

Review on Vertisol Management for the Improvement of Crop Productivity in Ethiopia

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Abstract
Vertisols (deep black clay soils, often known as "black cotton soils") cover 8 million ha of the Ethiopian highlands. They account for about 70 percent of all highland soils with slopes between 0 and 8 percent. The high clay content of the Vertisols is responsible for their heavy water logging in highland areas with abundant rainfall and relatively low evaporation rates. This imposes severe restrictions on the traditional agricultural use of these soils and only 25 percent are currently cropped, mainly using residual moisture. Much of this land is left fallow and subject to erosion during the heavy rains. Evidence suggests there would be substantial increases in crop yields on Vertisols if excess surface soil water were drained off and if appropriate cropping practices were used. A research and outreach project on the improved management and utilization of highland Vertisols is examining the use of animal- powered devices for surface soil drainage, planting and tillage, the development of new cropping systems on drained Vertisols, and improved management of plant nutrients with the use of low cost phosphates and legumes as sources of nitrogen.The current BBM is found to be a good example of appropriate and sustainable technology that meets the needs of smallholder agriculture. It is very simple and low-cost technology and its application does not require farmers to have or develop advanced skills. However, combining the BBM technology with other complementary technologies like improved high yielding rust resistant wheat varieties and fertilizers is very important in increasing the impacts of BBM adoption.
Keywords: clay content, cropping practices, improved management, Vertisol management

1. Introduction

Vertisols are dark-colored clays which develop cracks when expanding and contracting with changes in moisture content. They are geographically widespread, but it is only in the past decade or two that they have received scientific attention. Finck and Venkateswarlu (1982) indicated that Vertisols have an enormous yield potential but that this is often not realized.

Vertisols represent a vast crop production resource. It is estimated that there are at least 280 million ha of these montmorillonitic clays in the world, located mainly in Africa, Australia, India and the USA. Many of these soils are underutilised because they are difficult to manage hard and cloddy when dry, and very sticky when wet (Willcocks and Browning, 1986).

Of the total Vertisol area, 126.5 million ha are found in three developing countries (Sudan, Chad and Ethiopia), where resources, facilities and trained scientific manpower are scarce, and where food is in short supply.

Debele (1985) reported that of the 25 FAO/Unesco soil orders, 17 exist in Ethiopia. Lithosols, Cambisols, Nitosols, Vertisols, Xerosols, Solonchaks, Fluvisols and Luvisols cover more than 80% of the country, and are the most important soils. Vertisols cover 12.6 million ha, or 10.3% of the country; 7.6 million ha are found in the highlands. One quarter of these soils are presently cropped 24% of all highland soils cropped in Ethiopia (Jutzi and Mesfin, 1987) which indicates their importance in Ethiopian agriculture.

In general the traditional system of late planting of crops has often resulting in poor crop yields and soil erosion. Experiences from countries like India and Australia, show that proper knowledge and management of Vertisols has resulted in increased yields. Hence the proper management applications of the technology for Vertisols are believed to increase productivity and food security levels in Ethiopia. The objective of this paper is to review the management of vertisol for the improvement of crop productivity in the highlands of Ethiopia.

2. Importance of Vertisols in Ethiopian Agriculture

The largest Vertisol areas are on the volcanic plateau, colluvial slopes and side slopes of volcanoes in central Ethiopia; on the colluvial slopes and alluvial plains bordering Sudan; and on the vast limestone plateau of central Harerge province. Limited areas are found in such varied sites as the granitic colluvium in basins with seasonal drainage deficiencies in southern Sidamo; on sandstone colluvium in valleys in Tigray; on the floodplains of the Wabi Shebele and Fafen rivers in the Ogaden; and in basins in western Ethiopia, where rainfall reaches 2000 mm (FAO/LUPRD, 1984).

Donahue (1972) reported that of 29 randomly sampled pedons in four major agricultural areas of the country (Setit Humera in Gonder, Gambela in Ilubabur, Chilalo in Arsi, and Middle and Lower Awash river basins in Harerge regions), 19 were classified as Vertisol and 10 as Entisol.

Rainfed crops such as teff, durum wheat, chickpea, lentils, linseed, noug, and bread wheat are generally grown on Vertisols. Wherever drainage conditions are favorable, faba bean, field peas and barley are cultivated.

In the lowlands, irrigated crops such as cotton, sugarcane, citrus, and some vegetables are grown on these soils. Small farmers grow sorghum, haricot beans, maize and other lowland crops. Average yields on these soils are low: 500-800 kg ha^{-1} for cereals, 500-700 kg ha^{-1} for highland pulses and 300 kg ha^{-1} for oil crops.

3. Problems of Vertisols

3.1. Cultivation and Seedbed Preparation

Ethiopian Vertisols have a high content of clay, particularly expanding lattice clays. High clay content, type of clay mineral, unfavorable consistency and absence of pores make them difficult to work in both dry and wet conditions. A substantial amount of rainfall is needed to wet a dry Vertisol. The rain tends to move into cracks rapidly and wets the deeper layers of the soil profile, leaving the surface relatively dry. Achieving optimum moisture conditions for cultivation is difficult under present management practices. Once the rainy season starts and the surface is wet, cultivation is virtually impossible.

