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Integrated Management of Vertisols for Crop Production in Ethiopia: A Review

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Abstract
In Ethiopia, Vertisols account for 12.6 million hectares, of which about 7.6 million ha found in the highlands and are generally waterlogged due to abundant rainfall during the growing period. These soils are generally hard when dry and sticky when wet, a very low infiltration rate when the surface is sealed, very low saturated hydraulic conductivity and compaction as a result of swelling, and therefore presents serious limitations to their use. Crop production on these soils is limited because of impeded drainage, difficulty of land preparation, soil erosion and low fertility. Long-term adaptations to climate changes on Vertisols management require structural changes to overcome the harsh conditions. Vertisols have considerable productive potential, but they are usually underutilized in the traditional production system. Hence, achieving sustainable and improved management of Vertisols has been a major challenge for Ethiopian farmers for many years. Vertisols management technologies essentially early planting, drainage using BBM, improved variety, and fertilizers application were developed to effectively and efficiently utilize these soils. Early planting of short maturing wheat and teff varieties opened an opportunity for double cropping; excess water drained from the furrows would be utilized for supplemental irrigation. The literatures lines of research on integrated Vertisols management for crop production in Ethiopia were reviewed in this paper.
Keywords: Vertisols, Integrated Fertility Management, Crop Production

1. INTRODUCTION

The main soil forming process affecting Vertisols is the shrinking and swelling of clays as the soils go through periods of wetting and drying. Vertisols have a high content (>30%) of sticky, swelling and shrinking type of clays to a depth of 1 m or more (Brady and Weil, 2008). According to the authors, Vertisols comprise about 2.5% of the total land area and large areas of Vertisols are found in India, Ethiopia, Sudan, northern and eastern Australia. In Ethiopia, Vertisols covered more than 18% of the cultivated lands and 10% of the country. The high shrink-swell potential of Vertisols makes them extremely problematic for highway and/or building construction and agricultural purposes. Because Vertisols are very sticky and plastic when wet and become very hard when dry. These properties make the timing of tillage operations of the soils are critical for sustaining agricultural production and productivity.

Crop production on the Ethiopian Vertisols is limited because of impeded drainage, difficulty of land preparation, soil erosion and low soil fertility (Tekalign *et al*., 1988; Haque, 1992). However, these soils have considerable productive potential, but they are usually underutilized in the traditional production system (Paulos *el al*., 2001). Hence, achieving sustainable and improved management of Vertisols has been a major challenge for Ethiopian farmers for many years. Realizing the potential of Vertisols in the Ethiopian agriculture, national and international agricultural research institutions have participated in developing sustainable technology to increase the productivity of crops grown on Vertisols. To this effect, several management options such as developing improved animal drawn implement, the broad bed and furrow maker (BBM), varietal development for waterlogged Vertisols, and a package of early planting, fertilizer application and weeding was developed to effectively and efficiently utilize these soils. Early planting of short maturing wheat and teff varieties opened an opportunity for double cropping, and excess water drained from the furrows would be utilized for supplemental irrigation.

Vertisols have crucial importance for increased and sustained food production in Ethiopia. Bull (1988) estimated that about 11.9 million ha (over 90% of total) of Vertisol area in Ethiopia are potentially arable. Out of this about eight million ha can provide about 150 days of growing period. Tillage is difficult, except for a short period at the transition between the wet and dry season. Vertisols are productive if properly managed. The advantage of Vertisols is that they have good chemical fertility and their occurrence in extensive level plain, where reclamation and mechanical cultivation can be envisaged are assets of Vertisols.

Their physical characteristics and notably their water management short comings need to be overcome to reap this potentially fertile resource. The reality faced by Ethiopia's farmers who till Vertisols is that their landholdings are small, often scattered and produce relatively low yields. Farmers' problems are compounded by the fact that they can grow only a single crop of teff or pulses each year because their fields become waterlogged soon after the rainy season begins. Conversely, even in areas where farmers make the broad beds by hand, they do not plant early because the soil is too hard to work. That's why the most recent design of the broad bed maker has proved so valuable.

A group of national and international research organizations had been collaborated to tackle the waterlogging problems of central highland Vertisols for about two decades. However, there are little success stories in the adoption of the Vertisols management technologies by the small scale farmers. The problem of slow and/or little adoption of Vertisols management technologies by the small scale farmers were confined by the lack of compatibility of the technologies with the farmers' socio-economic conditions. Regardless of lack of adoptions of improved Vertisols management technologies, Vertisols sustain millions of people with the centuries old traditional management techniques which became an obstacle to achieve food self-sufficiency in Ethiopia. Therefore, revisiting the improved and traditional Vertisols management technologies will help to design, generate, adapt and disseminate technologies compatible to the farming systems. Thus, the objective of this paper is to review on integrated management of Vertisols for crop production in Ethiopia.

