CHANGES OF SOIL CONDITIONS AND MAIZE YIELD AFTER YEARS OF CONVENTIONAL OR REDUCED TILLAGE ON A MOLLIC ANDOSOL

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ABSTRACT

Soil tillage affects soil physical, biological and nutrient cycling capacity. Field studies were conducted from 2016 to 2018 on same site using two tillage systems Conventional and Reduced tillage. Conventional tillage was done using a 3-disc plough while reduced tillage was done using a Chisel plough. The objective of this study was to evaluate changes in some soil properties induced by two different tillage treatments and their effect on maize grain yield. The trial was set at Kenya Agricultural Livestock & Research Organization (KALRO) Njoro on a Mollic Andosol. The design was randomised complete block replicated four times. The factor tillage had two levels. Changes in water stable aggregates, compaction as measured by changes in bulk density, soil water retention at pF 4.2, total soil organic carbon and hence soil organic matter, microbial biomass [bacteria and fungi] in form of total microbial biomass-N and microbial biomass-C and maize yield were obtained after three years in 2018. With exception of bulk density that was found to be higher in Conventional tillage, results showed that aggregate stability water stable aggregates, soil water retention capacity at pF4.2, soil organic matter. Total microbial biomass-nitrogen and microbial biomass-carbon were higher in reduced tillage. Maize grain yield was higher ($p<0.05$) in reduced tillage. Bulk density of the soil was observed to be higher after three years of conventional tillage compared to reduced tillage. Reduced tillage increased soil organic matter, structure, water retention and microbial biomass and maize yields. This study has revealed that reduced tillage is pivotal in healing the highly weathered soils that have become degraded and soil fertility has declined through decades of continuous disc and plough tillage, lengthy exploitation and nutrient mining leading to low crop yields.

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INTRODUCTION

The biggest threat to sustainability of crop production in Kenya is decline in soil fertility associated with declining levels of soil organic matter (SOM), available soil moisture and soil nutrients. Many farmers focus on applying inorganic fertilizers to increase the chemical soil fertility neglecting the soil physical and biological fertility which are equally important. Application of inorganic fertilizers where soils have low organic matter, reduces crop nutrient and water uptake efficiency (Wolf and Snyder, 2003). Soil organic matter also remove toxicities in the soil where root exudates and microbial by products chelate toxic cations such as Al, Fe and Mn in soil solutions which bind applied- P fertilizer making it unavailable to the plant (Hargrove *et al*., 1981; Hue *et al*., 1986). To improve nutrient uptake and use efficiency, it is necessary to increase SOM by reduced soil disturbance through reduced tillage and increasing soil cover by way of application of crop residues.

Traditional land preparation is Conventional Tillage (CT) that includes use of ploughs (either mould board or disc plough) followed by two to three disc harrows (Mahasi *et al*., 2003). During CT, the soil surface is traversed by a heavy tractor which pulls a heavy disc or mould board plough exerting great pressure each time it passes on the soil surface. The tractor makes at least four passes and on numerous turning during the tillage, it lifts, inverts, and shatters the soil destroying its structure, infiltration, percolation, soil moisture retention and encourage soil erosion causing the soil physical fertility decline and environmental degradation by air pollution through dust and emission of gases and interferes with hydrological processes including ground water recharge (Simpson *et al*., 2004; Mwangi *et al*., 2008). Less water becomes available to plant growth leading to low crop yields. Intensive tillage may break the soil physical structure and influence soil water retention capacity. Soil disturbance may affect soil biological biodiversity that provide essential services for the sustainable functioning of all ecosystems (Six *et al*., 2002). Tillage may also affect availability of C, N and S nutrients that are largely mediated through microbial community. Tillage also affects soil biological properties including soil organic matter and microbial biomass (Herman, 1990; Feng *et al*., 2003). Main reason farmers use conventional tillage is to help control weeds and manage crop residues getting a fine seed bed (Brade, 1986).

Minimum (Reduced) tillage (RT) is a seedbed preparation method that involves minimizing the number of tillage operations by making only limited slots for placing the seed, either by using specialized machines (seeders) that open up small furrows in which seed is placed or by manually using 'jab planters', hoes or dip sticks to bore holes into which seeds are placed (Marenya *et al*., 2017). Up scaling RT may meet some resistance with some farmers who argue that RT often results in more weed density than conventional tillage (Malik, 1996) and does not manage plant residue which they sometimes find a menace at planting. Controlling weeds requires use of more herbicides, increasing costs and sometimes the herbicides are ineffective or farmers use wrong herbicides leading to losses (Lai, 1986). Other effects where weeds are not properly controlled could be allelopathy where weeds emit compounds that reduce yield and quality of crops.

