5 Land, soil and water management

K L Srivastava, Abiye Astatke, Tekalign Mamo, Hailu Regassa and Selamyihun Kidanu

Introduction

Several technical constraints relating to hydro-physical properties of Vertisols are of particular significance in small-holder, subsistence-oriented farming systems in Ethiopia where cash inputs and farm power sources are meagre. Firstly, accumulation of excess water in the soil profile and on the soil surface create serious problems for growth of most of the crop plants. Secondly, time periods available for carrying out tillage operations are usually very small as the soil becomes hard when dry and too plastic when wet. Thirdly, cultivated Vertisols are generally susceptible to excessive soil erosion if they are not protected from rain drop impact and gully-forming processes.

The technical constraints, coupled with socioeconomic factors, have led to severe underutilisation of Vertisols in spite of their positive attributes like relatively high moisture storage capacity, several favourable chemical properties, and capacity for structural restoration through swelling and shrinking. Only about 30% of the Vertisol area in the Ethiopian highlands is supporting annual crops; the remaining area is mostly under natural pasture. As described in other chapters, the current productivity levels are quite low and technological innovations are urgently needed. The main aim of land, soil and water-management techniques is to modify and manipulate the land features and soil properties in order to create a favourable environment for seedling establishment and crop growth while preserving the natural resource base. This chapter reviews relevant Vertisol properties, experimental results and the overall experience of the project on this subject.

Hydrophysical properties

The JVP has conducted investigations and compiled information on hydrophysical properties for a number of Vertisol sites (e.g. Kamara and Haque, 1988a; Kamara and Haque, 1988b; Selamyihun Kidanu, 1992). Some examples are presented below.

Kamara and Haque (1988c) found curvilinear relationships between soil moisture and bulk density at two locations (Debre Zeit and Shola). The following regression equation was developed for Debre Zeit:

$$d = 2.068 - 0.02118\ w - 0.00004017\ w^2$$

where:
d = bulk density (g per cubic cm)
w = gravimetric moisture content (%)

The available water capacity (AWC), which is the difference between moisture content at 333 mbar and 15 000 mbar suctions, was determined in laboratory for a wide range of locations. Table 1 shows AWC values for five locations which ranged from 14% at Akaki to 20% at Debre Zeit. The moisture content values in relation to nine levels of metric potential at Akaki are shown in Table 2.

Table 1. Soil moisture characteristics of the surface layer for five sites.

Location	Volumetric moisture content		
	Field capacity	Permanent wilting point	Available water
Debre Zeit	45	25	20
Akaki	55	41	14
Inewari	47	32	15
Dejen	584	40	18
Dogollo	51	32	19

Measured values of plant available water capacity (PAWC) for Ethiopian Vertisol locations are not yet available. Field determinations of PAWC (Gardner, 1988) at some representative locations need to be taken up for improved assessment of crop production potential.

Kamara and Haque (1988b) observed dramatic changes in initial and base infiltration rates in different periods of the rainy season (Fig. 1). Apparently, these changes could be attributed to swelling in soil mass and closure of macropores.

Kamara and Haque (1988b) and Selamyihun Kidanu (1992) reported consistency limits for different sites. The plastic limit ranged from 29 to 39% moisture content (volumetric) at different locations. Tillage implements can smear a soil readily if it is wetter than its plastic limit, but below the limit it will remain friable. Table 3 presents measured values of liquid limit, plastic limit and sticky point and plasticity index for Akaki.

Drainage improvement

Where external drainage is inadequate, the surface runoff may accumulate in Vertisol fields and cause waterlogging. The infiltrated water often forms an excess water zone in the profile because of extremely low hydraulic conductivity in the subsoil. This may lead to formation of a perched watertable in the root zone.

Thus there are several types of drainage problems in Vertisols whose magnitude may vary from site to site as follows:

- Low airfield porosity caused by inherent soil properties and prolonged wetting
- Ponding of runoff water on the soil surface (specially in depressions)
- Formation of watertable rising into the root zone.