2. LITERATURE REVIEW

2.1. Distribution of Vertisols in Ethiopia

Vertisols cover 12.6 million ha where 7.6 and 5.0 million ha are found in the highlands and lowlands, respectively. The largest Vertisols areas are on the volcanic plateaux, colluvial slopes and side slopes of volcanoes in central Ethiopia; on the colluvial slopes and alluvial plains bordering Sudan; and on the vast limestone plateaux of central Hararghe province. Furthermore, areas are found in the granitic colluvium in basins with seasonal drainage 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.

2.2. Importance of Vertisols in Ethiopian agriculture

Vertisols are geographically widespread in Ethiopia, however; the resources have been underutilized because these soils are difficult to manage (hard and cloddy when dry, and very sticky when wet). However, some attempts had been done to improve surface drainage using oxen drawn implement. The physical characteristics of Vertisols, coupled with the limited resources of small farmers, limit crop production on these soils in Ethiopia.

Rain-fed crops such as teff, durum wheat, chickpea, lentils, linseed, noug, and bread wheat are generally grown on Vertisols, wherever drainage conditions are favorable, particularly for faba bean, field peas and barley production. Moreover, in the lowlands, irrigated crops such as cotton, sugarcane, citrus, and some vegetables are grown on these soils. Small farmers also grow sorghum, haricot beans, maize and other lowland crops. However, the productivity of Ethiopian Vertisols are very low under the current management systems that need to use appropriate management practices to improve the life and livelihood of small scale farmers live on scrunching the soils.

2.3. Climate change adaptation

Climate change adaptation for agricultural cropping systems requires a higher resilience against both excess of water (due to high intensity rainfall) and lack of water (due to extended drought periods) (FAO, 2007). These contrasting conditions are among the bottleneck problems that limits the productivity of Ethiopian Vertisols. Different national and international research organizations had conducted intensive research to increase the agricultural productivity of the central highlands of Ethiopian for about 15 years with Joint Vertisols Project (JVP) (Paulos *et al*., 2001). During the second phase of the JVP (1994 to 2000), Vertisols management technologies generated in the first phase (1986 to 1992) were tried to be verified under farmers' condition where most of them were not adopted by the farmers because of many factors (Workneh, 2001). According to the author, the farmers claimed that the furrow made by the broadbed and furrow maker (BBM) was shallow and could not drain excess water in Vertisols, repeated plowing exert extra cost, the implement was too heavy to oxen, and costs associated with BBM itself. As a result, farmers have continued to use their local drainage practices such as handmade BBF, ridge and furrow, late planting etc. However, the centuries old agricultural practices do not give sustainable agricultural production and productivity under high population pressure and unpredictable climate conditions. Therefore, it has paramount importance to revisit the traditional and improved agricultural practices in Ethiopian Vertisols management and design mechanisms to grow food and feed crops tolerant and/or resistance to waterlogging, harvest the excess water and utilize for supplemental irrigation in double cropping.

Long-term adaptations to climate changes on Vertisols management require major structural changes to overcome the harsh conditions. Thus, changes in land-use to maximize yield under new conditions; new land management techniques and water-use efficiency related techniques. According to Reilly and Schimmelpfenning (1999), major classes of adaptation to climate change are seasonal changes and sowing dates, different varieties of species, water supply and irrigation system, fertilizers, tillage methods, and promotion of agroforestry with suitable species and silvicultural practices.

2.4. Physical characteristics of Vertisols

Most Vertisols in Ethiopia generally contain more than 40% clay in the surface horizons and close to 75% in the middle part of the profiles. The sand fraction is low, often less than 20%, is found in the bottom horizons. In the highland Vertisols where soil burning (guie) is practiced, the sand fraction is normally high in the surface horizon because the clay bakes into sand-size particles (Berhanu, 1985). Landform is normally level to gently undulating and drainage seems to be rather poor. When Vertisols occur in a landscape with a more pronounced relief they invariably form in the depressions, together with reddish-colored soils occurring on the higher ground. The cropped Vertisols on medium to higher elevation plateau's are on slight slopes averaging possibly 2% and almost never exceeding 8%. The ecology of these plateaus is characterized by high annual rainfall, in excess of 900 mm, and moderate temperatures, which leads to relatively low evaporation, particularly during the growing period. Moderate to severe waterlogging and serious water-borne soil erosion are common features in these Vertisol areas.

The high proportion of heavy, cracking, clay soils in overall Ethiopian cropland has presumably facilitated historically the predominance of the teff crop with its considerable waterlogging tolerance as well as the widespread use of animal power for tilling the soil. The major crops grown on Vertisols are barely, wheat, teff and pulses. In the highlands due to the cooler temperatures, longer growing period is required for these crops (Berhanu, 1985).

The high content of montmorillonitic clays in the soil determines the major physical and morphological characteristics, for example the plastic consistency, shrinking and hardening upon drying, extensive swelling upon wetting, formation of deep cracks, formation of slickensides and pressure faces, self-churning process, micro-relief feature, etc. It should be noted, however, that the montmorillonitic clays in Vertisols are normally saturated with calcium and magnesium. In view of this, these physical characteristics might be more firmly associated with the high clay content than with the clay species. These physical characteristics bring about certain difficulties in utilizing the soil for agriculture or as a base for the construction of buildings and roads.