Soil is a finite resource and once degraded through erosion, nutrient depletion or loss of organic matter, the soil becomes infertile and may not recover in a human life span (Resck and Silva, 1990). Soil quality is the continued capacity of the soil to function as a vital living system within ecosystems and land boundaries, to sustain biological productivity and promote air and water quality and maintain plant and animal health (Seybold *et al*., 1999). Microbial biomass/carbon is a good index of soil quality because it responds promptly to environmental changes and climate change often much earlier than physical and chemical parameters and even crop yields (Balota *et al*., 1998). Sustainable agriculture assures healthy environment and least disruption of land, water, energy and other resources. In consideration of these facts, this study was targeted to assess the effects of tillage on selected soil properties and maize yield for in mollic Andosol.

MATERIALS AND METHODS

Study site

The study area was near Menengai crater (35^0 15^1E, 0^015^1S) in Nakuru County of Kenya and lies within Rongai –Njoro plain that marks the beginning of the slopes of Mau Hills. Except for the scarps formed by banks of river Njoro and Molo river, the topography is flat to undulating. The soils have been described as mollic Andosol (FAO, UNESCO, 1990) with a distinctive property of having high amounts of Aluminium, allophane and imogolate in humus complex (Wada, 1985).

Experimental design, layout and crop husbandry

The study was superimposed on an integrated soil fertility management (ISFM) trial set by KCEP at Field 4 of KALRO-Njoro that was started in 2016 and ran continuously for three years up to 2018. The design was randomised complete block replicated four times. The factor had two levels of RT and CT.

Land preparation in conventional till (CT) was done using a 3-disc plough later, two harrows were done with a two way trailed disc harrow and followed by a one light tine harrow. Land preparation in reduced till (RT) was done using a Chisel plough. This was to ensure minimum soil disturbance i.e. no soil inversion and that soil surface is covered with plant residues and one harrowing with a two way trailed disc harrow. Estimated tractor weight of 5.101 tons and when a plough of 2.7 t is pulled, the total weight per pass of the CT system on the soil surface becomes 7.601 t and a speed of 10 km/hr. Compaction and bulk density of the soil is increased when this system passes over soil exerting pressure greater than 30 bars per pass of the rear tyre of the tractor. In CT the tractor made four runs, while in RT, the tractor made two runs. Two maize seeds of variety 6213 were planted per hill in 75 cm between rows and 25 cm within row, later thinned to one after two weeks leaving a plant population density of 53,300 plants/ha. Fertilizer used was DAP at 60 kg/ha. All other agronomic practices including weeding and pest control were done as recommended.

Data collection

Determination of bulk density BD, Soil water content at pF4.2 and hydraulic conductivity HC

At the end of three years, soil samples for bulk density were collected using a core sampler of length 51.00 mm and diameter 49.55 mm (ASTM, 1958). The cores were driven into a vertical soil surface for each 0-10 cm and 10-20 cm depth, far enough to fill the sampler but not so far as to compress the soil into the confined space of the sampler (Blake and Hartage, 1986). The soil volume was taken as the volume of the core. The soil was transferred into an oven set at 105^0 C for 48 hours until constant weight established. Bulk density was determined using the formula:

$$\text{Bulk density} = \frac{\text{Oven dry weight of soil}}{\text{soil volume}}.$$

Soil water retention was taken at 4.2 pF (permanent wilting point) using pressure plate (Kirchhoff and Basnet, 1989). Briefly, core rings were put on the ceramic plate marked pF4.2, Soil samples of 10g from both depths 0-10 cm and 10-20 cm from different tillage systems CT and RT were put in the rings that were then saturated overnight and applied pressure of 15 bars the next morning until the soil water and the external gas pressure came into equilibrium. After four days, the chambers were opened and soil water retention of the samples determined. The auger hole method after Smedema and Rycroft (1983) was used to determine HC.

Determination of water stable aggregates (WSA)

A representative sample of top soil was taken from each of the treatments CT and RT at depths 0-10 cm and 10-20 cm using a spade. Ten soil sub-samples were bulked, mixed well and a sample taken for determination of WSA. Each sample was gently shaken to separate it into natural aggregates, screened to pass through 8 mm sieve and allowed to air dry. Three sieves were nested together in decreasing size of sieve opening so that the upper most was ATSM 2 mm (10 mesh) followed by ATSM 0.250 mm (60 mesh) followed by ATSM 0.053 mm (270 mesh). An 80 g of soil was submerged into deionized water on top of the 2 mm sieve for 5 minutes at 25^0C (Elliot, 1986). Sieves were then oscillated vertically and rhythmically for 50 times in 20 minutes so that water was made to flow up and down through the sieves and the assemblage of soil aggregates. After which the nest of sieves was removed from water and oven dried at 60^0 C, the aggregate size fractions (>2 mm; 0.25-2 mm; 0.053-0.25, and the silt clay fraction (<.053 mm) material left on each sieve were weighed and WSA determined thus:

$$\%\text{WSA} = \frac{\text{weight retained}}{\text{Total sample weight}} x100$$