The management practices should tee developed for minimising water accumulation on the soil surface and improving aeration within the top 30-40 cm of the profile. Conventional subsurface drainage techniques (e.g. tile drainage) are generally uneconomical because of the narrow drain spacing requirements as determined by the saturated hydraulic conductivity of the soil. Other options to improve drainage are: land-forming techniques, surface drainage structures such as diversion and relief drains, and management of soil structure through improved tillage and organic matter management.

Camber beds

Based on experiments at Sheno, Holetta and Ginchi stations, construction of camber beds, 7-11 m wide for improving drainage was recommended. Wheat and barley yields were two to three times higher by using these structures compared with traditional land preparation (Berhanu Debele, 1985). The domed shape of the beds encouraged water movement towards the drains provided they were properly aligned to evacuate excess runoff efficiently and safely. Although these were effective in improving drainage, Jutzi and Mesfin Abebe (1986) noted that the structures were inappropriate for the smallholders in the Ethiopian highlands. This led to a search for alternative technologies.

Broadbeds and furrows (BBF)

Encouraged by the traditional use of manually constructed broad- beds and furrows for drainage improvement in Inewari area of the Ethiopian highlands and also by ICRISAT's experience (Kanwar et al, 1982), the JVP decided to evaluate and adapt BBF technology at a number of locations. As discussed in other chapters, BBF and some other technology elements have been found effective and economically attractive at several locations.

Table 2. Moisture content (% volume) in relation to metric potential and soil depth at Akaki

Soil depth (cm)	Matric potential (mbar)									
	0	-10	50	-100	-150	-200	-333	-1020	-15000	AW%
0-10	67.64	65.21	63.92	63.71	60.48	58.81	55.05	49.02	41.21	13.84
10-20	68.88	65.25	63.48	61.11	60.81	58.56	55.86	49.51	42.61	13.26
20-50	68.48	66.33	65.86	63.48	60.45	59.85	55.86	48.16	42.48	13.38

Source: Selamyihun Kidanu (1992).

Figure 1. Infiltration rates in different periods of the rainy season at Debre Zeit, Ethiopia, 1987/88.