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 Vertisols. 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 the traditional management practices. Once the rainy season starts and the surface is wet, cultivation is virtually impossible.

The subsoil consists mostly of strongly developed fine to medium angular blocky structures with developed slickensides. The soil often contains lime concretions throughout the profile and gypsum crystals occasionally occur as well in the subsoil. As the soil is fine-textured, the consistency is usually very sticky and very plastic when wet and very hard when dry. This, together with strong swelling nature of the clay during the wet season, causes self-churning phenomenon and the gilgai microrelief characteristic of Vertisols (Probert *et al*., 1987). In addition to the generally poor surface drainage of the soil, heavy impervious clays in the subsoil also inhibit internal drainage.

There is few data on bulk density of Ethiopian Vertisols are available; it is not possible to characterize bulk densities of very widely distributed Vertisols. A limited report on bulk densities of Ethiopian Vertisols indicate that it is in the range of 1.5-1.8 g cm^{-3}, and may reach 2.05-2.1 g cm^{-3} (Murthy *et al*., 1982). These variations in bulk density are caused by swelling and shrinking with changes in soil moisture content. The soils have high bulk density when dry and low density when wet (Virmani *et al*., 1982).

Vertisols have a relatively high water storage capacity in the root zone because of their depth and high clay content. The available water range has been reported as 110-250 mm for the top 1 m of the soil profile (Virmani *et al*., 1982). The high water-storage capacity of Vertisols is important in regions with uncertain rainfall. The growing season on deep Vertisols is usually longer than on other soils; on the highland Vertisols, wheat, lentil, chickpea and vetch grow to maturity entirely on residual soil moisture after establishment at the end of the rainy season. Farmers practice late-season planting to avoid the serious drainage problems characteristic of these soils during the rainy season.

2.5. Chemical characteristics of Vertisols

The pH of Vertisols increases with depth, the topsoil being neutral or weakly acid. According to Berhanu (1985), about 61% of the Vertisols have pH values of 5.5-6.7, 21% have pH values of 6.7-7.3, and 9% have pH values of more than 8. He stated that nearly all of the Vertisols of Ethiopia have CEC of 35-70 meq/100 g soil.

Analytical results from selected sites on Vertisol areas show that N and P are deficient. Available P in these soils is generally higher than 20 ppm. Berhanu (1985) reported that in 70% of the cases available P is below 5 ppm. In the surface horizons (0-30 cm) most of the Vertisols contain about 3-10% organic matter. Generally soil organic matter is related to texture, increasing with higher clay contents. Total N contents vary from 0.08 to 0.22% and the C:N ratio is about 11-18. The wide range in C: N ratio is attributed to increased nitrification and loss of N. The loss of nitrogen might also be caused by denitrification resulting from poor drainage.

The clay fraction is dominated by smectites. The predominant exchangeable cation, which accounts for up to 80% of the exchange complex, is Ca, followed by Mg: K and Na contribute nearly equal proportions (Berhanu, 1985, Mitiku, 1987). In the highlands, base saturation, even in the presence of calcium carbonate nodules, is rarely greater than 80-90%. These nodules are largely crystalline, hard, chemically inactive, and have practically no effect either on the pH or on the base saturation of the soil.

2.6. Integrated Vertisols management for crop production

Integrated natural resources management (INRM) is an approach to research that aims at improving livelihoods, agroecosystems resilience, agricultural productivity and environmental services. Integrated natural resources management has ability to empower relevant stakeholders, foster adaptive management capacity, focus on key causal elements (and thereby deal with complexity), integrate levels of analysis, merge disciplinary perspectives, make use of a wide range of available technologies, guide research on component technologies, generate policy, technological and institutional alternatives. On the other hand, the farming systems approach was too descriptive, looked in from the outside and did not fully understand resource enterprise feedback processes, making extrapolation difficult (Place and Were, 2003). These clearly showed that germplasm and agronomy improvement alone are not enough and there is a need to conserve/enhance natural resources to gain benefits of improved germplasm and agroecosystems functions and services. Natural resources are a key to rural livelihoods, but their unsustainable use by poor people themselves or by other powerful stakeholders, can result in land degradation, loss of habitat and biodiversity, and pollution.

Traditional single-disciplinary and single-scale approaches for agriculture and natural resources management (NRM) technologies disseminations have only short-term impacts in Ethiopia in general and in central highland of the country in particular. This doesn't mean that technologies have problems rather small scale farmers in Ethiopia have been bound by complex problems that cannot be solved by the traditional approaches. For instance, farmers need cashes for different purposes, energy for cooking and heating, high yielding food and feed crops, improved breeds of livestock and poultry, multipurpose trees, fertile lands, enough water etc. If one of the important elements is missed, the adoption and/or impact of the other technologies will be poor regardless of the quality of the technologies. This clearly showed that improving the whole farming systems of the small scale farmers in Ethiopia can bring radical change to their life and livelihood thereby sustainable development of the country can be enhanced.

