

A Review on "Vertisol Management, Challenges and Future Potential for Food Self- Sufficiency in Ethiopia"

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Abstract
Ethiopia, the second populous country in Africa next to Nigeria, located 9.145^{0}N, 40.4897^{0}E latitude and longitude respectively was a sub-Saharan African country. Agriculture is the main stay of the nation economy and Eighty five per cent of the population engaged in this sector at subsistence level. In Ethiopia recurrent drought, low land productivity, population pressure, flooding, Rural-urban migration, poor saving trends, lack of infrastructure, poor rural asset base, low education and technological levels were the factors to prolong the time for achieving food self-sufficiency. The government's absolute prime concern is ensuring food self-sufficiency at both national and household level. So it is essential that, parallel to its activity of scaling up the productivity of small farmers with traditional farming systems, the government must introduce and implement modern agriculture systems through credit and extension services to increase food production and enable the agricultural sector to play its crucial role in achieving food self-sufficiency and other economic developments. From those modern agriculture systems vertisols management is the one future potential to boost crops productivity consequently to achieve food self-sufficiency with simple technologies and less expenses by exploiting the under-utilized land resource. So, different sources such as journals, proceedings, thesis works, symposium and annual reports have been reviewed in this paper to emphasize the role of vertisol management for food self-sufficiency in Ethiopia to enable getting attention by decision makers.
Keywords: Vertisols management, Food Self-sufficiency, Ethiopia.

1. INTRODUCTION

Vertisols are deep, dark-colored clayey soils of predominantly smectitic mineralogy. They are characterized by deep and wide cracks and at places have gilgai microrelief with frequent micro knolls and micro-depressions. These soils have characteristic cyclic pedons, which make them different from other soils. The slow and steady process of haploidization induced by argillipedoturbation (Hole, 1961) inhibits the process of horizonation (Simonson, 1954; White, 1967; Buol *et al.,* 1973; IBSRAM, 1987) and favors the development of Vertisols having characteristic structural profiles.

Vertisols (often known as "black cotton soils") 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; Amare Aleminew, 2015). 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. They account for about 70 % 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 % 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 (Amare, 2015).

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 (Amare, 2015).

Food self-sufficiency is defined as being able to meet consumption needs (particularly for staple food crops) from own production rather than by buying or importing (BMoAF, 2010). In its broadest terms, food self-sufficiency refers to a country's capacity to meet its own food needs from domestic production. It is typically measured either by the proportion of a country's food consumption that is met by domestic production, or by per capita food production per day at the level of an adequate diet (FAO, 2016).

There is a long-standing debate on whether food self-sufficiency is a useful strategy to achieve world food security. Supporters of this proposition argue that relying on the market for to meet food needs is a risky strategy because of volatility in food prices and possible interruption in supplies. The opposing view is that it is costly for a household (or country) to focus on food self-sufficiency rather than producing according to its comparative advantage and purchasing some of its food requirements from the market (BMoAF, 2010).

However, despite the fact that food production has doubled during the past three decades globally, demand has also accelerated from highly populated and fast- growing economies countries. Higher food prices are reversing progress towards reducing hunger and poverty in the developing world. About 40 countries are already suffering from serious hunger or are at risk in the short term. Even before food prices began to rise, the number of undernourished people in the developing world was growing. The FAO estimates that 860 million people cannot meet their daily nutritional needs in 2008. Hunger in Africa remains persistent and prevalent. More than a third of all people in sub-Saharan Africa suffer from chronic hunger, and the number of undernourished people rose to 213 million by 2004. The UN estimates an additional 130 million people worldwide will become malnourished because of the high price of food during the current food crisis (FWW, 2008).

Sub-Saharan Africa is lagging behind with respect to food and nutrition intake. Self-sufficiency is also decreasing. General GDP and income growth, especially of the middle class, is projected to trigger changes in food intake towards more quality and processed food. As indicated by a FAO-study (2012), Africa shows a food trade deficit since the mid 1970's, due to strong population growth, low and stagnating agricultural productivity, policy distortions, weak institutions and poor infrastructure. Sub-Saharan Africa shows high annual population growth rates of nearly 3%, doubling its population over a period of 30 years. Available income per capita remains low compared to the rest of the world, but growth rates are improving. The same story holds for the total food supply per capita, which is far below the world average and is only growing at a small pace below 1% per year. Similarly, animal products are largely absent in the Sub-Saharan diet, which mainly consists of cereals, roots and tubers.

Urbanization is rapidly increasing (urban population increased from around 20% in 1961 to 40% in 2013), having an influence on the available income and the dietary preferences. The Sub-Saharan region shows high production growth numbers for all commodities over the different periods, although these are not sufficient to meet the rising domestic demand. Self-sufficiency is decreasing for all commodities with the exception of dairy (EU, 2015. Meanwhile, further efforts should be made to achieve food self-sufficiency globally, regionally and at country level. Therefore, it is the objective of this paper to review different sources such as; journals, proceedings, thesis works, symposium and annual reports about the management of vertisol and its vital role in achieving food self-sufficiency in Ethiopia to emphasize the issue for decision makers.

2. STATEMENT OF THE PROBLEM

Vertisols, the fourth most important soil order in Ethiopia after Lithosols (16.2%), Cambisols (15.3%) and Nitosols (11.8%), cover 10.3% or 12.6 million ha of Ethiopia's land mass. It is suspected that more detailed surveys may reveal many more Vertisol areas than are reported here on the basis of an exploratory study. It has been estimated that 7.6 million ha of these Vertisols are located in the highlands above 1500 masl, and that of these 1.93 million ha are currently cropped (IBSRAM, 1987).

