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Effect of Soil Physical Properties on Crop Production in Ethiopia: A Review

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Abstract: One of the most important ways to boosting the production and productivity of the crops by knowing the characteristics of soil physic-chemical properties, especially physical soil properties that play a great role in the production of crops. As the compactness of the soil structure increases, bulk density of the soil also increases, while the yield of crops decreases considerably. Physical properties of cultivated soils are known by low fertility status as it has high bulk density (b), low total porosity (f), low pH and very low organic matter (OM) or organic carbon (OC) content. The survival and well being of the present and future generation in countries with subsistence agriculture like Ethiopia depend on the extent of maintaining soil physical properties, hence increases soil fertility. So, land must be carefully managed which incites to establish land use system for staying its good physic-chemical properties in the long term. The rate of increase in stickiness or ability to tight together as the moisture content increases is a function of silt and clay particle content, the degree to which the clay particles are bound together into stable granules and the organic matter (OM) content of the soil. The formation and maintenance of a high degree of aggregation are among the most difficult tasks of soil management and yet they are among the most important properties, since they are a potent means of influencing ecosystem function. The review deals with the effects of different physical properties of soils on crop production and their characteristics exhibits based on their texture , structure, color, bulk density and particle density, water retention capacity are assessed through this reviews. Assessment of physic-chemical properties is an important tool to identify the nutrient status of the soil in different land use system. Investigating soil physical properties under different land uses could assist policy makers, researchers, extension workers and farmers to have baseline information to improve the physical properties and productivity of soils of the study area and elsewhere which have similar agro ecology. Research on this line is of vital importance as the results obtained from such studies could also be used for generating information on characteristics of a given soil to determine the changing capacity, within its alleviating mechanisms to increase the production and productivity of the soil. A number of studies have been conductedusing soil physical properties as an indicator of soil fertility, for instance, farmers in Dejen district of Ethiopia use soil color, soil depth, water holding capacity and crop yield performance to evaluate soil fertility. These studies indicate that farmers 'understanding of soils more general than that of scientists.

Key words: Soil · Physical Properties · Organic Matter · Organic Carbon · Bulk Density · Porosity

INTRODUCTION

As agricultural point of view, soil is a component of varied ingredients such as minerals, air, water and organic matter, as well as numerous living things (organisms) and the decomposed remains of once living matter (humus). It forms the uppermost layer of the Earth's covering that supports the growth of plants [1]. It is the frame for crop growth [2]. It is further describe morphologically in diverse ways, depending on the soil genesis, which entails the factors and processes involved in the creation of the soil solum (i.e. the true soil).

The soil structure is the most important parameter in crop production. This factor decides how soil conducts water, nutrients and air, which are vital for plant root activities [2]. Therefore, any force or external pressure that results in compressing the soil particles together, thereby requiring plant's roots to exert extra effort to penetrate the

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thick layer (structure) due to an increase in soil strength is termed compaction. In present day agriculture, farm animals, machines use and incorrect soil water content worsen the compaction process. Prominent among the causal effects of compaction are mechanical land preparation such as tractor trafficking, which major consequence is on the soil structure. As compactness of soil structure increases, the bulk density increases, while the yield of crops decreases considerably [3]. Therefore, in its utilization, care is taking to avoid abnormalities resulting in compaction, etc. that will hinder soil's normal functions.

Abreha *et al*. [4] reportedthat soil productivity also declining as a result of soil erosion, characteristics of physical properties, nutrient and organic matter (OM) depletion. In sub-Saharan Africa, soil fertility depletion is the fundamental cause for declining per capital food production in crop lands with poor soil properties and has a negative nutrient balance, with annual losses ranging from 1.5 - 7.1 tha^{-1} of nitrogen, phosphorus and potassium mainly due to crop harvest, leaching and low inputs applied to the soil [5, 6].