However, there is little success story of research and development interventions to tackle natural resources degradation in Ethiopia since great emphasises are given to germplasm and agronomy improvements alone. The application of INRM research approach in Ethiopian in general and in Vertisols predominant parts of the country in particular can help to solve socio-economic, cultural, and institutional problems for sustainable agricultural development. Because INRM balances hard and soft sciences, merging research and development, setting up a system for adapting and learning, focusing the right types of sciences at the right levels, changing scientific cultures and organizations (ICARDA, 2005).

2.6.1. Agronomic practices and cropping systems

Crop productivity on Vertisols can be increased through early planting and improved surface drainage. Appropriate cropping systems are required for efficient use of the whole growing season. Some forage legumes are known to benefit food crop production by enhancing soil fertility when planted in association, or in rotation, with a major food crop. Most of the available information is relevant to maize and sorghum production in mid-altitude areas, such as Debre Zeit. In the higher areas, small grains are major food crops, so cropping systems based on such crops would be more appropriate. Some *Vicia, Trifolium* and *Medicago* species have high potential for sequential cropping with cereals. Some useful cropping systems may include forage legume-cereal sequences in the off-season and main rainy season, and cereal-pulse sequences in the main season.

The wastage rate of fertilizers is high on Vertisols due to the broadcast method of sowing and denitrification due to waterlogging. Proper methods of seeding and method and time of application of fertilizers are important for efficient fertilizer use. Since nitrogen and phosphorus are the two most important nutrients limiting the yield of many crops, most studies in the area of nutrient response have concentrated on the two.

Crop response to nitrogen has been reported by many authors in the country. There was a marked N response in most of the crops tested on Vertisols (Amsal and Daglas, 2001). The high response to N is understandable because total N in most Vertisols is low. Because of rapid nitrification, most of the N added as fertilizer containing NH_4 or NH_2 is subject to leaching or denitrification soon after application. Ammonia fixation also affects fertilizer efficiency in heavy Vertisols (Finck and Venkateswarlu, 1982). Therefore, the application of 90 kg N ha^{-1} for most crops may be justified under such conditions since the maximum yield for grain crops was found at this fertilizer level. The efficiency of the N fertilizer applied could be improved through the use of nitrate forms of fertilizer and the deep placement of split application of the ammonium forms of fertilizer.

For most crops there was a marked response to phosphorus fertilizer (Desta, 1986). At Sheno, barley reached a peak yield of 2057 kg ha^{-1} with the application of 13 kg P ha^{-1}, but higher concentration of fertilizer produced lower yields. Significant P responses were observed for teff and bread wheat at Ginchi. For teff the maximum yield was obtained with 40 kg P ha^{-1}, and for wheat 20 kg P ha^{-1} gave the highest yield. The largest yield increment for bread wheat at Holleta and barley at Sheno was observed with the lowest rate of 13 kg P ha^{-1}. For faba bean maximum yield was obtained at 26 kg P $ha^{-1.}$ Trials at Tefki, Inawari and Bichena showed that P was necessary for bread wheat, durum wheat, teff, and faba beans (Adugna and Hiruy, 1986). Oilseeds and pulses showed little response to P. Two forage grasses *(Guinea* and *Phalaris)* at Holetta gave high yields with 40 kg P ha^{-1}.

Variation in P response among crops at the same site is mainly due to the complexity of soil P. There are four important soil factors that affect the availability of applied P (Finck and Venkateswarlu, 1982); soil moisture, native available P, nature of the clay, and the amount of clay. Because Ca is the dominant cation in the CEC complex of the Vertisols, added P is usually transformed to calcium phosphate.

A survey was conducted in Raya valley to study the physic-chemical characteristics of Vertisols of the area. The area is characterized by crop failure mainly due to moisture stress and crops tend to wilt soon after heavy rains cease. Information was gathered by opening representative pedons for factors affecting soil moisture retention. In general, soil of the valley has alkaline reaction with potential sodicity hazard and have medium to high available water capacity. The high silt to clay ratio and low organic matter content in the surface horizons limit structure stability causing slaking of the surface soil, which reduce permeability and infiltration of rain water. It was recommended that the improvement of soil structure and organic matter content could increase available water capacity. Further investigation on pF, surface crusting and rainfall simulated infiltration test was also recommended to further substantiate the findings.

It has been reported that N use efficiency of crops was enhanced by management factors such as drainage, variety or precursor crop. The response to nitrogen of durum wheat was improved by drainage of Vertisols at Akaki. At 120 kg ha^{-1} durum wheat planted on BBF gave 2923 compared to flat bed which was 1667 kg ha^{-1}. (Progress report, Debre Zeit Agricultural Research Center, 1990). Similarly, Selamihyun et al. (1999) reported that in a study conducted from 1990 t0 1995 to determine the residual effect of fertilizer N applied to teff following chickpea, it was found that response was not obtained by application of N in the first year but some response was obtained in 1993 and 1994 . The results demonstrated a residual fertilizer N benefit equivalent to 36.3 and 46.9 % of response to the current season application, and 25.7 and 36.1 for previous season N application. An experiment was conducted on Fogera flooded plain to determine the optimum N and P fertilizers on the yield and yield components of flooded lowland rice. Nitrogen was applied in two equal splits and P was applied basal as triple super phosphate at sowing. Application of N and P significantly ($P\leq 0.01$) increased grain yield of rice up to levels of 60 kg N ha^{-1} and 13.2 kg P ha^{-1} and the yield advantage over the control was 38.49 %. Application of both N and P fertilizers enhanced N uptake by rice. Applied N was positively correlated with N uptake by straw (r=0.94**), grain (r=0.43) and total N uptake (r=0.72).