The highlands in Ethiopia cover 40% of the total landmass of the country but account for about 95% of all cultivated land. Vertisols account for about 70% of all highland soils with slopes between 0% and 8%. Hence, the importance of Vertisols in the country is unquestionable. However, most of the Vertisols suffer from excess water and poor workability and are also underutilized, and largely used for dry season grazing (Srivastava *et al,* 1993; Gezahegn, 2001).

Twenty-four percent of Ethiopian highland soils presently cropped are deep black clay soils classified as Vertisols. These 2 million ha represent one quarter of the total Vertisol acreage in the Ethiopian highlands, the balance being uncultivated primarily because of physical constraints especially the lack of sufficient drainage. Vertisols in Ethiopia account for about 70% of all highland soils on slopes between 0% and 8%. Heavy waterlogging of most highland Vertisols is common. This is due to their generally high contents (60-70%) of (montmorillonite) clays, to the normally high rainfall of the Ethiopian highlands (above 900 mm/yr.), and to low evaporative demands because of moderate temperatures (IBSRAM, 1987).

Despite the long tradition of animal traction in the Ethiopian highlands, and the general awareness among farmers of the waterlogging constraint, there is no traditional animal-powered surface-drainage implement available. In many highland Vertisol areas farmers follow a strategy of avoiding much of the waterlogging effect by planting crops late in the season, towards the end of the rains. The crops thus rely on residual soil moisture. This practice implies incomplete utilisation of the growing period, low crop yields and considerable soil losses at the start of the rains due to soil erosion. Large areas of highland Vertisols are presently not cropped because of the waterlogging problem (Getachew *et al,* 1993). Consequently, Vertisols in Ethiopia are currently underutilized. Considering their large moisture-holding capacity and relatively high fertility, Vertisols are capable of producing many times more food and livestock feed than they do today. Therefore, removing Vertisol constraints to crop production in both cultivated and uncultivated areas will have very high importance in food deficient Ethiopia. If food self-sufficiency is to be achieved in Ethiopia, Vertisols which cover immense land mass of the country, needs to be put under cultivation with proper excess water draining innovations and integrated nutrient management strategies.

3. LITERATURE REVIEW

3.1. Definition, Classification and Distribution of Vertisols

The Vertisol definition stresses cracking, pedoturbation, and movement within the soil mass (slickensides). It should be noted, however, that from the management viewpoint, other characteristics appear to be more important: hardness when dry, plasticity when wet, a very low infiltration rate when the surface soil is sealed, very slow saturated hydraulic conductivity, compaction as a result of swelling, available water capacity, presence or absence of surface mulch, sodium saturation, possible salt content, rooting volume, and occurrence of permeable materials in the subsoil. The definition of Vertisols in Soil Taxonomy is based on four obligatory properties. Vertisols:

1. Do not have a lithic or paralithic contact, petrocalcic horizon, or duripan within 50 cm of the surface;
2. have 30% or more clay in all sub horizons to a depth of 50 cm or more after the soil has been mixed to a depth of 18 cm (for example, by ploughing);
3. have, at some time in most years unless irrigated or cultivated, open cracks at a depth of 50 cm that are at least 1 cm wide and extend upward to the surface or to the base of a plough layer or surface crust; and
4. Have one or more of the following:
    a. gilgai;
    b. at some depth between 25 cm and 1 m, slickensides close enough to intersect;
    c. at some depth between 25 cm and 1 m, wedge-shaped natural structural aggregates that have their long axis tilted 10-60° from the horizontal (Eswaran and Cook, 1988).

Vertisols (from the Latin, vertere = turn) are churning heavy clay soils, that contain a high proportion of swelling clays such as smectites. 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 (Amare, 2015).

Despite their unique attributes, Vertisols were not recognized as a separate class of soils until the 7th Approximation (predecessor of Soil Taxonomy) was published in 1960 (Soil Survey Staff, 1960; Eswaran and Cook, 1988). Because Vertisols frequently occupy basin and lower landscape positions, they were referred to as alluvial soils and were differentiated from other similar soils by their dark colors. Soon, terms such as black clays and cracking clays appeared in the scientific literature. Farmers living on or near such soils gave them vernacular names. For example, in south India, farmers recognize at least four different kinds of Vertisols and use at least four names to connote their surface properties (Eswaran and Cook, 1988).

The mineral montmorillonite, which belongs to the smectite family of minerals, is responsible for the general attributes of the soils and their vertic properties. Identification of this mineral in the soil was made possible when X-ray diffraction techniques became commercially available in the early 1950s. Since montmorillonite has the property of swelling and shrinking, the classification concept of Vertisols was based on their shrink-swell potential. This potential is a function of the clay content of the soil and the relative amounts of montmorillonite in the clay fraction. A soil layer 10 cm thick with this property is not a Vertisol. A minimum amount of clay, as well as a specific clay type, must be present in a minimum soil volume to provide the minimum expression. In addition, these soils crack during the dry season; the presence of cracks and the duration of cracking are also included in the definition of the Vertisols (Eswaran and Cook, 1988).

Each class in Soil Taxonomy is identified by a defining property or properties as well as by its position in the key. The definition of each taxon excludes or includes other properties which further define the soil. Although these default attributes are not spelled out in the definition, they are equally important for classification. Since, Vertisols are recognized in the key to the orders after the Histosols, Spodosols and Oxisols; they cannot have the defining characteristics of these soils. Their placement in the key before the Aridisols, Ultisols, Mollisols, Alfisols, Inceptisols and Entisols implies that these soils may have only subordinate vertic properties. Since the classification of Vertisols in Soil Taxonomy was based on a limited number of soils, the International Committee on Vertisols (ICOMERT) is now working to improve the classification (Eswaran and Cook, 1988).