To overcome cultivation difficulties, seedbed preparation for all crops in the Ethiopian highlands starts with two ploughings during the short rainy season (March/April), when workability is relatively good. Up to six passes are made to prepare a seedbed for teff and durum wheat. It is not always possible to prepare a fine seedbed. Even after repeated cultivations the seedbed is rough. For the other crops, two or three passes are considered sufficient.

3.2. Drainage

The highland Vertisol areas are generally characterized by smallholder mixed cereal-livestock farming systems with a marked subsistence orientation. Land cultivation is almost exclusively done using oxen-drawn implements. The area is characterized by high rainfall (>900 mm $year^{-1}$) and low evaporative demand due to moderate temperatures, which vary widely with altitude, but might average 15°C annually. As a result, most vertic soils are severely waterlogged (estimated at 2.5 million ha, especially vertic Cambisols and vertic Luvisols) (Jutzi and Mesfin, 1987). As the result of poor drainage, crops sown in early June suffer from prolonged water logging they are stunted and show signs of poor aeration and nutrient deficiency. Grain yields are low.

3.3. Erosion

Vertisols in Ethiopia are located on either relatively flat or slightly sloping land. Erosion is a serious problem under present management, especially on fallow cultivated during the rainy season and on some sloping land in the highlands.

4. Potential and Management of Vertisols

Vertisols (from the Latin, vertere = turn) are churning heavy clay soils, that contain a high proportion of swelling clays such as smectites. When drying out, they form deep wide cracks from the surface downwards at some period in most years (Deckers *et al*., 2001). They cover a total of 311 million hectares or 2.4% of the global land area, out of which about 150 million ha is potential cropland. In the tropics, they cover some 200 million ha or 4% of the land surface (Driessen and Dudal, 1991). They make up over 10% of the Ethiopian landmass covering about 13 million hectares, of which about 8 million ha are in the Central Highlands.

Because of their relatively high inherent fertility, they can be very productive, when properly managed. However, their unique physical properties are the greatest limitations to the dominantly low-input agriculture. They require a careful management in order to tap the potential, while avoiding decline in soil quality. The wide-scale use of Vertisols has occurred only in the last four decades, and there are large areas, particularly in Africa, which are yet to be used (Deckers *et al*., 2001). A thorough understanding of the properties and processes of these soils is crucial to develop and implement farming practices that will keep them productive for the current and future generations. To this end, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has made significant contributions both in land management technology and cultivars development to enable the sustainable use of these soils (Eswaran *et al*., 1999).

According to Mesfin (1998) montmorillonite (smectite) dominates the clay minerals of the Ethiopian Vertisols, with little aluminium inter-layering. They are extremely diverse and occur under various climatic conditions, where Pellic and Chromic Vertisols are plentiful (Mesfin, 1998). The Pellic Vertisols are the majority with over ten million hectares (Debele, 1985). They have the moist chroma of less than 1.5 throughout the upper 30 cm.

Although it was claimed that they typically occur in areas of elevation less than 1000 m asl and on relatively flat topography (Ahmed, 1983), Vertisols in Ethiopia are found above 2000 m asl (Fisseha, 1992). Also, Ethiopian Vertisols occur on a wide range of slope up to 15% (Jutzi *et al*., 1988) though the majority occurs on slopes less than 5%, against the claims of Mohr *et al*. (1972) and Debele (1985), who assert that Vertisols occur on slopes less than three percent.

However, their productivity is often constrained by their hydro-physical properties, that their percolation rate is very low. As land preparation is a problem under insufficient moisture content as well as under wet conditions, and due to the traditional late planting to avoid water logging, crop yields from these soils are often very low (Teklu, 1997, 1998; Demeke, 1998; Teklu *et al*., 2004).

Traditionally, farmers cultivate the land early in the season using the short rain (April-May), and keep it bare during the main rain season with occasional tillage until they plant low yielding crop species or varieties late in the season (August – September) after the excess water naturally drained away so that the crops grow on residual moisture. In good years (if the rain extends to September and October), the harvest may be very good. However, as this often fails, the consequence can range from substantial yield reduction to total crop failure. The practice exposes the bare cultivated land to the erosive summer rainfall (June-July) (Teklu, 1997, 1998). The use of tolerant crops is another traditional alternative. Tef (*Eragrostis tef*), Ethiopia's staple cereal, is among the few crops, that tolerate a mild water logging condition, and hence is well preferred in areas where the temperature is warm enough for the crop. However, as the altitude increases over 2000 m asl, its performance gets poorer because of the reduced temperature.

4.1. Improved Utilization of Vertisols

There is evidence that substantial increases in crop yield could be obtained on Vertisols if excess surface soil water is drained off and if appropriate cropping practices are used. During the past 12 years ICRISAT (the International Crops Research Institute for the Semi-Arid Tropics) has been developing a management technology for Vertisols in India (with 100 million ha of Vertisols). The technological package developed at ICRISAT is designed to make optimum use for crop production of both the rainy season and the post-rainy season growing periods. The package - essentially a double-cropping system - includes the following elements:

- ✓ Shaping the land to drain off excess surface water by the broad-bed-and-furrow (BBF) system and by grassed waterways to counter soil losses;
- ✓ Cultivating the land immediately after the post-rainy season harvest before the soil dries and hardens;
- ✓ Dry seeding crops before the main rains;
- ✓ Using improved cultivars and moderate amounts of fertilizers in improved cropping systems;
- ✓ Improving placement of seeds and fertilizers for better crop stands;
- ✓ Improving plant protection (from weeds, pests, diseases).