Effects of fertilizer application on N and P uptake, recovery and use efficiency of bread wheat on Vertisols of west Shoa zone, Ghinchi district was studied. The experiments were conducted in factorial combination of for N rates (20.5, 41, 82, and 164 kg ha^{-1})from urea by three P rates (10, 20 and 40 kg ha^{-1}) from triple super phosphate plus a control treatment without no fertilizer application. The results from the combined analysis indicated that wheat N and P content, uptake, recovery and use efficiency were significantly affected by fertilizer application. Application of N and P fertilizer increased grain and straw N and P content. Higher application of rates of each nutrient significantly decreased the A R and AE of that nutrient, while increasing The AR and AE of the other nutrient. In this study, applied N and P.

An experiment was conducted at Ghinchi sub centre to assess the potential of selected legumes for their nitrogen fixing capacity. The experimental factors were two legume species: vetch (*Vicia villosa* susp. *varia* (Host) Corb.) and clover (*Trifolium quartinianum* A. Rich) and a cereal teff each sowed with two P fertilizer levels. Teff was included as a reference crop to assess the relative performance of the legumes and provide a basis for the estimation of N fixation.

Significant differences were observed between years and land preparation methods regarding dry matter (DM) production, N concentration, N content and legume N_2-fixation. Across treatments and seasons, the dry matter production of teff ranged between 3.63 and 9.32 t ha^{-1}; for vetch it ranged from 1.49 to 7.17 t ha^{-1} and for clover from 0.61 to 4.28 t ha^{-1} (Table 1). Estimated atmospheric N input was less than 20 kg ha^{-1} in 3 out of 4 experiments for clover with 56-94 kg fixation in the fourth experiment. For vetch the estimates of fixation ranged from 44 to 165 kg ha^{-1} N (Table 2). The performance of teff and clover were well correlated. Crop performance was better on camber bed than on BBF by a factor of 1.3 in 2001 and 1.5 in 2000. Teff and vetch were very responsive to P; the extra dry matter production ranged from 0.64 to 2.29 t ha^{-1}. On residual moisture, legume DM production and N content declined linearly with soil moisture content at planting; ranges of 1.60-0.60 t ha^{-1} DM and 40 - 13 kg ha^{-1} N content. Further work is needed to assess practical options for the cultivation of legumes for soil improvement or as feed for cattle.

Legumes showed nitrogen concentrations in the dry matter generally ranging from 2.2 to 3.0 %. This implies a C: N ratio of maximally 20 and this in turn implies that such material will not initially immobilize N upon incorporation into the soil (Giller and Wilson, 1991). On residual moisture, forage legume biomass production and N content were low (maximally 2000 kg ha^{-1} dry matter and 55 kg ha^{-1} N) in comparison to main season legumes crops. The current limited data do not allow a definite judgment on the usefulness of legume cultivation on residual moisture. This study has shown that, where temperature is not a major limitation, two short duration crops can be produced in sequence per year on the same land. Normally, traditional crops are grown on residual moisture late in the season (September to January) when waterlogging is less of a problem (Hailu, 2009). This study was conducted on a Vertisol in Ethiopia to determine the optimum farm yard manure (M) and nitrogen (N) application rates for maximum return under cereal-pulse-cereal rotation system.

Table 1. Dry matter and N yield of legumes and teff grown under two land preparation methods on Vertisol at Ghinchi

Crop type	Experiment I		Experiment II	
	BBF 00		Camber bed 00	
	Dry matter (t ha^{-1})	N Yield (kg ha^{-1})	Dry matter (t ha^{-1})	N Yield (kg ha^{-1})
Vetch - P	2.95	87.1	5.65	142.0
Vetch + P	5.23	168.3	7.17	186.0
Clover - P	1.25	27.0	2.95	67.2
Clover + P	1.64	37.4	4.28	98.6
Tef - P	4.23	17.7	7.92	29.2
Tef + P	6.52	28.4	9.32	34.0
SEDa	0.38	8.6	0.35	6.6

SEDa= Standard error of the difference between means

Table 2. Calculations of amount of N balance and estimated N fixation (kg ha $^{-1}$) of crops under two land preparation methods