Vertisols are remarkably homogeneous soils; but differences within their taxa may be caused by climatic components, slope and landforms, the amount and composition of smectite minerals, and the nature of saturating cations. The soils are fine to very fine in texture, have a high CEC, base saturation, bulk density (dry), coefficient of linear extensibility, predominance of saturating cations such as Ca2+, Mg2+and Na3 (either singly or in combination), a high water storage capacity, low saturated hydraulic 'conductivity, and a neutral to alkaline reaction. They are normally low in plant-available nutrients (IBSRAM, 1987).

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 underutilized because they are difficult to manage hard and cloddy when dry, and very sticky when wet (Willcocks and Browning, 1986; Amare Aleminew, 2015). Vertisols (heavy black clay soils) cover some 43 million hectares comprising 19% of total land area in Sub-Saharan Africa. Nearly 30% of the Vertisols area is located in Ethiopia alone, particularly in the highland region (Mohamed Saleem, 1995; Gezahegn Ayele, 2001).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 (Amare, 2015).

Vertisols and associated vertic soils are the most widely dispersed soils in the world, and can be found under varied climatic conditions. Such soils are spread over five continents from 45°S to 45°N, mainly in tropical and subtropical areas, and their major areas of distribution are located in Asia and Africa (Dudal, 1963; IBSRAM, 1997). There are about 310 million ha of these soils in Asia (mostly in India), in America (mostly in the USA, Venezuela and Argentina), in Australia, and in the African continent. Vertisols occur extensively in several countries in Africa under arid, semi-arid, and humid climates, and have an agro-ecological potential for food production well above their present level of use. According to Swindale (1982), there are approximately 104 million ha of Vertisols and vertic soils in Burkina Faso, Niger, Nigeria, Chad, Sudan, Ethiopia, Somalia, Kenya, Burundi, Malawi, Zambia, Zimbabwe, and Botswana. Some small areas occur in other countries of Africa, and altogether about 30% of the world's Vertisols are located in Africa (IBSRAM, 1987).

3.2. Physical Characteristics of Ethiopian Vertisols

In order to appreciate the management-related properties of Vertisols, it is necessary to know not only the general soil properties, but also the properties in different parts of the soil. The situation is complicated for Vertisols by the temporal changes of soil properties in different parts of the soil as a function of depth, and the micro-variability on the surface (Eswaran and Cook, 1988).

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%, and is found in the bottom and the surface (plough layer) 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; Asnakew, 1988).

Vertisols are naturally fertile soils, but poor drainage and difficult workability limit nutrient availability. The most important characteristic of Vertisols is their high water-holding capacity (commonly 60-70%), a consequence of the deep profile and high content of montmorillonitic clay. Because of waterlogging, these soils remain unused during part of the rainy season, and many highland crops such as teff, barley, durum wheat, chickpea, lentil, noug and vetch are grown on residual moisture at the end of the rains (Desta, 1988).

Because few data on bulk density of Ethiopian Vertisols are available, it is not possible to characterize bulk densities of very widely distributed Vertisols. Reports from elsewhere show that Vertisol bulk density is usually high, 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; Asnakew, 1988). When dry, Vertisols are hard and impossible to plough with oxen-drawn implements and may even be difficult to cultivate with heavy machinery. Seedbed preparation is therefore difficult; the seedbed is generally rough even after repeated cultivation. When wet these soils become plastic and sticky. Tillage and seedbed preparation are only possible within a narrow soil-moisture range. In the dry season, surface horizons are characterized by huge, strongly developed prismatic primary structures separated from each other by deep vertical cracks, of various sizes, at intervals of 20-30 cm. These prisms break into strongly developed, often coarse, angular to sub-angular, secondary aggregates. In the wet season, both primary and secondary structures are almost completely destroyed, reducing the surface horizon to a massive block. At this time only shiny pressure faces and/or well-developed slickensides are visible (Berhanu, 1985; Asnakew, 1988).

Pores, except for the cracks developed during the dry season and occasional root channels, are limited. The plant roots are confined to cracks and slickenside faces. 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; Asnakew, 1988). Virgo and Munro, as quoted by Virmani *et al* (1982), observed that the moisture content in deeper layers of the soil profile is lower, apparently due to compression effects on metric potential. 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 (Asnakew, 1988).

The available information on the chemical properties of Vertisols is very limited. Available P in these soils is generally higher than 20 ppm. Berhanu Debele (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 losses of N as the Ca and moisture status are very favorable to increased microbial activity (Krishnamoorthy, 1971). The loss of nitrogen might also be caused by denitrification resulting from poor drainage (Desta, 1988).

3.3. 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; Desta, 1988). 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 (Amare, 2015). Vertisols are extensively found in Setit Humera, Gambela, Chilalo and Amibara. These soils occur in the lowlands (<1500 m), at intermediate altitudes (1500-1800 m) and in highland areas (2000 m or higher) (Desta, 1988).

The highland Vertisols are found mainly on high-elevation plateaus (> 2500 masl) in temperate ecosystems. The general slope range of the landscapes on which Vertisols occur is 0-8% (Debele, 1983; IBSRAM, 1987). They occur throughout this range but are more frequent in the 0-2% range, and are prevalent in landscapes of restricted drainage such as seasonally inundated depressions, basins, deltas, aIluvial/colluvial plains, pyroclastic plains, undulated plateaus, valleys and undulating side slopes (Debele, 1983; IBSRAM, 1987). On the basis of the limited studies available, it can be concluded that they are generally dark, deep, heavy-textured (> 50% clay), with strongly developed prismatic structures and wide deep cracks, strongly developed slickensides, and pH in the acid range (61% between 5.5 and 6.7), and with a CEC between 35 and 70 me/l00 g soil.