Results obtained at the ICRISAT Centre (Hyderabad, Andhra Pradesh) with this technology showed consistently superior production and profits when compared with the traditional rainy-season fallow system. It allows two crops per year and both are more productive than the traditional post-rainy season crop (Ryan and von Oppen, 1983). Maximum impact of improved Vertisol management techniques on crop yields and resource preservation can be expected if entire watersheds are involved.

Various cultivation practices aimed at draining the surface water are used in different parts of the highlands. Hand made Broad Bed and Furrows (BBF) are practiced in some localities like Enewari in North Shoa, but its high labor requirement is a constraint to its wider application. Ridges and furrows (RF) is a common practice in Caffee Donsaa areas. Although it is meant to drain the excess moisture and could have allowed early planting, farmers plant late, may be due to its limited drainage efficiency, as the water often stagnates in the furrows than being disposed (Teklu, 1997). The late planting accompanied by high tillage frequency (5-9 tillage operations) under the RF system results not only in reduced crop yield, but also affects soil quality by exposing it to erosion, increased OM oxidation and soil structural deterioration (Teklu and Gezahegn, 2003). The high tillage frequency also destroys all the herbs, which could otherwise cover the soil surface against rainfall and runoff or grazed by the livestock.

4.1.1. Vertisol Management and the Broad Bed Maker Technology

Large areas of highland vertisols are presently not cropped because of the water logging problem and traditional method of drainage, such as ridges and furrows or drainage furrows, which can't effectively overcome the problem causing considerable human drudgery and low economic return. In general, the water logging situation constrains crop yields in two major ways (Parent *et al.*, 2008). First, muddy soil complicates plowing, forcing farmers to delay planting until the end of the main rainy season, using the short growing period on residual moisture. Second, water logging leads to modification of soil physical and chemical characteristics, leading to a decrease in output.

A surface drainage technology known as "Broad Bed and Furrow" (BBF), constructed by Broad Bed Maker (BBM), has been developed and popularized after on- station and on- farm testing in various areas in the highlands (Teklu *et al.*, 2001). Despite a considerable effort of popularization, the BBF technology is not well adopted. This was often attributed to various socio-economic, cultural and technical constraints. Weed infestation induced by early planting, time available for BBF preparation, and difficulty in appropriate site selection are among the technical constraints that limited the success and adoption of the technology (Deckers *et al.*, 2001; Fassil *et al.*, 2001). To comprehensively address the issues and provide alternative systems, which ensure land cover during the main rainy season and allow production of livestock feed, need to be developed, in addition to the surface drainage practices. Spatial and temporal multiple cropping systems might be potential alternatives to be evaluated both economically and ecologically for such purposes. In addition, reducing tillage practices could be potential options (Teklu, 1998).

The development of BBM technology was the response to the observed problems in vertisol management practices in Ethiopia. The BBM is a low-cost surface-drainage implement (with initial investment capital of about 93 Birr), an oxen powered plough developed by modifying a local farm implement called maresha, the traditional plough pulled by a pair of oxen. The need for BBM depends on the soil slope and soil moisture content. It can be used only on soils with slope greater than 2% and if the soil is not muddy. If the slope of the land is less than 2% it can only be used for teff and other crops; for BBM the slope has to be greater than 2%. The instructions to use BBM are: (i) 80 cm width of the bed; (ii) use of BBM only, for Vertisol; (iii) slope of field should not be completely flat, but between 2-8% and (iv) not to use BBM when there is too much rain (Aredo *et al.*, 2008). The latest version of BBM and National BBMTP (Broad Bed Maker Technological Package) usage 2007/08 drained land of ha in Ethiopia out of 13 million hectares is indicated in (Figure 1) and in (Table 1), respectively.

Figure 1. The latest version of BBM

Table 1. National BBM TP usage 2007/08 drained land of ha in Ethiopia

Region	BBM TP drained land (ha)
Oromia	35,805
Amhara	24,736
Tigray	5000
Southern Region	52
Total	**63,566**

Source: (Alemayehu and Hailemariam, 2008).

The BBM also allowed double cropping of short season pulses after the harvest of the main cropping season. This is a significant transformation of the cropping system in the vertisol areas. A partial budget analysis was used to assess the profitability of the BBM technology and BBF farming in Ethiopia; results are summarized in (Table 2) and in ((Figure 2), respectively.

Figure 2. BBF farming in Ethiopia: BBFs.

Table 2. Estimated wheat partial budgets for different vertisol management practices

Benefits/Costs	Vertisol management practices	
	Conventional plough	Broad bed maker
Average yield (qt/ha)	13	28
Average price (Birr/qt)	400	400
Gross income (Birr/ha)	5200	11200
Variable costs (Birr/ha)	60	15
Fixed costs (Birr/ha)	0	12
Total costs (Birr/ha)	60	27
Profit (Birr/ha)	5140	11,173

Source: (Aredo *et al*., 2008)

The use of BBM resulted in 6033 Birr more profit per hectare than a conventional plough (Table 2). However, this profit was only from a onetime cultivation of wheat, and the benefits from an eventual second harvest of pulse crop were not included due to data unavailability.