Assessing soil physic-chemical properties are used to understand the potential status of productivity soils of different land uses. To meet the food demands of rapid increasing population, vast area of land are being cultivated more intensively and large areas of grass and forestlands are being overgrazed and deforested. Changes in land use and soil management can have a marked effect on poorly changing soil physical properties, which resulted in decline of soils physico-chemical and biological properties [7]. Physical and chemical properties of the soils on land under continuous cultivation could vary from the other land uses. Physical properties of cultivated soils are known by poor fertility status as it has high bulk density (?b), low total porosity (f), low pH and very low OM or organic carbon (OC) content.

The survival and well being of the present and future generation in countries with subsistence agriculture like Ethiopia depend on the extent of maintaining soil physical properties, hence increases soil fertility. So, land must be carefully managed which incites to establish land use system for staying its good physic-chemical properties in the long term. Investigating soil physical properties under different land uses could assist policy makers, researchers, extension workers and farmers to have baseline information to improve the physical properties and productivity of soils of the study area and elsewhere which have similar agro ecology. Research on this line is of vital importance as the results obtained from such studies could also be used for generating information on characteristics of a given soil to determine the changing capacity, within its alleviating mechanisms to increase the production and productivity of the soil.

Getahun Fente [8] reported that, a number of studies have been done using soil physical properties as an indicators of soil fertility, for instance, farmers in Dejen district of Ethiopia use soil color, soil depth, water holding capacity and crop yield performance to evaluate soil fertility, these studies indicate that farmers 'understanding of soil is more general than that of scientists. Therefore, the objective of thereviewwas assessing "effects of soil physical properties on crop production in Ethiopia".

Literature Review

Soil Physical Properties: The physical properties of soils determine the degree of cultivation of soil and the level of biological activity that can be supported by the soil. Soil physical properties also largely determine the soil's water and air supplying capacity to plants. Many soil physical properties change with changes in land use system and its management such as intensity of cultivation, the instrument used and the nature of the land under cultivation, exposé the soil less permeable and more susceptible to runoff and erosion losses.

Morphological Properties: In order to place a soil in its perfect position in the classification system, a detailed knowledge on its morphological characteristics is necessary. Morphological properties of soil are the most important tool than physical and chemical properties of soil in soil classification because it is perceived under natural undisturbed condition [9].

Color: One of the most important properties which support to identify the kinds of soils and recognize the sequences of soil horizons or layers in soil profiles is soil color. It has long been applied in order to identify soil and for qualitative measurements of soil properties and is a supportive field soil property for describing soil types. Wakene Negassa [10] reportedthat color of each soil type is a function of soil mineral contents, pH, redox reaction and organic matter content. A change in soil color from adjacent soil also indicates a difference in the mineral origin of soil (parent material) or in soil development [9], geologic origin and degree of weathering of the soil material and leaching or accumulation of chemical compounds such as iron, which may seriously influence the quality of soil.

According to Munsell color chart system, color is described in reference to the color's "hue", "value" and "chroma". Hue describes where in the color spectrum the soil color exists, which for soils includes the colors yellow, red, blue, green and gray. Value, describes the lightness of the color. Chroma indicates the strength of the color. In a Munsell notation, the color is written in the order hue-value-chromadark color (low chroma) of soils could be related to the strong impregnation (high in amount) of the soil profile by organic matter hence having high humus contents, frequently holds more water in the course of pedogenesis [11].