The predominant exchangeable cation is Ca, which accounts for 80% of the exchange complex, and this is followed by Mg. In the highlands, base saturation: even in the presence of calcium carbonate nodules, is rarely greater than 80-90%. In the surface horizon (0-30 cm) most of the Vertisols contain 3·10% organic matter. This percentage decreases with depth but is still about 1% at one meter depth - an indication of the self-cultivating characteristic of many Vertisols (IBSRAM, 1987).

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 (Amare, 2015).

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 (Amare, 2015).

3.4. Challenges of Vertisol Management in Ethiopia

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 (Amare, 2015).

However the Vertisol technology being a new innovation would be affected by a number of factors for a wider adoption by the smallholders in Ethiopia. As a result the contribution of the technology may diverge from the potential. The multitudes of factors affecting the performance of the technology at small-holders levels can be explained through many interconnected subsystems of vertisol related resource utilization. Such as interaction between crops and animals, energy and nutrient flows, economic transaction and interaction at farm level and farm's external environment. Policy environment (price policy, subsidy tax, credit etc.) affects the performance of the technology (Gezahegn and Heidhues, 1999).

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 favor 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. 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 (Amare, 2015).

3.5. Natural Problems of Vertisols

3.5.1. Seedbed Preparation

Soil moisture has a major influence on the behavior of Vertisols during tillage, weeding and at harvest. While interest in estimating soil moisture has been strong, the relationship between soil moisture content and other soil properties that affect management and use has received little attention, particularly in sub-Saharan African soils. Soil consistency is closely related to soil moisture. The moisture content affects the ability to work the soil, and the consistency is an index of that ability. The indices are important for tillage operations, and traffic by farm animals, farm implements and humans. Soil consistency has also been related to shrinking and swelling of clays, compressibility, strength and soil permeability, and has been used as a guide to when to begin soil manipulation (Sowers, 1965; Kamara and Haque, 1988).

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; Amare, 2015). The problem is serious particularly for small farmers using handheld or animal-drawn implements (Kadu *et al.,* 2003; Amare, 2015).

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; Amare, 2015).

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. When drying out, they form deep wide cracks from the surface downwards at some period in most years (Deckers *et al.,* 2001; Amare, 2015). 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 (Amare, 2015).

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 (Amare, 2015).

3.5.2. 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 vertics 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 (Amare, 2015). Waterlogging adversely affects the growth of crops, primarily due to reduced oxygen supply to the roots (Armstrong, 1982; Amsal *et al.,* 2000; Meles *et al.,* 2013). According to Donald and Gardner (1987), waterlogging during tillering and stem elongation leads to fewer tillers, more floral sterility, fewer grains per spike, reduced kernel weight and a final yield loss of 50% or more. To overcome the waterlogging stress, farmers in Ethiopia traditionally plant late in the season. However, planting late in the season has yield penalty as the crop would be exposed to terminal moisture stress and frost damage (Jutzi and Abebe, 1987; Teklu *et al.,* 2005; Meles *et al.,* 2013).

3.5.3. 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 (Amare, 2015). Erosion losses during the rainy season are also promoted by the low infiltration rates of Vertisols once the soil profile is filled to field capacity. A high percentage of rain falling onto the soil will then be lost as runoff, with substantial risk of erosion (Swindale, 1988).

3.5.4. Nutrients Availability

Next to N, P is the most limiting nutrient in Vertisols (Finck and Venkateswarlu, 1982; Tekalign *et al.,* 1988) and this holds true for Ethiopian soils. The Ethiopian soils, similar to the other agricultural soils of the tropics, are generally low in N and P. Several authors have reported independently that 70-75% of some Ethiopian agricultural soils are deficient in P (Desta, 1982; Pulschen, 1987; Tekalign and Haque, unpublished data 2; Tekalign *et al.,* 1988). However, very little detailed work has been done on the P status of Ethiopian soils and most of the studies on these soils have been concerned with crop productivity. The characterization and the distribution of the different chemical forms of P have received little attention. Nitrogen and Phosphorus are the two most important elements which are relatively low in Vertisols (Dudal, 1965; Hubble, 1984; Tekalign *et al.,* 1988). With Phosphorus the problem is more of unavailability than of total quantity present in the soil. Our research results show a wide range of differences in P status of the soil samples studied. The majority of the soils are low in available P; about 70% of the soil samples are deficient in P. Phosphorus fraction results show low levels of the available forms. Phosphorus sorption studies indicate high sorption capacity of the soils. Phosphorus sorption is mainly controlled by content of Fe and Al oxides. More studies are needed to understand the P status of other Ethiopian Vertisols and related soils (Tekalign *et al.,* 1988).

3.6. Potential and Management of Vertisols

Potentially, Vertisols are productive soils, but they are not easy to cultivate due to their poor internal drainage and resultant flooding and water logging during the wet season which contribute for lower crop yields. In Ethiopia about 2 million hectares of highland Vertisols are currently being cropped. This means presently only 25% of the 7.6 million hectares Vertisols in the highlands are cultivated. The common crops grown on Vertisols are teff (Eragrostis tef), wheat (Triticum spp.), barley (Hordeum vulgare), faba bean (Vicia faba), field pea (Pisum sativum), grass pea (Lathyrus sativus), chikpea (Cicer arietinum), lentils (Lens culinaris), lineseed (Linum usitaissium), noug (Guizotia abyssinica) and fenugreek (Trigonella foenum-graecum). But the yields of these crops are quite low on the vertisols due to waterlogging and unavailability of improved technology for drainage (Gezahegn, 2001).