Crop type	Experiment I (BBF 00)		Experiment II (camber bed 00)		Experiment III (BBF 01)		Experiment IV (camber bed 01)	
	N balance	Estimated N fixation	N balance	Estimated N fixation	N balance	Estimated N fixation	N balance	Estimated N fixation
Vetch-P	57	71	115	132	40	63	58	44
Vecth+P	136	151	147	165	55	78	108	95
Clover-P	-1	14	39	56	-17	6	36	22
Clover+P	-0.3	14	76	94	-15	7	36	23
Tef-P	-33.4		-25		-5		16	
Tef+P	-15		-17		-23		14	
SED_a	10		11		5		5	

SEDa= Standard error of the difference between means

The main and interaction effects of M and N significantly affected biomass, grain and straw yields of wheat (*Triticum durum*) and teff (*Eragrostis tef*), but the residual effect on chickpea (*Cicer arietinum*) was not significant. Application of 6 t M ha-1 and 30 kg N ha-1, gave the largest grain yield of both crops but a comparable result was obtained due to 3 t M ha-1 and 30 kg N ha-1. The economic analysis revealed that 6.85 t M ha-1 and 44 kg N ha-1 for wheat, and 4.53 t M ha-1 and 37 kg N ha-1 for teff were the economic optimum rates. The additional benefit obtained due to these rates was about 450 USD ha^{-1}. Therefore, application of the economic optimum combination of both organic and inorganic sources of nitrogen is recommended for use on cereals in the cereal-legume-cereal rotation system

In soil fertility management trials conducted since 1966, on red and black soils both nitrogen and phosphorus significantly affected wheat grain yield (60/60 N/P_2O_5). Farm yard manure, bone meal and blood meal were effective sources of plant nutrients. Green manuring improved soil fertility status and increased the efficiency of applied nutrients. Studies of N application timing on Vertisols at Ghinchi showed that application of 50 % of the total N at sowing and the rest at full tillering stage significantly increased grain yield as well as the protein content of wheat.

An experiment was also conducted on N and P uptake, recovery and use efficiency on bread wheat (cultivar Kubsa) on Vertisols at Ghinchi, in west Showa zone. The results from the combined analyses for each soil type indicted that increased grain and straw P content on Vertisols, Application of P fertilizer increased grain and straw P content. All wheat N and p uptake parameters exhibited a significant response to both applied N and P in Vertisols (Amsal and Doglas, 2001).

The grain yield potential was significantly increased, primarily as a result of a reduction in plant height and an increase in harvest index and the number of grains per spike and per unit area (Amsal *et al*., 1994). Increased usage of fertilizer, particularly N, has also been recommended as a primary means of increasing wheat grain yields in this region. To this end, a serious of zone specific fertilizer recommendations had been issued by the national bread wheat research program (Amanuel *et al*., 1991a), focusing on economically optimal rates of N and P derived from on farm trials using the previously recommended wheat cultivars. However, Tilahun et al. (1995; 1996) reported varietal differences in response to applied N, including differences in N uptake, N use efficiency and apparent N recovery. Given the fertilizer is imported and costly in Ethiopia, the effects of alternate N sources, rates and timing on N uptake recovery, and utilization by wheat on Ethiopian Vertisols were reported by (Tilahun *et al*., 1995; 1996). In general, large granular urea split application of N exhibited beneficial effects on most of the measured crop yield and N recovery characteristics. These positive effects were most pronounced when severe water logging extended through out the growing season. Agronomic efficiency of N use may be measured relative to the total N available (i.e. soils and fertilizer) or to fertilizer N (Tilahun *et al*., 1996). Given the difficulty of precise measurement of available soil N and the economic importance of fertilizer N, most efficiency studies relate to fertilizer N. The efficiency recovery or apparent recovery of fertilizer N can be measured as a fraction of fertilizer N applied. The effect of fertilizer N and P application on post harvest soil mineral N levels have been studied only to a limited extent in Ethiopia (Tanner *et al*., 1993; Tilhaun *et al*., 1998). Tilahun et al. (1998) recommended that to minimize the risk of detrimental effects of fertilizer N on the quality of surface and ground water, the use of agronomical appropriate fertilizer N sources, rates and application timing should be encouraged on the most productive crop species and cultivars.

The use of surface drainage methods, broad bed and furrow and ridge and furrow increased surface runoff from Vertisols. In addition to the consequent improvement of crop performance, this has significance if water harvesting is to be considered or supplemental irrigation is practiced for dry season (Teklu *et al*., 1998).

Crop rotation exhibited beneficial interaction effects with fertilizer N and P on wheat grain yield. Wheat grain yield response to fertilizer N was minimal or non-significant after faba bean break crop, and in the first wheat crop after any precursor crop; P response was occasionally enhanced in wheat grown after dicots, particularly faba bean, and in the first wheat crop after any crop (Tanner *et al*., 1998).