Soil Texture: Texture is an important soil physical characteristic that are comprised of soil particles of varying sizes, the size composition of elementary grains in a soil is referred as soil texture, because it in part, it determines a number of physical and chemical properties of soils and has its own influence on water intake rate (infiltration) and water storage in the soil (retention of water), soil aeration(vital to root growth), absorption of nutrients, microbial activities, the ease of tilling the soil and irrigation practicesand also influence soil fertility [12]. It is one of the inherent soil properties less affected by management and which determines nutrient status, organic matter content, air circulation and water holding capacity of a given soil [13]. Soils at higher slops are less developed pedogenically and have low clay content than the soils in the lower slops due to topographic and vegetation differences [14]. Soil texture or the 'feel' of a soil, is determined by the proportions of sand, silt and clay in the soil. When they are wet, sandy soils feel gritty, silty soils feel smooth and silky and clayey soils feel sticky and plastics or capable of being moulded. Soils with a high proportion of sand are referred to as light and those with a high proportion of clay are referred to as heavy. The rate of increase in stickiness or ability to tight together as the moisture content increases is a function of silt and clay particle content, the degree to which the clay particles are bound together into stable granules and the organic matter content of the soil. Berhanu Debele [15] reported that the vertisols in Ethiopia generally contain more than 40% clay content in the surface layer (0-20 cm depth). The silt to clay ratio is one of the indices used to assess the rate of weathering and determine the relative stage of soil development. A ratio of silt to clay below 0.15 is considered as low and indicative of an advanced stage of weathering and/or soil development while >0.15 indicates that the soil is young containing easily weather-able minerals [16].

Soil Texture Classes: The names of soil texture classes are intended to give you an idea of their textural make-up and physical properties. The three basic groups of texture classes are sands, clays and loams. Soil in the sand group contains at least 70% by weight of sand, a soil in the clay group must contain at least 35% clay and, in mostcases, not less than 40% and a loam soil is, ideally, a mixture of sand, silt and clay particles that exhibit light and heavy properties in about equal proportions, so a soil in the loam group will start from this point and then include greater or lesser amounts of sand, silt or clay. Additional texture class names are based on these three basic groups. The basic group name always comes last in the class name. Thus, loamy sand is in the sand group and sandy loam is in the loam group listed below.

Soil Structure: The term structure relates to the arrangement of primary (sand, silt and clay) soil particles in to aggregates or peds (natural aggregates). Peds of soil structure are grouped based on three characteristics: type (shape), class (size), grade (strength of cohesion). Soil structure is one of the soil physical properties, which is very sensitive to soil management practices. Brady and Weil [17] reported that, the formation and maintenance of a high degree of aggregation are among the most difficult tasks of soil management and yet they are among the most important properties, since they are a potent means of influencing ecosystem function. Both biological and physico-chemical processes are involved in the formation of soil aggregates. A well-structured soil forms stable aggregates (aggregates that don't fall apart easily) and has many pores of varying sizes. A well-structured soil is easily workable and allows germinating seedlings to emerge and quickly establish a strong root system, while, a poorly structured soil has either few or unstable (readily broken apart) aggregates and few pore spaces. A poorly structured soil can result in unproductive, compacted or waterlogged soils that have poor drainage and aeration, thereby a more likely to slake and to become eroded.

Particle and Bulk Densities: Debele Hunde *et al.* [18] Stated that soil bulk density shows the compactness of the soil and has inverse relationship with the amount of pore space and soil organic matter content, hence textural differences between soils influence the value of bulk density for example, clay, silt clay and clay loam surface soils show low bulk density as compared to sands and sandy loam soils which show high bulk density values.

Table 1: Soil Texture

Soil Types	Particle Size
Sand	2.0-0.02mm
	Inert, Large pore space, poor water retain and high permeable Not charged
Silt	0.02-0.002mm
	Intermediate, lack cohesion and they crust on drying
Clay	Less than 0.002 mm
	Active, large volume minute pores space, negative charge High water retain, slowly permeable, contains minerals Al and Si

Source:Hunt and Gilkes, (1992)

Table 2: Mean values of physical properties of soils in Borana lowlands as affected by different land uses

