season can, in some circumstances, be used to overcome these problems Studies at Raichur (India) showed that Alfisols subjected to summer plowing had a higher rainfall-intake capacity than soils that were not (Hadimani and Perur 1971) Even shallow surface cultivation was found to be of advantage in helping the early rainwater to soak deeply into the soil Hadimani et al (1982) observed that rainwater penetrated to a depth of 30 cm in harrowed plots, but to only 15 cm in adjacent unharrowed plots

The benefits of intensive tillage in terms of crop performance have been documented on many Alfisols In Senegal, with shallow hoe cultivation the bulk density of the top few centimeters of soil decreased from 1 6 to 1 4 g cm^{-3} With plowing by tractor the [illegible] to a depth of 10-30 cm [illegible] 1971, Charreau 1972). In these [illegible] g cm⁻³ in bulk density signifi- [illegible] development and crop yields. [illegible] Charreau and Nicou (1971), and [illegible] (1979) found very clear relation- [illegible] as reflected by poros- [illegible] indices of root development [illegible] crop yields. Nicou and Chopart [illegible] the proliferation of the root [illegible] millet, and groundnut could be [illegible] more than 100% in soil depths [illegible] through cultivation that need [illegible] Nicou (1977) has made similar [illegible] hypothesized that

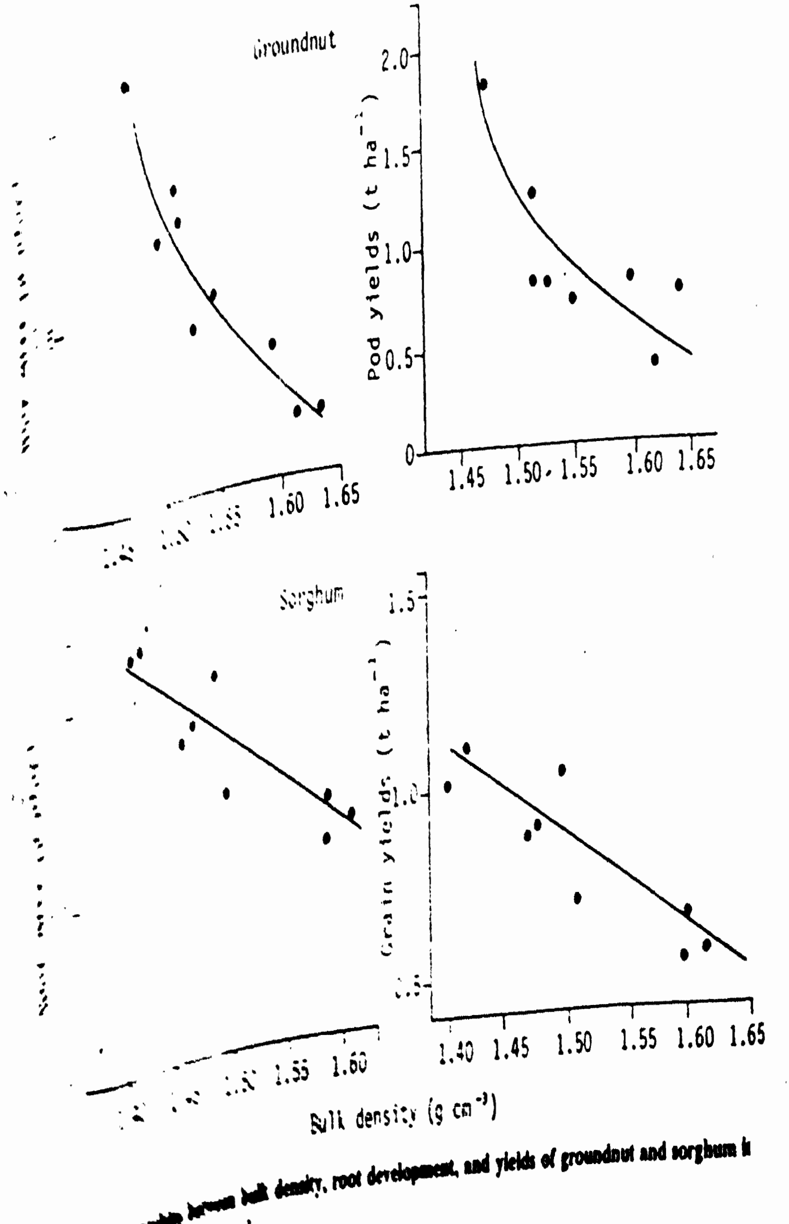

Figure 4. Relationship between bulk density, root development, and yields of groundnut and sorghum in sandy Alfisol at Bambey, Senegal.