Lack of improved cultural practices is among the major production limitations that contribute to the low productivity of teff. Under appropriate cultural practices, however, improved varieties can yield up to 2.2 t/ha^{-1} on farmers' fields (Hailu *et al*., 1988). This implies that there is a chance to increase teff production by the combined use of high yielding varieties and improved management practices. Teff performs well on various soil types. However, its yield is limited by nutrient deficiencies, mainly nitrogen and phosphorus. Several site specific fertilizer recommendations were given on the results from studies conducted on various soil types across the country. The results generally showed that teff responded to N application rates, but not to P. These results are in agreement with those from other studies where response to P by both cereals and legumes grown on Vertisols were reported to be minimal or absent (NFIU, 1993). The general recommendation from studies conducted so far shows that maximum teff grain yield was obtained with the application of about 60 kg N ha^{-1} on Vertisols of the central highlands (DZARC, 1993). For maintenance purpose, P application at a rate of 10 kg ha^{-1} was also recommended. Teff, when compared to other crops, is prone to a high degree of lodging when higher doses of N are applied. Studies conducted at several locations to determine time of N application on teff grown on major soil types in the central highlands indicated that due to site specific factors such as rainfall and soil conditions, the result varied across locations and seasons. Therefore, making general recommendation was difficult. Nevertheless, split application, where half dose is applied at planting and the remaining half at tillering or booting stages were the common results. It appears that where waterlogged soil condition prevails during early stage of crop growth period, split or delayed application of N until the roots are well established may increase the crop's N uptake. In addition, split application of N can be practiced when higher levels of N rates are used. Consequently, for lower N, one time application at the appropriate growth stage may be a better practice (Tekalign *et al*., 2000).

An experiment conducted at Holetta research center to determine the N uptake recovery of four teff genotypes using two sources of chemical fertilizers, namely urea and ammonium sulfate and with the help of ^{15}N isotopic. The highest N uptake was for the late maturing varieties and the lowest was for the early maturing cultivars. The N source and the interaction also significantly affected the fertilizer N recovery. Nitrogen fertilizer use efficiency was monitored on farmer's fields as part of IAEA nutrient monitoring project supported by FAO special project on food security in sub-Saharan Africa. The results showed that 64-84 % of the nitrogen taken up by teff comes from the soil and 7-34 % from the applied urea nitrogen. The only account of teff response to N sources other than chemical fertilizers was that of dealing with mustard meal. Yield increases high as 42, 37 53 % over the control were obtained with the application of 31 kg/ha of mustard meal (Tekalign *et al*., 2000).

A soil sample was collected for micronutrient studies from different agro-ecological zones of the country, where the soils are dominantly Vertisol and the major crops grown are teff and wheat. The samples were collected from 24 zones, (1083 soil samples from Nitsols, cambisols, Vertisols and fluvisols) encompassing Amhara, Oromia, Tigray, Southern Nations and Nationalities and Benshagul-Gumuz regional states (Table 3).

Table 3. Micronutrient content of Vertisols collected from different parts of Ethiopia

Soil type	No. of samples collected	Range, mean and percent deficient samples	Micronutrient content (mg/kg)			
			Fe	Mg	Zn	Cu
		Range	1.7-109.2	0.0-205.5	0.0-10.0	0.1-24.8
		Mean	22.7	35.2	0.9	2.8
Vertisol	291	Deficient samples (%)	3.4	0.7	78.4	51.6

The findings indicate that generally Zn and Cu deficiency are wide spread in major crops and soil types. Over 75 % of the soil samples analyzed were deficient Zn and 52 % of the soil samples were deficient in Cu. Fe was found in maximum range in Vertisols and Mn is adequate in Vertisols. The effect of Zn and Cu application on growth and biomass yield of teff and wheat in green house conditions on Vertisols from Sinnana was non-significant, except the plant height for wheat. Zn is more deficient in Vertisols (but green house experiment didn't show a response). The report concluded that the micronutrient study in Vertisols needs further investigation.

Four land preparation methods namely BBF, RF (ridge and furrow), RT (reduced tillage), and GM (green manure) was evaluated on Vertisols of Chefe Donsa. The test crops wheat, teff and lentil were rotated following their traditional sequence. The planting dates were varied with the treatment and crop types, as well as on the onset of rain. The effect of land preparation methods on grain yields varied with crops (Table 4). The mean grain yield and straw yields of wheat and lentil were significantly increased by the land preparation methods and their interaction with year. For lentil BBF significantly increased the grain yield (59 %) as compared to the control. On the other hand, the highest mean grain yield of wheat was obtained due to RT (10 %) higher than the control. BBF significantly reduced the grain yield of wheat (35%) less than the control. This doesn't corroborate the recent and previous reports in which the use of BBF increases wheat grain yield and straw yield in other parts of the central of Ethiopia.