	*Particle Size (%)						Water Content (%)		
Land use type	Sand	Silt	Clay	Tex.class	BD (gcm^{-2})*	Comp ($kgcm^{-2}$)	FC	PWP	AWC
Savannah grass	39^{b}	25^{a}	36	Cl	1.37^{b}	1.85^{d}	22.98	14.99	8.00
Bush land	52^{ab}	14^{b}	34	Scl	1.60^{a}	3.11^{b}	21.87	14.70	7.18
Degradedbush	71^{a}	9^{b}	20	SI	1.70^{a}	4.35^{a}	10.94	6.55	4.39
Crop	40^{b}	22^{a}	38	Cl	1.42^{b}	2.64^{c}	21.06	12.84	8.24
LSD(0.05)	21.8	5.9	18.85	-	0.23	0.16	15.22	10.84	6.26
SE	8.92	2.4	7.70	-	0.09	0.07	6.22	4.43	2.56

Source: Grupta [12]

*Means within a column followed by the same letter are not significantly different at P=0.05. BD=Bulk density; Comp= Compaction; FC= Field capacity; PWP=Permanent wilting point; AWC=Available water capacity; Cl= Clay loam; Scl=Sand clay loam; Sl= Sandy loam; LSD=Least significant difference; SE=Standard error.

Table 3: Selected soil physical properties of WATVET college research farm along toposequence

		Particle size (%)				Bd	pd		Moisture content (%)		
Depth (cm)	Horizon	Sand	Silt	Clay	Tex. class	---- gcm^{-3}	----	Total porosity (%)	FC	PWP	WHC
					Pedon 1: Eutric Vertisols (Toeslope)						
0-20	Ap	11	26	63	Clay	1.24	2.76	55.07	40.8	29.37	11.43
20-70	B1	9	26	65	Clay	1.43	2.78	48.56	40.75	29.02	11.73
70-150	B2	9	20	71	Clay	1.36	2.79	51.25	43.35	30.63	12.72
150-200	B3	9	16	75	Clay	1.41	2.79	49.46	49.17	33.06	16.11
					Pedon 2: Dystric Nitisols (Lower foot slope)						
0-80	Ap	19	30	51	Clay	1.27	3.08	58.77	36.02	26.63	9.39
80-140	Bt	9	22	69	Clay	1.31	2.84	53.87	36.81	28.16	8.65
					Pedon 3: Haplicc Nitisols (Upper Backslope)						
0-20	Ah	17	24	59	Clay	1.15	2.83	60.61	35.23	26.74	8.49
20-90	Bt_1	17	18	65	Clay	1.29	2.83	54.42	38.52	30.25	8.27
90-140	Bt_2	15	18	67	Clay	1.27	2.86	55.59	43.47	33.37	10.10
140-180	Bc	15	20	65	Clay	1.17	2.86	59.10	49.84	36.75	13.09
180-200	C	17	20	63	Clay	1.01	2.79	63.80	57.05	40.32	16.73
					Pedon 4: Mollic Leptosols (Backslope)						
0-25	Ah	39	32	29	Clay	0.92	2.70	66.07	34.41	24.12	10.29
					Pedon 5: Mollic Leptosols (Summit Area)						
0-18	Ap	25	32	43	Clay	1.09	2.78	60.97	38.46	25.37	13.09

Bd=Bulk density, Pd= particle density, FC=Field capacity, PWP=permanent wilting point, WHC=Water holding capacity

Gupta [12] reported thatany factor that influences soil pore space will affect soil bulk density, hence, bulk density of a soil increase, with the increase in soil profile depth because of variations in organic matter content, porosity and bulk density commonly decreases as mineral soils become finer in texture. Soils with low bulk density shows favorable physical conditions while soils with high bulk density show unfavorable physical conditions. Loose and porous soils have low weight per unit volume than compacted soils with limited pore spaces [12]. The solid particles of the fine textured soils tend to be organized in porous granules, especially if adequate organic matter is present. In such aggregated soils, pores exist between and within granules. This ensures high total pore space and a low bulk density.