even limited tillage was sufficient to enhance rapid and deep root establishment by the crop, thereby allowing it to escape the effects of detrimental dry spells early in the rainy season. Water losses through evaporation are considerable from deeply tilled Alfisols, and this may prove detrimental when rainfall is limited. Klaij (1983) demonstrates the need for ensuring good seed-soil contact by pressing the soil after sowing to allow adequate crop establishment on Alfisols. He also showed that an intensive form of tillage (split-strip plowing) can help increase crop yields.

Management of soil crusts for improving seedling emergence and crop stand on rainfed Alfisols is gaining increasing importance (Klaij 1983). Strong surface crusts develop when seals created by rainstorms are subjected to rapid drying under direct sunlight. It has been found that a rolling crust-breaker with spokes mounted at precalculated positions can substantially improve seed emergence (in the case of susceptible seeds) when available soil moisture is not a limitation to growth (Awadhwal and Thierstein 1983). Soman et al. (1984) have developed a simple technique for field screening of genetic resistance of millet and sorghum to emergence through soil crusts. Little investigation to date has been done on the effects of chemical amendment on the strength of crusts formed on these soils. The benefits of increased shallow intercultivation—conducted frequently to break crusts subsequent to the normal practices—have been recently investigated. The practice was effective in increasing infiltration (Pathak 1984, Weststeyn 1983) and to some extent in reducing moisture losses through evaporation by producing a dust mulch. Breaking crusts reduced both runoff and soil loss (Table 10). During a high-rainfall year, no significant increase in crop yield was obtained from additional intercultivations. However, during normal and low rainfall years, crop yield increased significantly.

Addition of organic mulches on Alfisols was quite effective in reducing runoff and soil loss (Table 11). At ICRISAT, even in a high-rainfall year (1981), mulch applied at the rate of 10 t ha⁻¹ reduced the seasonal runoff by 74% and soil loss by 80%, compared with the situation when no mulch was applied. In a normal rainfall year (1982), no significant runoff or soil loss was recorded from the mulch treatment (10 t ha⁻¹). During the same year a runoff of 205 mm and soil loss of 3.7 t ha⁻¹ were recorded from the control treatment with no mulch added.

Table 10. Effects of shallow interrow tillage and landshaping on runoff and soil loss from an uncropped Alfisol, ICRISAT Center, 1981.

Tillage system		Runoff	Soil loss
Depth	Land shaping	(mm)	(t ha⁻¹)
Shallow	Flat	138	3.2
	BBF	168	5.9
Nil	Flat	214	3.6
	BBF	289	8.9
SE		±8.2	±0.57

BBF = Broadbed-and-furrow system.

Table 11. Effect of different levels of organic mulch¹ on crop yield, runoff, and soil loss on Alfisols, 1981.

	Intercrop system			
Mulch rate (t ha⁻¹)	Sorghum yield (kg ha⁻¹)	Pigeonpea yield (kg ha⁻¹)	Runoff (mm)	Soil loss (t ha⁻¹)
No mulch	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

1. Groundnut shells. Source: Pathak 1984.

Addition of organic mulch also increased crop yields in a sorghum/pigeonpea intercrop system. In a high-rainfall year, the mulch applied at the rate of 10 t ha⁻¹ increased the sorghum yield by 9%, and that of pigeonpea by 35% over the no-mulch treatment. In normal- and low-rainfall years, more substantial increases in sorghum yield were recorded. When groundnut shells were used, a mulch rate of 5 t ha⁻¹ appeared to be the minimum needed for increasing crop yields.