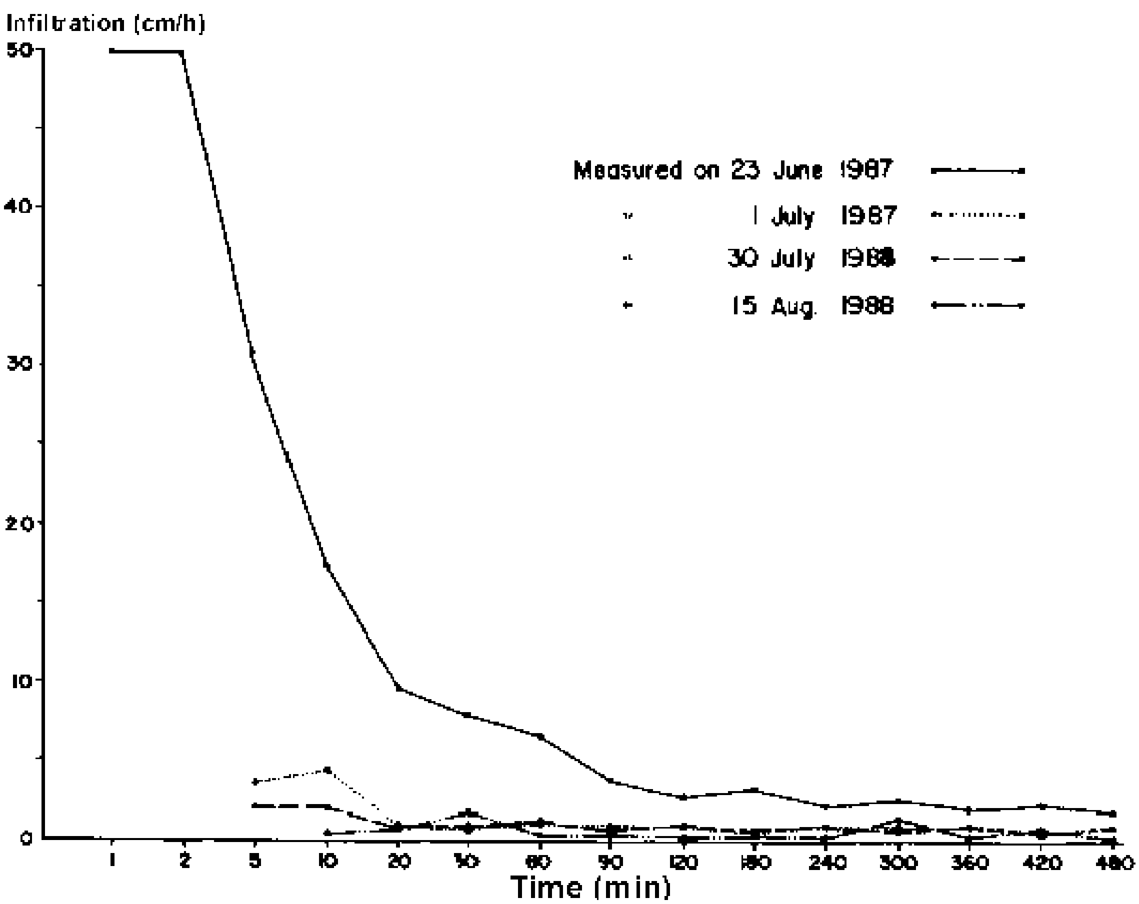


Table 3. Consistency limits (volumetric moisture contents) for the soil at Akaki.

Depth (cm)	Liquid limit	Sticky point	Plastic limit	Plasticity index
0-20	96.0	47.0	35.0	55.0
10-20	98.0	48.0	38.0	61.0
20-50	99.0	51.0	38.0	61.0

Source: Selamyihun Kidanu (1992).

Operational experience obtained through extensive use of BBF method on research stations and farmers' fields is summarised below:

- The BBF should be formed before the soil becomes wet, preferably when the soil moisture is below plastic limit. This helps in keeping draught requirement low and in preserving the soil structure.

- The length of furrow in any one direction of gradient should not exceed 60-70 m. This minimises overflows of runoff from furrows and consequent breakage of beds.

- Special care should be taken to divert external runoff away from BBF plots. It is also important that the discharge end of furrows should be cleared of any deposited sediments.