5. Land Preparation Methods and Crop Productivity

Crop production in the highland Vertisols area of Ethiopia is highly constrained by the soil physical and hydrological properties. Land preparation is constrained by the hardness of the soils when dry and their stickiness when wet, and their very slow internal drainage with infiltration rates between 2.5 – 6.0cm day $^{-1}$ (Teklu *et al*., 2004). The problem is serious particularly for small farmers using handheld or animal-drawn implements (Kadu *et al*., 2003).

Early planting is prohibited since most crops in the region are severely affected by water logging and fungal diseases. Several authors reported increased yields of some crops grown on Vertisols due to the use of the BBF as compared to the flat seedbeds (Astatke *et al*., 1995). They suggested that the improvement in surface drainage and yield increase was spectacular during the excessive rain years.

In this review BBF is compared to Green Manure (GM) and Reduced tillage (RT) as alternative to arrest some of the above problems in terms of crop productivity and economic profitability while the traditional practice Ridge and Furrows (RF) was included as a control.

5.1. Agronomic Productivity and Profitability

Among the several interdependent factors considered for the selection of appropriate land preparation methods include, agronomic performance and the economic benefits of the alternative practices were considered. However, as they are related to the economically important grain and straw yield of the crops, the agronomic characteristics were also discussed.

5.1.1. Effect on Agronomic Characters

The effects of the land preparation methods on the crop growth parameters depended on the crop types and year. The effect was significant on plant height, days to heading and maturity of wheat. During this year, BBF resulted in the highest number of days to heading but lowest plant height as opposed to RF, which resulted in the lowest number of days to heading and highest plant height. This indicates that crop growth was retarded under BBF during the early stage.

BBF caused the lowest number of days to heading and the highest number of days to maturity. It gave also the highest number of tillers per plant showing enhanced performance at early stage and hence more vegetative cover. The higher moisture availability due to early sowing explains the longer duration between heading and maturity. On the other hand, the poor vegetative performance of lentils under no drainage conditions is related to water logging, which caused poor aeration of the roots and poor nutrient uptake leading to weak growth and development and hence low crop yield. In addition, the crops on undrained plots were subjected to forced maturity due to the terminal moisture stress, induced by late sowing. The result is consistent with the previous findings, a better growth and yield of legumes like lentils under BBF due to enhanced drainage was reported (Abate and Saleem, 1992; DZARC, 1990; ILCA, 1990).

RF significantly increased the number of days to heading, while the residual effect of BBF and GM increased the number of tillers per plant. RF resulted in the highest number of days to heading and the highest plant height of wheat, while the residual effect of BBF reduced the number of days to heading. Due to the heavy storm event, drought as well as associated disease and pests, the performance of lentils was poor. Consequently, although it was significant on the days to maturity in that GM and RF delayed, the treatments effect was not fully manifested.

5.1.2. Effect on Grain and Straw Yields

Similar to the other agronomic parameters discussed above, the effects of the land preparation methods on grain yields varied with the crops (Table 3 and 4). The mean grain and straw yields of wheat and lentil were significantly affected by the land preparation methods and their interaction with year. However, the effect of the land preparation methods on tef was not significant showing the insensitivity of the crop to physical manipulation of the land.

For lentils BBF significantly increased the grain yield (59% as compared to the control), corroborating the previous findings (Getachew, 2001) while the other alternatives were not different from the control. This is related to the advancement of the sowing date and the enhanced surface drainage, which resulted in earlier establishment of the crop so that it relatively tolerated the rainstorm and escaped the terminal moisture stress.

On the other hand, the highest mean grain yield of wheat was obtained due to RT (10% higher than the control). The straw yield was also significantly increased. While BBF significantly reduced the grain yield of wheat (35% less than the control), the effect of GM was not different from the control, both in terms of grain and straw yields. This does not corroborate the previous reports in which the use of BBF increased wheat grain and straw yields in other parts of the highlands of Ethiopia. However, the previous works often compared BBF against flat beds, unlike the current study, which compared it with RF and other alternatives (Efrem, 2001).

Table 3. Grain yield of the crops (kg.ha^{-1}) as affected by the tillage systems

Land preparation methods (L)	Wheat			Lentil			Tef		
	1998	2001	Mean	1999	2002	Mean	2000	2002	Mean
BBF	438	1763	1101^b	2732	532	1632^a	1260	1333	1296
GM	1940	1621	1780^a	1704	144	924^b	1194	1373	1284
RF	1209	2187	1698^a	1787	271	1029^b	1139	1409	1274
RT	1819	1904	1862^a	1482	212	847^b	1315	1443	1379
Mean	1352^b	1869^a		1926^a	290^b		1227	1389	
LSD (5%) L		217			193			NS	
Year		196			255			NS	
Year*L		307			273			NS	
CV (%)		10.73			13.85			9.50	

Means within the same column or same row are not significantly different at 95% confidence interval.