Because of their relatively high inherent fertility, vertisols 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; Amare, 2015). 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; (Amare, 2015).

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; Amare, 2015). The Pellic Vertisols are the majority with over ten million hectares (Debele, 1985; Amare, 2015). 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 masl and on relatively flat topography (Ahmed, 1983; Amare, 2015), Vertisols in Ethiopia are found above 2000 masl (Fisseha, 1992; Amare, 2015).

Also, Ethiopian Vertisols occur on a wide range of slope up to 15% (Jutzi *et al.,* 1988; Amare, 2015) 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; Amare, 2015).

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

(Amare, 2015).

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; Amare, 2015). The use of tolerant crops is another traditional alternative. Teff (Eragrostis teff), 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 masl, its performance gets poorer because of the reduced temperature (Amare, 2015).

3.7. Experience on 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) (Amare, 2015).

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 Oppens, 1983). Maximum impact of improved Vertisol management techniques on crop yields and resource preservation can be expected if entire watersheds are involved (Amare, 2015).

Various cultivation practices aimed at draining the surface water are used in different parts of the highlands. Handmade 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; Amare, 2015). 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; Amare, 2015). 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 (Amare, 2015).

3.7.1. Vertisol Management Using 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; Amare, 2015). 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 (Amare, 2015).

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; Amare, 2015). 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; Amare, 2015). 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; Amare, 2015).

Land cultivation in the Ethiopian highlands traditionally relies on an animal power. However, there is no indigenous animal-drawn surface-drainage implement available. Such an implement (a broad bed maker, BBM) has been developed at ILCA and tested on-station and on-farm. The BBM, a low-cost device based on the

Ethiopian arc, establishes 120 cm wide broad beds and furrows (BBF) for effective surface drainage (Getachew *et al.,* 1993). The implement thus leaves behind a raised bed about 1.2 m across and two drainage furrows about 20 cm deep. The implement can be pulled by a pair of local Zebu oxen, weighs about 28 kg (8 kg more than the "maresha"), and can be handled by one operator. It can cover up to 1 ha per working day (7 hours), depending on the moisture and tilth status of the soil. Its cost, in addition to the two "mareshas" used, is about US$l5, and it can be made and maintained by village craftsmen. The BBM can be used as a seed-covering device while making the BBFs (IBSRAM, 1987).

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; Amare, 2015).

3.7.2. Traditional Strategies for Vertisol management

Traditionally farmers use low yielding crop varieties adapted to poor surface drainage, ridges and furrows late planting, handmade broad-beds and furrows, and soil burning practices to solve waterlogging problems (Gezahegn, 2001). Traditional methods of surface drainage, such as ridges and furrows or drainage furrows at various spacing's, are in general use, but they cannot effectively overcome the waterlogging problem. Very effective surface drainage is, however, practiced on the high elevation Inewari plateau at 2600 m altitude in central Ethiopia. There, raised beds about 80 cm wide, with 40 cm-wide furrows in between, are established each year on about 35,000 ha. This work is done by hand, without the help of any tool, which results in considerable human drudgery and low economic returns to labor (Getachew *et al.,* 1993).

3.8. Achievements of Vertisols Management in Ethiopia

The National BBMTP (Broad Bed Maker Technological Package) usage 2007/08 drained land of ha in Ethiopia out of 13 million hectares is indicated in Table 1.

Table1. National BBMTP 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; Amare Aleminew, 2015).

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 (Amare, 2015).

Table2. 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; Amare Aleminew, 2015)

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 (Amare Alem, 2015).

Table3. Effects of BBM on wheat yields

Location	Grain Yield (Kg/ha)	
	Improved Vertisols technology	Traditional Vertisols technology
Debre Zeit	1442	1180
Eneway	1105	1072
Dogollo	1844	1258
Dejen	1263	918
Ginchi	1453	686

Source: Gezahegn Ayele, 2001.

The results of wheat produced on Vertisols prepared by use of the BBM improved surface drainage and hence resulted in increased crop yields and economic returns than the traditional RF and Flat methods (Table2) (Gezahegn, 2001).

3.9. Definition, Measurement and status of Food Self Sufficiency

According to FAO, The concept of food self-sufficiency is generally taken to mean "the extent to which a country can satisfy its food needs from its own domestic production" (FAO, 1999; 2016). A more practical application of the concept of food self-sufficiency is defined as a country producing a proportion of its own food needs that approaches or exceeds 100 percent of its food consumption. Countries that are self-sufficient may specialize their food production to some extent and import as well as export food. But in caloric terms, a self-sufficient country produces as much or more food than it consumes, even if some of the actual food items consumed by its population are different from those that it produces domestically. This more pragmatic understanding of food self-sufficiency is captured by what the FAO terms the self-sufficiency ratio (SSR), which is defined as the percentage of food consumed that is produced domestically (FAO, 2012; 2016). The SSR is measured using the following equation with respect to food production and trade:-

$$SSR = \frac{Production}{(Production + Imports - Exports)} x100$$

More precise measurements of the SSR also include changes in domestic stock levels (Puma *et al.,* 2015; FAO, 2016). The SSR is typically measured in calories or in volume of food produced, although it can also be expressed as a ratio of monetary value. Another measure that captures self-sufficiency levels of countries focuses on dietary energy production (DEP) per capita within a country. This measure considers those countries that produce over 2500 kcal per capita per day to be self-sufficient as it is over this threshold that caloric intake is deemed to be required for an adequate diet (Porkka *et al.,* 2013; FAO, 2016).