Table 4. Effect of land preparation methods on the grain yield of crops

Land preparation methods (L)	Wheat			Lentil			Teff		
	1998	2001	mean	1999	2002	mean	2000	2003	mean
BBF	438	1763	1101	2732	532	1632	1260	1333	1296
GM	1940	1621	1780	1704	144	924	1194	1373	1284
RF	1209	2187	1698	1787	271	1029	1139	1409	1274
RT	1819	1904	1862	1482	212	847	1315	1443	1379
Mean	1352	1869		1926	290		1227	1389	
LSD (5%)		217			193			NS	
Year		196			255			NS	
Year*L		307			273			NS	
CV(%)		10.73			13.85			9.5	

In conclusion land preparation methods seem to be sensitive to rainfall with respect to wheat. The grain yield of wheat increased from 1988 to a high in 2001 under all the land preparation methods, but grain yield in response to the increased total rainfall during the cropping season. On the other hand, BBF performed best both under favorable and unfavorable weather conditions. Regarding runoff and soil loss, the highest runoff drained 13, 30, and 16 percent of the rainfall in 1988, 1999, and 2000, respectively. Teff planted on flat bed resulted in 2000, the highest runoff of 30 and 16 % as compared to the previous year. BBF drained more proportion of water as the total rainfall increased, which makes it not only efficient but also dynamic with respect to surface drainage. RT resulted in the highest soil loss followed by BBF. It can be concluded that, treatment effects and rainfall intensity can aggravate soil loss.

Water harvesting and double cropping on Vertisols has been successfully implemented in Amhara and Oromia regional states. The Ministry of Agriculture Extension department main and major focuses is to look if the work is successfully undertaken by the development agents as Vertisols are given due attention in poverty alleviation and solving food insecurity problems of the country.

Manure and N application was evaluated for different crops. The M and N application rates as well as their interaction significantly (*P* 0.05) affected the grain yield of wheat and teff, but their residual effect did not affect the yield of chickpea (Table 5). Evidently, the grain yield of wheat increased with increasing N rates under all levels of M, but with decreasing rate as M level increased.

However, there was a slight drop when 60 kg N ha^{-1} was applied together with 6 t M ha^{-1} due to lodging resulted from the luxurious vegetative growth of the crop indicating over fertilization. The highest grain yield of wheat (2 026 kg ha^{-1}) was ha^{-1}. This suggests that only half of the recommended N (30 kg ha^{-1}) from urea is sufficient for optimum yield of wheat, even when the precursor crop is cereal (teff), provided that 6 t ha^{-1} M is applied. The yield increase due to 60 kg N ha^{-1} was 300% as compared to the control under no application of M, but it was only 12.8% when 6 t M ha^{-1} was applied. This implies that the contribution of 6 t M ha^{-1} to grain yield was comparable to that of 60 kg N ha^{-1}, indicating the possibility of complete substitution of the urea through organic sources.

Table 5. Mean grain yield (kg ha^{-1}) of some field crops as affected by manure (M) and nitrogen applications rates (mean of two years)

M (ton^{-1})	Nitrogen (kg ha^{-1}) 0	30	60	mean
	Wheat			
0	460	1311	1886	1118
30	1135	1437	1980	1591
60	1737	2026	1960	1941
Mean	1219	1524	1908	
CV (%) = 26; LSD (5%) N = 222; M = 262				
	Chickpea			
	2379	2535	2548	2592
	2650	2347	2664	2493
	2746	2596	2448	2567
	2488	2553	2610	
CV (%) = 22; LSD (5%) = NS				
	Teff			
	1655	2134	1988	1982
	2160	2203	2213	2170
	2131	2174	2060	2087
	1926	2192	2122	
CV (%) = 12; LSD (5%) N = 127; M = 121				

Similarly, the effect of M and N as well as their interaction was significant on grain yield of teff, which was sown after chickpea. Confirming the previous findings in which 30 kg N ha^{-1} was recommended for teff succeeding pulses (Selamyihun *et al*., 1999), the grain yield increased as N rates increased from 0 to 30 kg N ha^{-1}, but dropped with further increase regardless of M treatments. Although the highest grain yield of teff was obtained with the application of 6 t M ha-1 and 30 kg N ha^{-1}, similar to that of wheat, this was not significantly higher than the yield obtained due to the combined application of 30 kg N ha^{-1} and 3 t M ha^{-1}. Therefore, with the application of 3 t M ha^{-1} in two out of three years in a cereal-pulse-cereal rotation system, only 30 kg N ha^{-1} may be sufficient to optimize grain yield of wheat and teff, but this needs to be confirmed in economic terms.

3. CONCLUSION

Vertisols occupying about 12.6 million hectares of land in Ethiopia, occur in different agro-climatic conditions in the country and show a considerable variability, which should be fully understood when developing technologies to improve their performance. The physical characteristics of Vertisols, coupled with the limited resources of small farmers, limit crop production on these soils in Ethiopia. The physical management of Vertisols depends on the climatic zone, relief, and type of Vertisol. A sizeable number of technologies exist for improved physical and chemical Vertisols management, which have proved their value. A group of national and international research organizations had been collaborated to tackle the waterlogging problems of highland Vertisols. However, there is little success in the adoption of the Vertisols management technologies by the small scale farmers in Ethiopia. Although Vertisols sustain millions of people in Ethiopia appropriate management technologies should be adopted by the farmers. Therefore, the integrated use of Vertisols management options in general improving the whole farming systems of small scale farmers and bring radical change to their life and livelihood thereby sustainable development of the country could be enhanced.

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