Although not significant, RT gave the highest grain and straw yield of tef resulting in 8% increase in grain yield, as compared to the control and the other alternatives. This indicates that tef is not sensitive to the type of seedbed or the changes in soil physical environment as wheat and lentil do. This challenges that tef requires well-pulverized and smooth seedbed (Ebba, 1969), a pre-text for high tillage frequency.

Table 4. Straw yields of the crops (kg.ha^{-1}) as affected by the tillage systems

Land preparation methods (L)	Wheat			Lentil			Tef		
	1998	2001	Mean	1999	2002	Mean	2000	2002	Mean
BBF	890	2679	1785^{c}	2812	1572	2192	2579	3102	2841
GM	2565	2643	2604^{b}	2342	1050	1696	2472	3317	2894
RF	2287	3265	2776^{b}	2375	1567	1971	2613	3156	2884
RT	3148	3040	3094^{a}	2287	1560	1924	2783	3178	2981
Mean	2222^{b}	2907^{a}		2454^{a}	1437^{b}		2612^{b}	3188^{a}	
LSD (5%) L		522			NS			NS	
Year		390			189			309	
Year*L		738			NS			NS	
CV (%)		16.18			17.43			8.53	

Means within the same column or row followed by the same letter are not significantly different at 95% confidence interval.

As the change of the yield from year to year was inconsistent (increase for wheat, decrease for lentil and a slight increase for tef) regardless of the treatments, it is not possible to predict if the soil quality is aggrading or degrading with respect to productivity. This may require longer time and more data, including soil quality indicators than the crop yield alone. The significant interaction between the land preparation methods and year is related to the performance of the effect of the land preparation methods and variation in the weather conditions. The land preparation methods seem to be sensitive to the rainfall with respect to wheat. The grain yield of wheat increased from the lower in 1998 to a higher in 2001 under all the land preparation methods, but GM in response to the increased total rainfall during the cropping season. On the other hand, BBF performed best both under favourable and unfavourable weather conditions. For instance, despite a poor performance of lentils in 2002 due to the unfavourable rainfall distribution, which started too late in June, followed by heavy storm events in August, and stopped earlier than normal years, the mean of the two years showed that BBF resulted in the highest grain and straw yields. As the weather in 2002 was particularly adverse for lentils, which suffered of hailstorms, various disease and pests, and terminal moisture stress, the effect of the land preparation methods was not sufficiently expressed. Nevertheless, similar to the previous year, BBF gave the highest grain and straw yields.

Considering the long-term (6 years) agronomic productivity, BBF gave the highest cumulative RPI followed by RT (Figure 3). This is attributed mainly to the consistent highest yield of lentil under BBF. However, using BBF or RT for all the crops reduced the benefits that could be obtained by selecting the best practice for each crop by 22 % and 33%, respectively. In other words, considering BBF for lentil and RT for wheat and tef may result in the maximum agronomic productivity.

5.1.3. Economic and Financial Performance

In order to realize the anticipated benefits, farmers have to invest financial and material resources. As these resources may limit the practicality of the options, economic evaluation is an essential aspect before implementing the alternatives. Yield comparison as conducted above can be one way. However as comparison of yield does not consider inputs, gross margin analysis has been conducted in this study. Gross margin is the difference between gross value of output and the total variable costs used in the production process. Although gross margin analysis is static, and does not take the time value of money into consideration, it is a useful tool, which can assist in improving the overall management of the farms as it addresses resource productivity in a given period (Senkondo *et al*., 2004).

The costs of inputs required for the production process under the different land preparation methods are variable (Table 5). GM and RT required the highest and the lowest total input cost, respectively. On the other hand, as compared to the control, an additional tillage cost of 90 Birr.ha^{-1} was required for BBF preparation except for tef, while RT saved 450 Birr.ha^{-1} on tillage. On the other hand, RT induced an additional herbicide cost of 480 Birr.ha^{-1} resulting in a marginal cost of 30 Birr.ha^{-1}. Similarly, GM required the highest additional cost of 120 Birr.ha^{-1}due to the extra labor for chopping the cover crop.

Table 5. Total variable costs (Birr. ha^{-1}) $ of the inputs that are affected by the treatments

Land preparation methods	Cost item	Wheat	Lentil	Tef
BBF	Tillage*	600	600	600
	BBF preparation§	90	90	-
	Total	690	690	600
GM	Tillage	600	600	600
	Chopping of the green manure**	120	120	120
	Total	720	720	720
RF	Tillage	600	600	600
RT	Herbicide****	480	480	480
	Tillage	150	150	150
	Total	630	630	630

§ Tef requires no broad-bed and furrow, *Tillage costs at 30 Birr per oxen day, ** one man-day cost @ 10 Birr a day and ***Herbicide cost was considered at 120 Birr per litre, $ 8.65 Birr = one US$