Table 4: Values of air-filled porosity (%) and bulk density (gcm^3) which are critical and which limit root growth for various soils

Textural Class	Non- limiting	Critical^{-1}	Limiting
Air-filled porosity			
Fine loamy	20	10	5
Coarse silty	20	10	5
Fine silty	20	10	5
Clay:			
35-45	15	10	5
>45	15	10	5
Bulk density			
Sandy	1.60	1.69	1.85
Coarse loamy	1.50	1.63	1.80
Fine loamy	1.46	1.67	1.78
Coarse silty	1.43	1.67	1.79
Fine silty	1.34	1.54	1.65
Clayey:			
35-40%	1.40	1.49	1.58
45%	1.30	1.39	1.47

Source: Pierce *et al*., 1983

1 "Critical" is defined as causing <20% reduction in root growth; "limiting" is about the value at which growth ceases

Brady and Weil [17] reported that in sandy soil, organic matter contents generally are low, the solid particles are less likely to be aggregated and the bulk densities are commonly higher than in the finer-textured soil, also they have been stated that bulk densities of subsoil layers are generally higher than surface soils, probably because of lower organic matter contents, less aggregation, fewer roots and other soil dwelling organisms and compaction caused by the weight of the overlying layer interns less yield productivity

Ahmed Hussein [5] stated that the surface soil layers possessed lower particle density values than the subsoil horizons and the highest particle density (2.93 g cm^{-3}) was obtained at the subsoil horizon (57-95 cm depth), also reported that bulk density showed greater variation with profile depth and higher bulk density was obtained at the subsoil horizons under all the elevation zones and land use types considered in the study.

Porosity: Porosity is the volume of soil voids (pore space). It is expressed in relation to the bulk volume of the soil. The dimensions (size, shape and arrangement) and number of pore spaces are most important in determining soil water and soil structure. Air-filled porosity (%) and bulk density (gcm^3) which are critical and which limit root growth for various soils.For soils with the same particle density, the lower the bulk density, the higher is the percent pore space (total porosity). Total porosity of soil usually lies between 30 to 70% and may be used as a very general indication of the degree of compaction in a soil in the same way as bulk density is used. As is the case with bulk density, management exerts a decisive influence on the pore space of soils [17]. Coarse-textured soils tend to be less porous than fine-textured soils, though the mean size of individual pores is greater in the former than in the latter [13]. Sands with a total pore space of less than about 40% are liable to restrict root growth due to excessive strength whilst in clay soils limiting total porosities are higher and less than 50% can be taken as the corresponding value [19]. The decrease in organic matter and increase in clay that occur with depth in many profiles are associated with a shift from macrospores (large size pores which allows water and air movement readily) pores mainly sand soils to micropores (small sized pores) and also called capillary pores in which movement of air and water restricted to some extents, clay soils has greater number of capillary pores [17].

Water Content and Retention Capacity: Soil water content is the basic parameter required to answer the wetness, quantity of water held in the soil, the amount of water absorbed before surface runoff started and the amount of water a particular soil supply to maintain optimum growth and obtain yield [20]. Soil water lubricates the soil permitting root penetration, essentially for microbial mobility and action and it allows nutrient mobility, thus, it can be said that water is a controller of soil physical, chemical and biological processes. Murphy [21] stated that the water-holding capacity of the soil is highly dependent on different soil properties include: particle size distribution (with coarse sands, clays, silts and fine sands holding the least water, the most and in the available water range respectively), the type of clay particles (montmorillonite or swelling clays holding more water than kaolinite type clays), the amount of organic matter in the soil, the bulk density and structure of the soil.

The availability of soil moisture to plants is a function of water input and rooting depth of a given soil, which is governed by the inherent soil properties and management practices. In general, roots are able to readily absorb soil moisture at field capacity, depending on mineralogy and soil structure and become less able to do so with decreasing water content to reach permanent wilting point [22]. Soil stratification or layering can markedly influence the available water and its movement in the soil. Impervious soil layers drastically slow down the rate of water movement and restricts the penetration of plant roots, thereby reducing the soil depth from which moisture is drawn by plant roots.