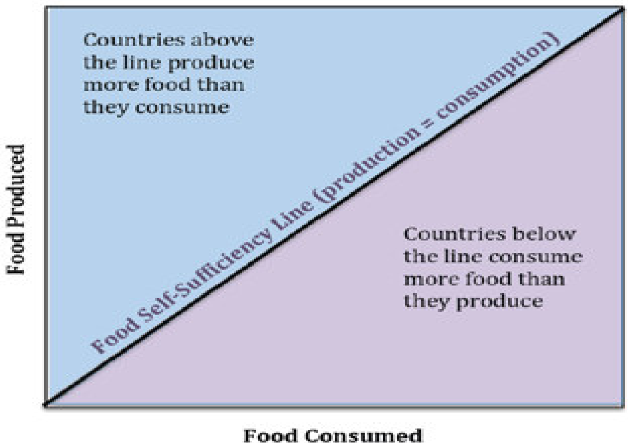

Figure 1: Basic representation of food self-sufficiency

It is important to note that food self-sufficiency is not an expression of food security, although the two can interact in important ways. The concept of food security does not include a consideration of the origin of food or a country's capacity to produce it, so long as it is available, accessible, nutritious, and stable across the preceding three elements. Food self-sufficiency is mainly concerned with the availability (i.e. supply) pillar of food security, and focuses on origin of food, or at least the domestic capacity to produce it in sufficient quantities. Some countries that are considered self-sufficient on a national scale can still have a proportion of their population experience hunger and malnutrition. Such countries may produce sufficient amounts of certain crops, such as grain, but they may still need to import significant amounts of fruits and vegetables to achieve a healthy diet. Some self-sufficient countries may also have higher poverty levels that hinder adequate access across the entire population. Other countries that are self-sufficient may have no problem in ensuring adequate and nutritious diets for their population (FAO, 2016).

In a more recent estimate, Porkka et al. (2013) show that levels of self-sufficiency, measured in production per capita per day over 2500 kcal, has not changed markedly in the 1965-2005 period, with data showing that around 25 percent of the world's population produces over that caloric threshold, while 75 percent is under it. However, data from this study show that the percentage of the world's population producing under 2 000 kcal/day has declined significantly since the 1965s. In other words, collectively, the countries producing under the 2500 kcal threshold have nonetheless still increased production since that time. Puma et al. conclude that 83 percent of countries either just met self-sufficiency (SSR close to 100) or had SSRs under 100 for the 2005–2009 period, which is similar to O'Hagan's findings over 30 years earlier (Puma et al., 2015; FAO, 2016). The lack of significant change in self-sufficiency rates overall is despite the fact that food production has increased globally by 50 percent since mid-1980s (D'Ororico *et al.,* 2014; FAO, 2016).

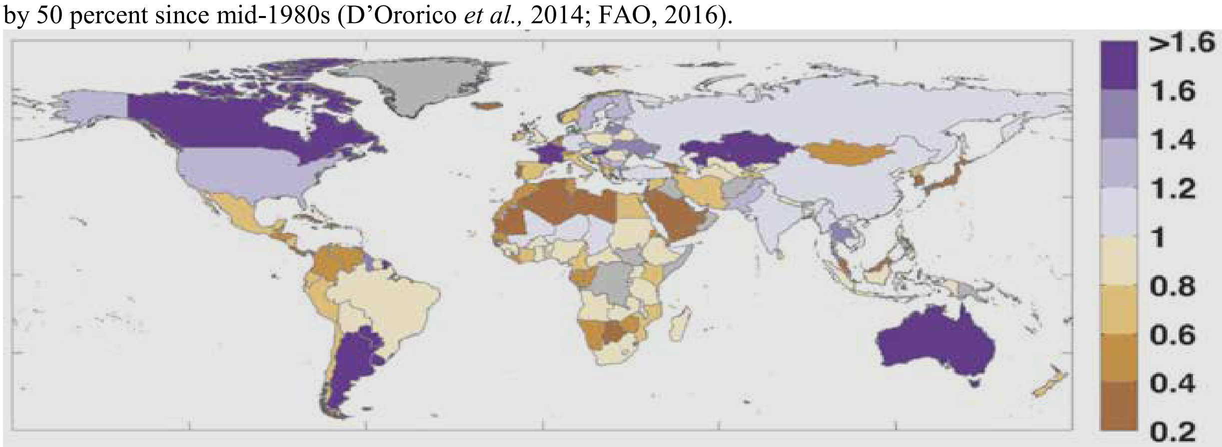

Figure 2: World food self-sufficiency ratios by country, 2005-2009
Source: Reproduced from Puma et al. 2015; FAO 2016.

Luan *et al.* (2013) examined trends in self-sufficiency in Africa since the 1960s and found that the continent's overall SSR has declined from 1.0 in 1961 to 0.8 in 2007(FAO, 2016).