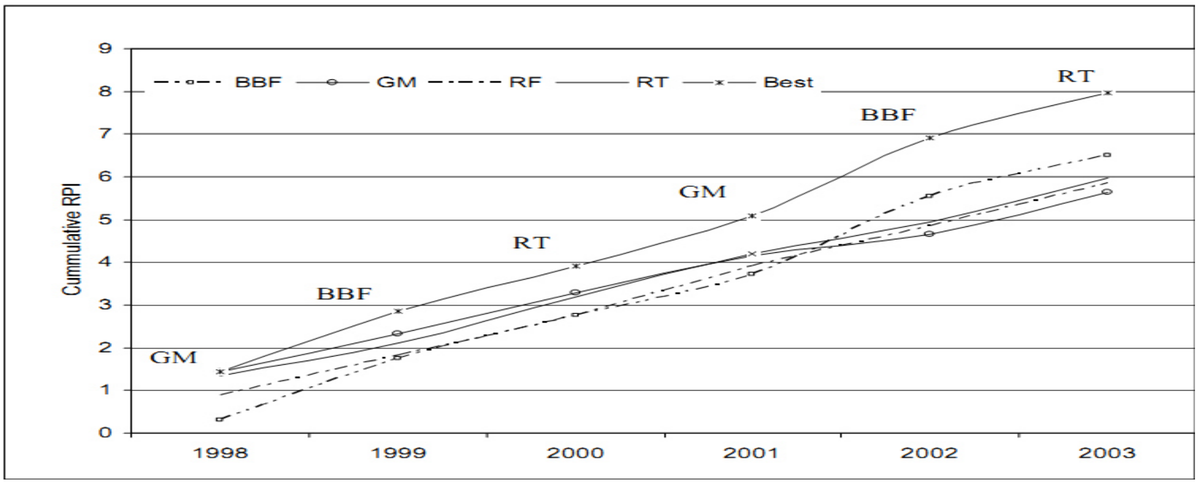

Figure 3. Cumulative relative productivity index (RPI) of the alternative land preparation methods and that of the best option for each crop

Considering the values of the outputs (grain and straw), BBF and GM gave the highest and the lowest total gross return, respectively (Table 6). This was due to the considerable decreasing and increasing effect, respectively of BBF and GM on the productivity of lentil, which is the major cash crop in the area. Consequently, BBF gave the highest gross margin followed by RT while GM gave the least (Figure 4). BBF increased the gross margin of lentil by 65% as compared to the control. This indicates that the different crops require different land preparation methods. Therefore, RT for wheat and tef, and BBF for lentil are the most profitable options.

Table 6. Gross values of outputs (Birr. ha^{-1}) $ from grain and straw yields of the crops as affected by the land preparation methods

Land preparation methods	Return item	Wheat	Lentil	Tef	Total
BBF	Grain	2202	4896	3240	10338
	Straw	357	219	710	1286
	Total	**2559**	**5115**	**3950**	**11624**
GM	Grain	3560	2772	3210	9542
	Straw	521	170	724	1414
	Total	**4081**	**2942**	**3934**	**10956**
RF	Grain	3396	3087	3185	9668
	Straw	555	197	721	1473
	Total	**3951**	**3284**	**3906**	**11141**
RT	Grain	3724	2541	3448	9713
	Straw	619	192	745	1556
	Total	**4343**	**2733**	**4193**	**11269**

Grain price (Birr. kg^{-1}): 2, 3 and 2.5 for wheat, lentils and tef and straw: 0.2, 0.1 and 0.3, respectively; 10kg bale at 7Birr, Tef does not need Broad-bed and furrow, $8.65 Birr = one US$

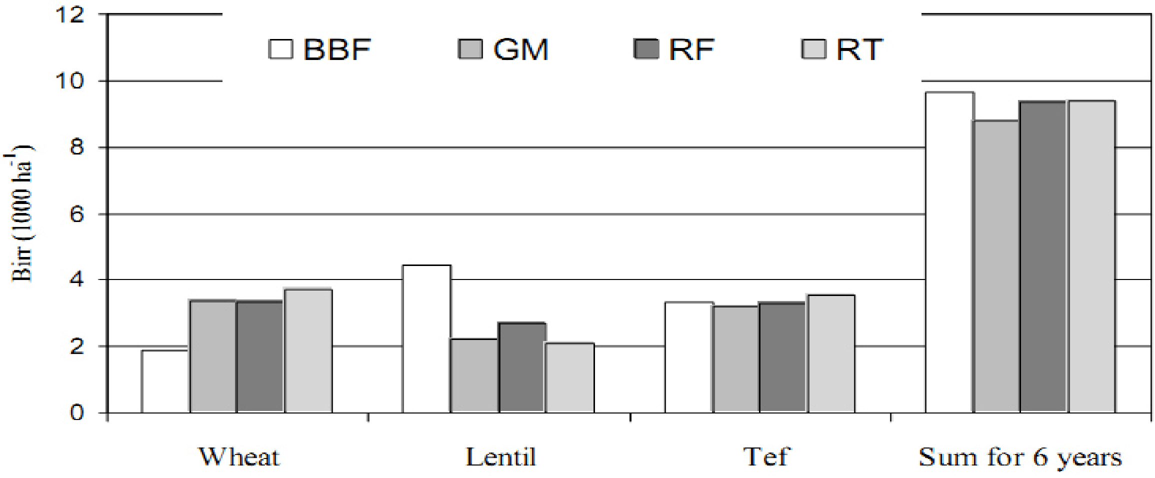

Figure 4. Gross margin (1000 Birr. ha^{-1}) as affected by the land preparation methods for the individual crops and the sum over the 6 years

6. Conclusions

The industrialization of agriculture led to societal concerns for environmental protection and food quality in developed countries. On the other hand, the need for increased agricultural productivity to address the persistent poverty and food insecurity in developing countries is intensified. Thus, improved management systems to meet the double objectives of increased productivity and sustained environmental quality are increasingly required.