Soil water contents at field capacity (FC), permanent wilting point (PWP) and available water holding capacity (AWHC) increased with depth for the soils under different management practices [5, 10]. The increases of these three components of soil moisture holding capacity of soils with depth were positively and significantly correlated with the increase of the clay fractions of the soil with profile depth. Ahmed Hussein [5], Brady and Weil [17] reported that the variation in soil physical properties, topography and land use management system all affects the distribution of soil moisture. Water within the soil strongly influences plant growth and the biological functioning of the soil and provides a medium for substances to dissolve into, including nutrient elements allowing them to be accessible to plant roots, also enables nutrients to be transported off the farm and contributes to erosion and weathering processes.

Too Much Water: When all the soil pores fill with water during rainfall or irrigation the soil can become saturated or waterlogged, especially for periods longer than a couple of days, plants can suffer, while, plants require both air , water and oxygen Plants to respire and produce energy, without this they can't grow.

Too Little Water: As the soil dries out, the soil particles (particularly clay) tend to hold onto water more tightly than the plant is able to extract water, therefore, water is held in the soil with increasing strength as soil dries out, at this point, when the plant is unable to extract enough water it wilts and doesn't recover, resulting in wilting of the plants, at wilting point or the lower extractable limit.

The Right Balance of Air and Water: Just after the soil has been saturated and starts to drain, the large pore spaces have air again and there is ample water available for plants, this is when the soil is at field capacity. Once plants have used up the water that's readily available, the soil reaches refill point, soil moisture level between the refill point and field capacity, the readily available water (RAW), the water that plants can easily extract from the soil and is also the level that irrigators aim to maintain, unless they are intentionally stressing plants.

CONCLUSION

Using appropriate soil physic-chemical properties, especially physical soil properties, one of the most important strategies to feed the alarmingly increasing world population, will play a great role in the production of crops. Compactness of the soil structure is direct relationship with bulk density of the soil also; that means as compactness of soil increases, bulky density of soil also increases, while the yield of crops decreases considerably [3]. Physical properties of cultivated soils are determined by low fertility status as it has high bulk density, low total porosity, low pH and very low organic matter (OM) or organic carbon (OC) content. Carefully management of land is very important, which causes to establish land use system for staying its good physic-chemical properties in the long term. The silt and clay particle content increase attributes to stickiness or ability to tight together as the moisture content increases, the degree to which the clay particles are bound together into stable granules and the organic matter (OM) content of the soil. Soil structure are; formation and maintenance at higher level or in good aggregation are among the most difficult tasks of soil management and yet they are among the most important properties, since they are a potent means of influencing ecosystem function. This review deals with the effects of different physical properties of soils on crop production and their characteristics exhibits based on their texture, structure, color, bulk density and particle density, water retention capacity are assessed through this reviews. Nutrient status of the soil in different land use system is identified by an important tool; assessment of physic-chemical properties of the soil. Under different land uses could assist policy makers, researchers, extension workers and farmers to have baseline information to improve the physical properties and productivity of soils of the study area and elsewhere which have similar agro ecology. Research plays a great role as the results obtained from such studies could also be used for exploiting information on characteristics of a given soil to determine the changing capacity, within its mechanisms to overcome and increase the production and productivity of the soil. A number of studies have been done using soil physical properties as indicators of soil fertility.

Recommendation: To increase the production and productivity, the soil must be carefully managed for staying its good physic-chemical properties in the long term viz; crop rotation, intercropping, in adequate application of nutrients, mulching, cover crops, organic matter addition etc. Investigating soil physical properties under different land uses could assist policy makers, researchers, extension workers and farmers to have baseline information to improve the physical properties and productivity of soils of the study area and elsewhere which have similar agro ecology. Research on soil physical improvement is of vital importance as the results obtained from such studies could also be used for generating information on characteristics of a given soil to determine the changing capacity, within its alleviating mechanisms to increase the production and productivity of the soil. Generally to exploit reasonable finding using soil physical properties as an indicator of soil fertility an incorporation of farmer's knowledge in the research flow is a vital, because farmers understanding of soil is more general than that of researchers.

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