Harnessing runoff or development of other water sources for supplemental irrigation is important for optimizing the productivity of Alfisols since these soils are often shallow and have a low water-retention capacity (Fig. 5). The benefits from supplemental irrigation in terms of increased and stabilized crop production on Alfisols have been impressive, even in dependable rainfall areas. The potential for delivering excess water to surface water-storage structures (tanks) or groundwater reserves is good since even improved cropping systems use only 30-55% of the seasonal rainfall. The remainder, or 45-70%, runs off or drains to deeper layers. Both can potentially be tapped for supplemental irrigation. The high runoff on Alfisols during the early part of the rainy season (Pathak et al. 1985) provides a dependable surface-water source for most of the season. An analysis of 6 years' data collected from three tanks on Alfisol watersheds (Pathak 1980) showed that these tanks held sufficient water for supplemental irrigation during dry spells. Even in 1977, when runoff was the lowest in 9 years (1974-82), more than 35 mm of water was present in the tanks during periods when the probability of drought was high. In all years, a minimum of 50 mm of water was available in the tanks during 80% of the

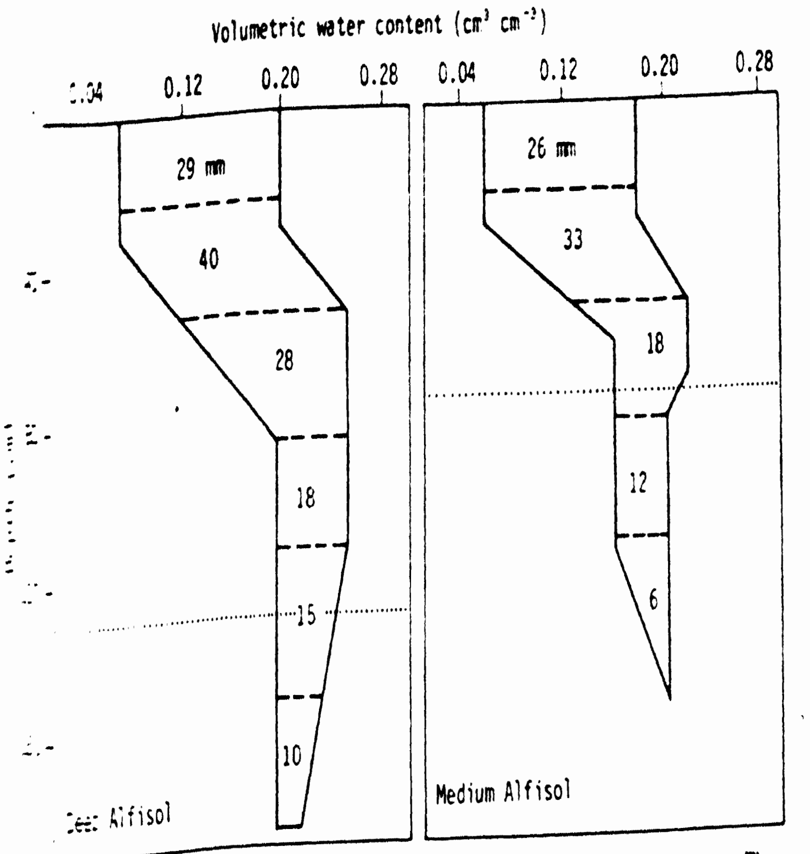

Figure 5. Available water profiles for deep (>1 m) and medium (1.0-0.5 m) Alfisols at ICRISAT Center. The dotted lines represent the approximate lower end of the soil layer and the top of the murrum layer.

[illegible] period, and 75 mm during 30% of the [illegible]. However, tank storage can often be hampered by the high seepage rates in Alfisols.

[illegible] is still in progress to determine the most [illegible] sealing materials and techniques (Mahesh-[illegible]). Analysis has shown that tanks can [illegible] water needed for supplemental irrigation [illegible] the average seepage rate is below 15 mm [illegible] long-term analysis using runoff modeling [illegible] et al. 1984) showed that the probability of [illegible] of water in July during periods of high [illegible] probability is 70%, while in August, September and October, the probability exceeds 92%. [illegible] and Krishnagopal (1981) have determined that [illegible] collection and storage potential for [illegible] at Hyderabad, India, was superior to that [illegible] Vertisols.

Data at ICRISAT indicate that supplemental irrigation increased yields in both the rainy and postrainy seasons (Pathak 1984). During the 1981 rainy season, good responses were obtained to supplemental irrigation of pearl millet, sorghum, and groundnut (Table 12). This table also shows that, as expected, the response to supplemental irrigation during 1982—a high-rainfall year—was quite low. In the postrainy season, the response to supplemental irrigation was significant in both years (Table 13). Deep-rooted crops, such as pigeonpea and castor, responded only to larger applications. Two irrigations, each of 4 cm, were therefore required.