The capacity of a soil to function depends on its inherent properties derived from its genesis and the dynamic properties resulting from the prevailing management systems. With a continually dwindling national land-holding average of only one ha per household, farmers struggle to produce enough to feed their families. Since the possibility of expanding agricultural land is limited, increased production is realistic only from higher productivity per unit land per unit time.

Covering about 8 million ha, Vertisols are among the high potential soils, where significant increase in productivity is likely. However, their productivity is constrained by their physical and hydrological properties, manifested by their hardness when dry and their stickiness when wet, impeding land preparation. The traditional management systems led neither to increased productivity nor to enhanced soil quality. Thus, the need for alternative technologies is paramount.

Despite a concerted effort during the last two decades to develop improved technologies for the soils, land preparation for agricultural productivity and sustainability remains a major challenge. In addition to technical difficulties associated with their nature and deep-rooted poverty and illiteracy, lack of farmers' participation is believed to have hampered the development and adoption of robust technologies. The challenge facing the soil management research in Ethiopia is thus double fold: development of technologies that swiftly increase agricultural production and ensure judicious use of the land resources.

Farmers are the ultimate decision makers on their plots, at least in Ethiopia, often irrespective of the consequences of their decisions. Simple technologies are required to manipulate their decisions in favour of the desired goals. This requires development of technologies that fit into their aspiration, tradition and socio-cultural values with their participation in the generation and evaluation of the technologies.

This review is to identify alternative land preparation methods for increased productivity and economic profitability, while maintaining or enhancing the soil quality of the Vertisols. Three alternatives, Broad Bed and Furrow (BBF), Green Manure (GM) and Reduced Tillage (RT) with the traditional method, Ridge and Furrow (RF) were compared for 6 years, setting crop yield, economic profitability, and soil erosion and soil quality as performance indicators. Land preparation methods influence soil functions through their effects on soils qualities. Among the soil physical quality indicators considered, GM increased aggregate stability and reduced surface crust strength due to its increased OM content and microbial activities. While RT led to least penetration resistance, infiltration, water-holding capacity, and moisture content were less sensitive to the treatments.

7. References

Abate, T. and Saleem, M., 1992. Cropping systems for Vertisols of the Ethiopian highlands. Pp. 55-66. In: Reports and papers on the management of Vertisols (IBSRAM/AFRICA LAND). Network document 1. IBSRA (International Board for Soil Research and Management). Nairobi, Kenya.

Ahmed, N., 1983. Vertisols. In: Pedogenesis and soil taxonomy, II. The soil orders. Elsevier. Amsterdam. The Netherlands. Pp. 91-123.

Alemayehu, J. and Hailemariam, F., 2008. The BBM: Impressions from the field. Field report prepared for ILRI. ILRI (International Livestock Research Institute), Nairobi, Kenya.

Aredo, D., Tsegaye, W. and La Rovere, R., 2008. Vertisol Management and the Promotion of Post-harvest Processing: Opportunities and Challenges in Becho, Shashemene and Mojo Districts. Nippon IA Research Report No. 5, 2008, Addis Ababa, Ethiopia.

Astatke, A., Saleem, M.A. and El Wakeel, A., 1995. Soil water dynamics under cereal and forage legume mixtures on drained Vertisols in the Ethiopian highlands. Agricultural Water Management 27: 17-24.

Debele, B., 1985. The Vertisols of Ethiopia: Their properties, classification and management. 5th meeting of the eastern African soil correlation and land evaluation sub- committee. 4-10 December 1983. Wad Medani. World soil resources report 56:31-54. FAO. Rome.

Deckers, J., Spaargaren, O. and Nachtergaele, F., 2001. Vertisols: Genesis, properties and soilscape management for sustainable development. In: Syers, J.K., Penning de Vries, F. and Nyamudeza, P. (eds): The sustainable management of Vertisols. CABI publishing.

Demeke, B., 1998. Economics of soil erosion and conservation: review of literature and a dynamic non-linear optimization model with risk and uncertainty, a case study for Ethiopia, MSc. Thesis, Wageningen University, and Department of Agricultural Economics.

Donahue, R. L., 1972. Ethiopia; taxonomy, cartography, and ecology of soils. Michigan State University Press, Monograph No. 1. Michigan, USA.

Driessen, P.M. and Dudal, R., 1991. The major soil of the world: Lecture notes on their geography, Formation, and Properties and use.

DZARC (Debre Zeit Agricultural Research Centre), 1990. Debre Zeit Agricultural Research Centre Annual research report. Debre Zeit, 1990.

Ebba, T., 1969. Tef (Eragrostis tef): The cultivation usage and some of the known disease and insect pests. Part I. Debre Zeit Agricultural Experiment Staion Bulletin no: 60, Haile Sellassie I University, College of Agriculture, Dire Dawa, Ethiopia.

Efrem, B., 2001. Performance of some cereal crops under drained Vertisols in the Ethiopian highlands. Pp. 151-157. In: Paulos D., Asgelil, D. Asfaw, Z., Gezahegn, A., Abebe, K. (eds): Advances in Vertisols Manamagement in Ethiopian Highlands.