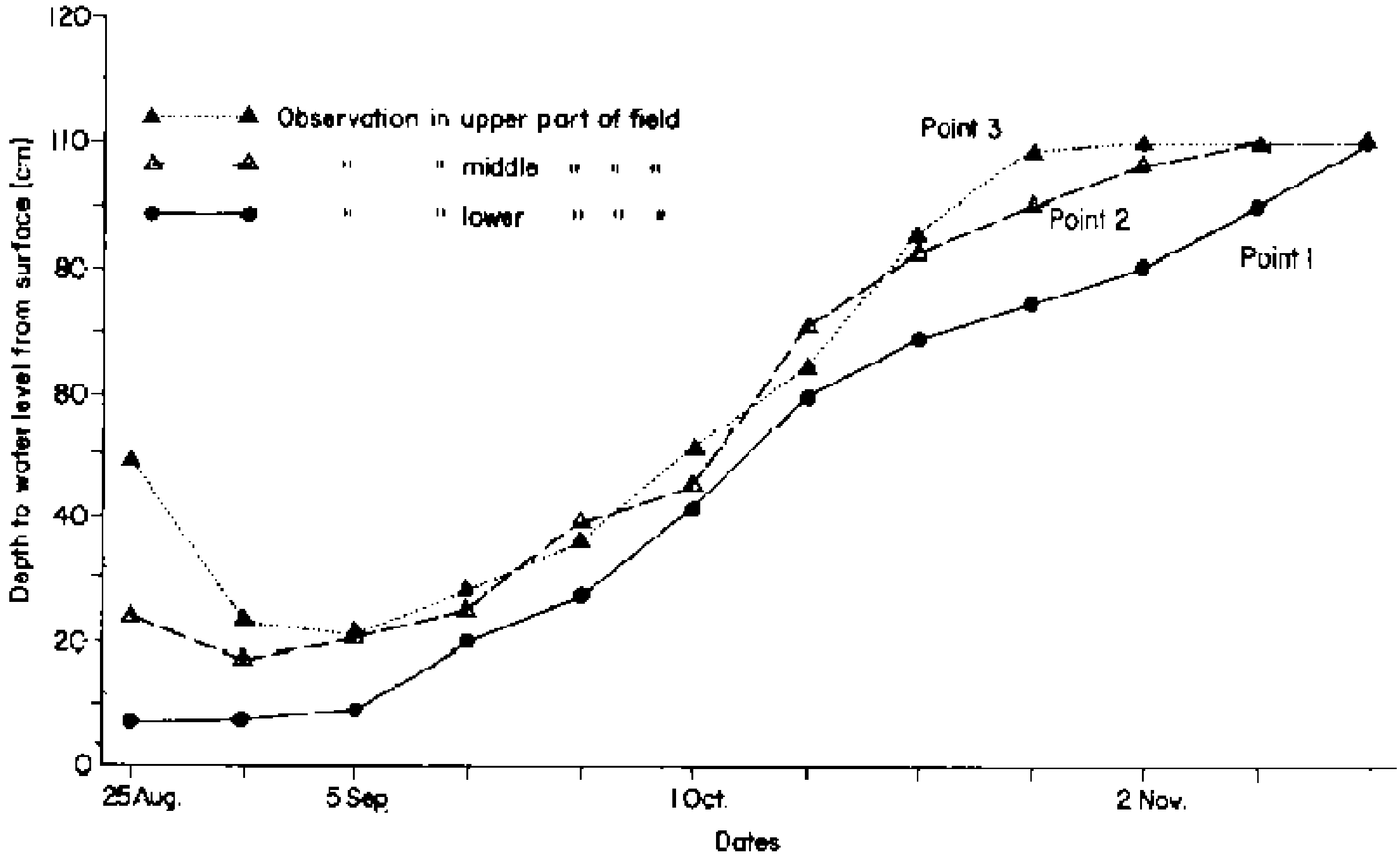
Field depressions

Vertisol fields in the Ethiopian highlands generally include several micro-depressions caused by gilgai 0microrelief. Observations at Debre Zeit and Ginchi have shown that wheat yields per unit area were 58% to 75% lower in depressed areas (maximum depth 15 cm) than in the smooth portions of the field. The positive effects of broadbed and furrow treatment (with 13- cm-high beds) was observed only in the smooth portions of the field and not in micro-depressions. Land-smoothing is, therefore, important for improving the surface drainage of these soils.

Perched watertable

Before 1991, there was no measured data of watertable in the root profile of rainfed Vertisols in Ethiopia. The piezometric measurements at Ginchi (Fig. 2) and Akaki in 1991 and 1992 have shown that perched watertable could rise upto 20 cm from the soil surface during certain periods. This may create anaerobic conditions in the root zone and damage upland crops like wheat, faba bean etc. In view of location specificity of drainage problems, the watertable data should prove useful for finding solutions.

Figure 2. Fluctuation of perched water-table at three observation points at Ginchi station, 1991.



Open ditches

Results of an experiment at Sheno research station in 1988 indicated that 30 cm wide and 40 cm deep parallel ditches (spaced 15 m apart) were quite effective in improving drainage and increasing barley yields (IAR, 1989). These ditches probably lowered the watertable and improved aeration in the root zone. There is need for a systematic and multidisciplinary evaluation of this practice as it appears promising for some situations.

Height of beds

The results from experiments at Ginchi and Akaki in 1991 have shown that broadbed and furrows with 26-cm-high beds produced significantly higher grain yield than the remaining two treatments: normal BBF with 13-cm-high beds and flat (Table 4).

The height of the bed is presently standardised on the basis of specifications of the available implement and draught power. It should be emphasised that the beds of inadequate height may be completely ineffective in some situations and may give suboptimal response in other situations. It, therefore, seems advisable to keep the technology specifications flexible so that, wherever possible, they could be adjusted to match with local requirements.