It should be emphasized at this point that buildup of organic-matter levels is essential to impart favorable physical and chemical properties to these soils, and to improve productivity. The organic-matter contents of SAT Alfisols undergo a rapid decline when virgin lands are brought under cultivation. The decline of soil organic matter to a new equilibrium level is determined by the mode of land clearing, environmental conditions, and the farming system in use. As much as 40 t ha^{-1} of soil organic matter are reported to have been lost from the 0-20 cm horizon of Alfisols following clearing and 15 years of continuous cultivation (Charreau and Fauck 1970). The loss was maximum in the first 6 years and then it tapered off, reaching a relatively stable level which, under conventional cropping, is very low. This decline is primarily due to the fact that crop residues and farmyard manure are valu- these regions for competitive uses other than return to the soil. However, both should be considered necessary components for enhancing organic-matter buildup and thereby contributing to enhanced productivity of Alfisols in the short term.

In the long term, strong clues for successful cropping and sustained productivity of Alfisols may be derived from experience gained in the humid tropics and temperate, semi-arid areas. In the humid tropics, these soils appear to be more amenable to management for sustained agricultural productivity than in the SAT. Considerable success has in fact been reported with minimum tillage, generous inputs of residues (e.g., mulching), and the application of herbicides within the cropping systems. The dependence on herbicides is necessarily heavy. The abundant water supply in these regions encourages some form of vegetative growth and overall biological activity throughout the year. Only certain types of vegetation are able to sustain themselves with significant viability despite the annual intense dry period in the SAT, particularly on Alfisols. Selected, fast-growing trees have this potential, and have been recommended for inclusion with conventional cropping systems in agroforestry schemes in the tropics. Cropping systems that capitalize on the attributes of such trees to the ultimate benefit of both the soil and the farmer are currently under increasing investigation in the SAT (Lundgren and Nair 1983).

Another strategy that has been favored for improving SAT Alfisols involves the combination of legume-ley farming and grazing animals (Jones and McCown 1983). Preliminary results indicate that this system, which has proved successful in the temperate regions of Australia, appears promising when the following features are included: (1) a self-

Table 12. Crop responses on Alfisols [illegible]RISAT Center to the application of 4 cm of supplemental irrigation[1] water during rainy-season droughts.

	Yield (kg ha^{-1})					
	Pearl millet		Sorghum		Groundnut	
Year and irrigation date	Control (no irrigation)	With supplemental irrigation (grain filling stage)	Control (no irrigation)	With supplemental irrigation (flowering stage)	Control (no irrigation)	With supplemental irrigation (pegging stage)
1981 (23 Aug)	2100	2710	2820	3218	690	1050
1982 (20 Aug)	1630	1725	1	1	686	890

1 Sorghum was not grown in 1982. Source: Pathak 1984.

Table 13. Crop responses on Alfisols at ICRISAT Center, to the application of 4 cm of supplemental irrigation water during the postrainy season.

	Yield (kg ha^{-1})											
	Pigeonpea			Castor			Cowpea			Tomato		
Year	Control	Once-irrigated (flowering stage)	Twice-irrigated (flowering & podding stages)	Control	Once-irrigated (flowering stage)	Twice-irrigated (flowering & podding stages)	Control	Once-irrigated (veg. stage: 30 days)	Twice-irrigated (veg. and flowering stages)	Control	Once-irrigated (veg. stage: 30 days)	Twice-irrigated (veg. and flowering stages)
1981-82	660	790	1120	715	920.	1280	310	665	725	9600	14400	23200
1982-83	850	910	1185	795	870	1335	500	685	795	13100	17500	29300

Source: Pathak 1984.

generating legume-ley pasture for 1-3 years grown in rotation with a cereal; (2) allowing cattle to graze on native grass pastures during the wet season and leguminous pastures in the dry season; (3) planting crops directly into the pasture after it has been herbicide-killed; and (4) allowing volunteer pasture legume sward from hard seed to form an understory in the main crop. In contrast to conventional Alfisol cropping this system allows implementation of minimum tillage concepts.

Final Remarks

It must be emphasized that a balanced approach to soil and water conservation and optimization of productivity should be followed in future research strategies for Alfisols (El-Swaify 1983). In view of the specific nature of this workshop's objectives, our discussions were restricted to a review of management options. The need for base-line data that allow quantitative and integrated watershed-based planning also merits equal emphasis.

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