Eswaran, H., Beinroth, F.H., Reich, P.F. and Quandt, L.A., 1999. Guy D. Smith memorial slide collection Vertisols: Their properties, classification, distribution and management. USDA Natural Resources Conservation Service website www.nrcs.usda.gov/technical/worldsoils (accessed: 15 Jan, 2004).

FAO/LUPRD (Food and Agriculture Organization/Land Use Planning and Rural Development), 1984. Ethiopia: geomorphology and soils. AG: DP/ETH/78/003. Field Document 3, Addis Ababa.

Fassil, K., Teklu, E., Teklu, T. and Assefa, G., 2001. On-farm demonstration of improved durum wheat varieties under enhanced drainage on Vertisols in the central highlands of Ethiopia. Paper presented on the 11th Regional Wheat Workshop for Eastern, Central and Southern Africa, 18-24 September, 2000, in Addis Ababa, Ethiopia.

Finck, A. and Venkateswarlu, J., 1982. Chemical properties and fertility management of Vertisols. Pp. 61-79. In: Vertisols and rice soils of the tropics. Twelfth International Congress of Soil Science, New Delhi, India, 8-16 February 1982. Indian Society of Soil Science, New Delhi, India.

Fisseha, I., 1992. Micro and macronutrient distributions in Ethiopian Vertisol Landscapes. Hohenheimer Bodenkundliche 2. Universität Hohenheim, Stuttgart. 202p.

Getachew, A., 2001. Cool season food legumes research on the highland Vertisols of Ethiopia. Pp. 171-183. In: Paulos, D., Asgelil, D., Asfaw, Z., Gezahegn, A. and Abebe, K. (eds): Advances in Vertisols Management in Ethiopian Highlands.

ILCA (International Livestock Centre for Africa), 1990. Annual research report. ILCA. Addis Ababa, Ethiopia.

Jutzi, S, Mesfin, A., 1987. Improved agricultural utilization of Vertisols in the Ethiopian highlands- an inter-institutional approach: Proceedings of the first regional seminar on management of Vertisols under semi-arid conditions held in Nairobi, Kenya 1-6 Dec. 1986. Pp. 173-183.

Jutzi, S.S., Haque, I., Mcintire, J. and Stares, J.E., 1988. Management of Vertisols in sub- Saharan Africa. Proceedings of a conference held at ILCA, Addis Ababa, Ethiopia, and 31 August to 4 September, 1987. International Livestock Centre for Africa, Addis Ababa, Ethiopia. 435p.
Kadu, P.R., Vaidya, P.H., Balpande, S.S., Satyavathi, P.L.A. and Pal, D.K., 2003. Use of hydraulic conductivity to evaluate the sustainability of Vertisols for deep-rooted crops in semiarid parts of central India. Soil use and Management 19: 208-216.
Mesfin, A., 1998. Nature and management of Ethiopian soils. Alemaya, University of Agriculture. 270p.
Mohr, E.C.J., Van Baren, F.A. and Van Schuylenborgh, J., 1972. Tropical soils. Mouton, The ratio law applied under field conditions. Pl. Soil 19: 33-48.
Parent, C., Cappelli, N., Berger, A., Crevecoeur, M. and Dat F.J., 2008. An Overview of Plant Respondes to Soil Water logging. Global Science Books, Isleworth, UK. Plant Stress 2: 20-27.
Ryan, J. G. and von Oppen, M., 1983. Assessment of impact of deep Vertisol technology options. Paper presented for the TTC meeting, ICRISAT, Hyderabad, India.
Senkondo, E. M. M., Msangi, A. S. K., Xavery, P., Lazaro, E. A. and Hatibu, N., 2004. Profitability of rainwater harvesting for agricultural production in selected semi-arid areas of Tanzania. Journal of Applied Irrigation Science 39: 65 – 81.
Teklu, E., 1997. Effect of surface drainage methods on soil and water conservation, root zone water balance and wheat performance, M.Sc. thesis, Wageningen Agricultural University, Wageningen, The Netherlands.
Teklu, E., 1998. Effectiveness of land preparation methods for surface drainage. Water. Arbaminch Water Technology Journal 2: 21-28.
Teklu, E. and Selamyihun, K., 2001. Soil Erosion and Conservation in Ethiopian Vertisols. P.107-114.In: Paulos D. Asgelil D., Asfaw Z., Gezahegn A. and Abebe, K. (eds) Advances in Vertisols Management in Ethiopian Highlands.
Teklu, E. and Gezahegn, A., 2003. Indigenous Knowledge and Practices for Soil and Water Management in East Wollega, Ethiopia. Technological and Institutional Innovations for Sustainable Rural Development.
Teklu, E., Assefa, G. and Stahr, K., 2004. Land preparation methods efficiency on the highland Vertisols of Ethiopia. Irrigation and Drainage 53: 69-75.
Willcocks, T. and Browning, J., 1986. Vertisols: (black) cracking clays. A bibliography with some abstracts, extracts, content analyses and comments. Overseas Division, AFRC Institute of Engineering Research (formerly NIAE), Beds, UK. 134 p.