Soil erosion

There are two aspects of Vertisol management technology which can affect soil erosion. On the one hand, the graded drainage furrow, while draining out excess water, can exacerbate soil erosion. On the other hand, early establishment of crop canopy in the early part of the rainy season can reduce soil erosion. It was, therefore, decided to study the effect of traditional and new land management technologies on soil erosion. The measurement of soil loss from wheat - cropped plots with 0.65% slope at Debre Zeit, have shown that annual soil loss was less than 2.5 t/ha in traditional as well as in new land management plots. In another experiment at Hidi, it was observed that on 2.7% slope, the plot with BBF laid along the slope had annual soil loss of 7 t/ha as shown in Table 5. It is tentatively being recommended that the furrow gradient should not normally exceed 1%. In fields where furrows are vegetated (e.g. through linseed grown in furrows in Inewari area), higher furrow gradient can be used.

In future, more attention is needed for developing appropriate technologies for controlling gully erosion on Vertisols. Gully erosion is already a serious problem and uncoordinatd drainage-water disposal from individual fields may further aggravate this problem.

Table 4. Effect of height of bed on grain yield of wheat (cv ET-13) at two locations in 1991.

Location	Treatment	Bed height (cm)	Yield kg/ha	% yield increase over control
Ginchi	Flat (control)	0	835 (±75)*	-
	Normal BBF	13	979 (±45)	17
	Raised BBF	26	1221 (±45)	46
Akaki	Flat (control)	0	960 (± 62)	-
	Normal BBF	13	1286 (± 73)	34
	Raised BBF	26	1481 (± 73)	54

* Figures in parentheses are standard errors.

Table 5. Effect of two land management treatments on runoff and soil loss from wheat cropped plots at 2.7% slope at Hidi, 1987.

Treatment		Rainfall (mm) (Jun - Sep.)	Runoff (mm)	Soil loss (t/ha)
1	Flat	453	66	3.72
2	Broadbeds and furrows laid at 2.7% gradient	453	124	7.0

Supplemental irrigation

From purely technical standpoint, there are three factors which suggest good potential for runoff collection and supplemental irrigation on Ethiopian highland Vertisols:

- In the middle and later parts of the rainy season, the runoff rates are high.
- In postrainy season, crops suffer from drought and establishment of sequential crops is often difficult without irrigation.
- The saturated hydraulic conductivity of subsurface layers is low. Consequently, seepage loss from ponds is likely to be quite small.

In spite of these favourable factors, this subject of runoff management has not been researched adequately in Ethiopia. This is probably due to recognition of problems in pumping and distributing water and the need for capital investments.

A preliminary study on response to supplemental irrigation applied to chickpea (in wheat - chickpea sequential system) was made in 1987 and 1988. It was found that irrigating once only at the time of planting of chickpea was essential for crop establishment in 1987 but not in 1988 (Table 6). Irrigating more than once was unnecessary or even harmful for Deci-type chickpea (*Cicer arietinum*) (Abiye Astatke et al, 1991).

The problem of runoff collection and supplemental irrigation would require further research for determining their technical, economic and social feasibility in different regions.

Need for watershed development projects

Watersheds as hydrologic units provide appropriate units for conceptualising and planning area-wide drainage improvements, resource conservation and land-use management. They comprise combinations of arable and nonarable lands and drainage lines and are utilised by a community of land users. Considering the need for improving area-wide drainage and land management on Vertisols, there is need for initiating pilot watershed projects at some selected locations. The watershed development involves preparation of inventory of resource-base and available technologies, adaptive and participatory research, planning and monitoring, and evaluation (Doolette and Magrath, 1990). JVP's achievements can form important building blocks for watershed management in the Ethiopian highlands.

Table 6. Effect of supplemental irrigation on yield of sequentially cropped chickpea at Debre Zeit, 1987 and 1988.

Year		Yield (t/ha)				Standard error
		T1	T2	T3	T4	
1987	Grain yield	ny	1.39[a]	1.38[a]	1.09[b]	0.07
	Straw yield	ny	2.16[a]	2.00[a]	1.92[a]	0.16
1988	Grain yield	0.96[ab]	1.29[b]	1.21[b]	0.72	0.15
	Straw yield	1.03[a]	1.57[b]	1.76[b]	1.32[ab]	0.20

T1 = No irrigation.
T2 = Irrigation at planting.
T3 = Irrigation at planting and vegetative stage (35-40 days).
T4 = Irrigation at planting vegetative stage and at 50% flowering (70-75 days).
a, b, ab = Means with different letters within a row differ significantly ($P < 0.05$).
ny = no yield.