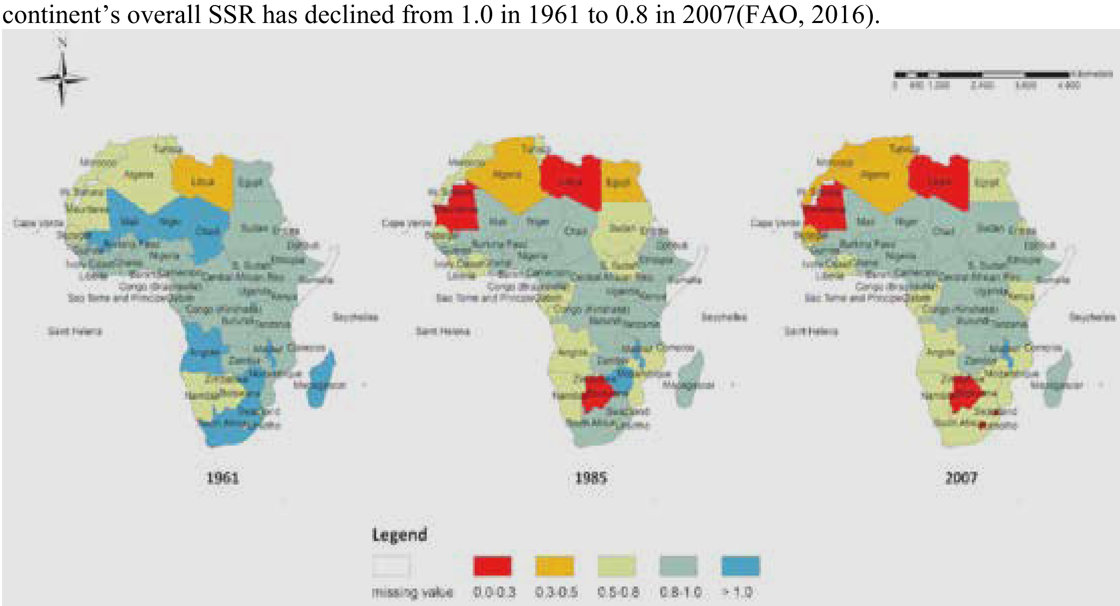

Figure 3: Changes in African countries' SSR over time.
Source: Luan et al., 2013; FAO, 2016

The world food crisis is threatening billions with hunger and starvation. An international call has been made for the FAO emergency conference in Rome 3-5 June to completely restructure world agriculture and double world food production (Davis, 2008). This fact is noteworthy given that 78 % of countries are not self-sufficient in terms of domestic calorie production (Davis *et al.* 2014, 2015). During times of scarcity (e.g., 2007/2008 food crisis and 2010 droughts/ wildfires in Russia), countries that are heavily dependent on food imports are at a distinct disadvantage in terms of food security as compared to nations who can rely on local crop production to meet dietary demands. Moreover, countries in surplus may need to reduce their food exports in the coming decades as a result of increasing domestic demand (Suweis *et al.* 2013; Davis *et al.* 2015). Indeed, recent work has shown that, as the global food system has become more dependent on trade, it has lost resilience and grown more susceptible to shocks and crises (Suweis *et al.* 2015; Davis *et al.* 2015). To minimize the vulnerability associated with dependence on food imports, national self-sufficiency policies have been implemented around the world (Davis et al., 2015). Countries in Asia, Africa and the Middle East have moved towards self-sufficiency in response to the food crisis, either by boosting agricultural production at home through subsidies and import tariffs or acquiring overseas farmland (Stephen, 2010). According to 2006 assessment of Defra, the UK is currently 74% self-sufficient in indigenous-type food (the sort that can be grown here), and 60% self-sufficient overall, for all foods; in other words, 40% of the food we eat is imported. It is also true that self-sufficiency is declining. Taking the long view, it has fallen from 100% to 60% over the past 200 years. More recently, the ratios for all foods and indigenous-type foods have fallen by 15% and 10% respectively over the past 20years (Barling, 2008).

3.10. The Role of Vertisol Management for Food Self Sufficiency in Ethiopia

On-farm research results indicated that in some cases crop yields can be increased as much as 60% through drainage improvement by BBM method. However by adopting packages, crop yield can be raised two-fold or even more (Tekaugn *et al.,* 1993; Gezahegn and Heidhues, 1999). Research efforts on Vertisols should concentrate on improving drainage and tilth. Once drainage has been improved, these soils are among the most fertile, and can produce high yields. Improved management will not only give higher yields, but will also reduce soil erosion. Biological nitrogen fixation (BNF) is a field that requires special attention. Since N is the most limiting nutrient on Vertisols, the use of forage and grain legumes should be encouraged. Increased N fixation by these legume crops will lead to increased productivity of cereal crops (Desta, 1988).

In an on-farm verification test in Debre Zeit in 1985 with 15 participating farmers, wheat yields increased by 78% and 56% for grain and straw respectively when using BBFs, with all other inputs being identical for drained and undrained plot pairs (IBSRAM, 1987).

Currently about 2 million ha of Vertisols are cropped annually in Ethiopia and some 6 million ha are left under native pasture because of severe drainage problems in the main rainy season (Jutzi *et al,* 1987; Hailu, 1988). With the present trend of population growth in Ethiopia, estimated at 2.9%, there is a strong need for increased agricultural production which may be achieved by increasing productivity per unit area and/or opening new lands. Both options may be applied on Vertisols in the highlands. Some of the major limitations for crop production on Vertisols are poor drainage, difficulty of seedbed preparation, and low soil fertility. In the high altitude areas the impact of low temperature complicates the soil problems. Traditionally farmers cope with these problems by late sowing of crops to mature on residual moisture, fallowing the land in the main rainy season, and soil burning, or "guie" (Berhanu, 1985). Land that is ploughed early for late planting of crops is exposed to soil erosion due to high and intense rainfall, hence diminishing soil fertility (Hailu, 1988).

From the result of the study conducted by Meles *et al.* (2013) using different vertisol managements, the package of broad-bed and furrow and fertilizer application outperformed the ridge and furrow and flatbed in all the parameters measured. The effects of waterlogging on crop phenology and growth, biomass and grain yield and nutrient concentration was clearly reflected in the flatbed planting. Therefore, the package of broad-bed and furrow and mineral fertilization is recommended as it reduces the energy and time required to make the soil drainage and gives higher yield compared to the ridge and furrow and flatbed planting (Meles *et al.* 2013).

4. SUMMARY AND CONCLUSION

In Ethiopia water-logging during the main rains imposes severe restrictions on the traditional agricultural use of vertisols. Much of the cropped land is left fallow and is subject to water erosion during the main part of the long rainy season. Crops are sown only as the rains diminish and then mature on residual moisture stored in the soil. Many Vertisols are left totally un-cropped because of this excess surface water during the rains. The highland Vertisol crops grown in the Ethiopian highlands are generally low-yielding and have only a limited biological potential for incremental yield due to fertility degradation and poor management practices.

Ethiopian vertisols have fairly long growing seasons, and consequently can be used to harvest successfully two or three crops per year. There is much evidence for the possibility of producing substantial increases in crop yields on vertisols if the excessive surface soil water is drained off and if appropriate cropping practices are used.

Effective surface drainage enables farmers to use the full rainy season and the post rainy season for crop growth under residual moisture. A removal of the water-logging stress also allows the utilization of higher-yielding crop species and cultivars and more effective preservation of the soil due to more important crop vegetation cover. Therefore, decision-makers may need to empower extension service agents to educate farmers on the value of Vertisol Management to achieve the country's food self-sufficiency programme.

The previous parts in general indicated that vertisol are potential resources and will continue in the future to support both crop and livestock production systems and contribute to the food self- sufficiency program in the country. It will be clear that, Ethiopia to meet the demand for food and feed of its population, it has no other option except to maintain and utilize its resource base. Every effort should be exerted to conserve the soil and drain water of the vertisol farmlands. Without innovation supporting the resource base of the vertisols and use of the excess water in the Ethiopian highland, the use of external input such as fertilizer alone may not be a sustainable option for development being a food self-sufficient. For future direction to be food self-sufficient and better development, it is necessary to integrate the resource management of a vertisol in a watershed context and able to optimally use resources, by applying alternative technologies.

5. REFERENCES

Amare Aleminew Wubie. 2015. Review on Vertisol Management for the Improvement of Crop Productivity in Ethiopia. Journal of Biology, Agriculture and Healthcare. Vol.5, No.12 www.iiste.org

Asnakew Woldeab. 1988. Physical properties of Ethiopian Vertisols. Holetta Research Centre Institute of Agricultural Research (IAR). Addis Ababa. Ethiopia.

BMoAF (Bhutan Ministry of Agriculture and Forests). 2010. Food security and food self-sufficiency in Bhutan. Bhutan. South Asia.

C.S. Kamara and I. Haque. Soil moisture related properties of Vertisols in the Ethiopian highlands.

David Barling, Rosalind Sharpe and Tim Lang. 2008. Rethinking Britain's Food Security. A research report for the Soil Association. Centre for Food Policy City University. London. UK.

Desta Beyene. 1988. Soil fertility research on some Ethiopian Vertisols. Holetta Agricultural Research Centre Institute of Agricultural Research (JAR). Addis Ababa. Ethiopia.

FAO (Food and Agriculture Organization). 2016. The State of Agricultural Commodity Markets 2015-16; Food self-sufficiency and international trade: a false dichotomy? Italy.

FWW (Food and Water Watch). 2008. What's Behind the Global Food Crisis? How trade Policy undermined Africa's Food self-sufficiency. Washington, DC. USA.

Getachew Asamenew, S.C. Jutzi, Abate Tedla and J. McIntire. 1993. Economic evaluation of improved Vertisol drainage for food crop production in the Ethiopian highlands.

Gezahegn Ayele. 2001. Technological Innovation, Adoption and the Management of Vertisol Resources in the Highland Ethiopia. Debre Zeit Agricultural Research Center/EARO. Addis Ababa. Ethiopia.

Gezahegn Ayele and Franz Heidhues. 1999. Economic Returns of Vertisol Innovation: An Empirical Analysis of Smallholders Mixed Farming in the Highlands of Ethiopia.

Hailu Gebre. 1988. Crop agronomy research on Vertisols in the central highlands of Ethiopia: Jar's experience.

H. Eswaran and T. Cook. 1988. Classification and management related properties of Vertisols. Soil Management Support Services. USA.

IBSRAM (International Board for Soil Research and Management Inc.). 1987. Management of vertisols under semi-arid conditions. Proceedings of the First Regional Seminar.

Kyle Frankel Davis, Jessica A. Gephart and Thushara Gunda. 2015. Sustaining food self-sufficiency of a nation: The case of Sri Lankan rice production and related water and fertilizer demands. Royal Swedish Academy of Sciences.

L.D. Swindale. 1988. Developing, testing and transferring improved Vertisol technology: The Indian experience.

Meles Mekonen, Kindie Tesfaye, & Wondimu Bayu. 2013. Soil Drainage and Nutrient Management to Improve Productivity of Waterlogged Vertisols for Small-scale Farmers. Engineering International, Volume 1, No 2.

Mohd Peter Davis. 2008. Agriculture in the Tropics: Seeking To Be Self-Sufficient. Pakistan.

Stephen F. DeAngelis. 2010. Food Security: Globalization versus Self-Sufficiency. http://www.enterrasolutions.com

Tekalign Mamo, I. Haque and C.S. Kamara. 1988. Phosphorus status of some Ethiopian highland Vertisols.

EU (European Union). 2015. Regional perspectives on food supply and demand. European Union Agricultural Markets Briefs No 7.