Determination of soil organic Carbon, Microbial-C and Microbial-N

Top (0-10 cm) and (10-20 cm) soil samples were taken from each treatment by random sampling procedure using a soil auger. Ten cores from each treatment were collected and bulked together to provide a composite sample and thinly spread on a polythene sheet to air dry. The soil was sieved in a 2 mm sieve. Soil organic carbon was determined as described by Okalebo *et al*. (2002). Soil microbial carbon (MB-C) and microbial nitrogen (MB-N) were determined by the fumigation and extraction F and E technique that subjects a fresh soil sample to chloroform ($CHCl_3$) fumigation. The $CHCl_3$ was used to kill microbial cells and liberate C and N from cells. The C and N were then extracted immediately with 0.5M K_2SO_4 according to Brookes *et al*. (1985), Anderson and Ingram (1993) and Okalebo *et al*. (2002). Quantity of C or N was measured using a UV 1700 spectrophotometer. The quantity C in the extractant was subtracted from non-fumigated soil composed the flush of Organic C = $E_{C.}$ The quantity N in the extractant was subtracted from non-fumigated soil composed the flush of N = organic N= E_N.

Thus E_C= ($C_{\text{fumigated}}$ - C_{Control}), and E_N= ($N_{\text{fumigated}}$ - N_{Control})'

Conversion of organic C to biomass C was done using a factor of $k\ E_{C=}$ 0.30 for E_C and conversion of organic N to biomass N was done using a factor of $k\ E_{N=}$ 0.40 for E_N (Brookes *et al*., 1985; Anderson and Ingram, 1993)

Determination of maize yields

Fertilizer was applied at the recommended rate of 60 kg/ha in each tillage CT and RT. The maize were harvested manually when dry, threshed and grains dried to 13% moisture content. Grain yields for each plot were weighed and recorded.

Data analysis

Analysis of variance (ANOVA) was carried out on the data in GenStat (GenStat 5 committee, 1993). Means were separated using Fisher's least significant difference (LSD) at 5% level.

RESULTS AND DISCUSSION

The effects of tillage practice and depth on selected soil physical properties are in Table I.

TABLE I - EFFECT OF TILLAGE PRACTICE AND DEPTH ON SELECTED SOIL PHYSICAL PROPERTIES

Tillage practice and depth (cm)	Soil structure % WSA (%)	Soil BD (g/cm^3)	Soil Water retention SWR (pF 4.2)	Hydraulic conduct HC (cm/hr)
T (0 -10)	8	1.38	0.20	6.7
CT (10-20)	10	1.34	0.20	6.7
RT (0 -10)	23	1.31	0.21	7.8
RT (10-20)	18	1.33	0.23	7.8

In the top 0-10 cm, CT had 8% WSA compared to RT that had 23% WSA. This was attributed to the operation of the disc ploughs that break out, crumble and pulverize soil. At tillage, a row of four discs plough is pulled by a heavy tractor moving at 10 km/hr, a high energy and vertical force is applied to cause the discs penetrate the soil. During the operation of a mould board or a disc plough systems used in CT, a continuous slice of soil is cut and forced upward over the curved surface of the plough, as the soil is lifted, turned and finally cast off the plough, the furrow slice is accelerated so that when it finally strikes the ground, it is further shattered and deposited as a loose and highly porous assemblage of various sized clods (Nichols, 1929). Later, the two or three disc harrows applied pulverize the soil further destroying aggregation of the soil and hence the structure. In comparison, with chisel plough and disc harrow used in reduced tillage, there was less destruction in soil structure and hence reduction in % WSA (Table I). The increased water retention at pF 4.2 (Table I) due to RT was attributed to the chisel plough that leaves crop residue on soil surface. Plant residue retained on the soil surface increase soil water holding capacity SWHC by increasing rainfall interception losses by soaking incoming rainfall, reduces evaporation, protects soil from erosion, enhancing infiltration, and soil water storage, serves as source of nutrients for soil flora and fauna and returns organic nutrients C, P, S, to the soil and increases availability of P, K, Ca, Mg and S (Wolf and Snyder, 2003).

The bulk density BD of the soil after years of CT was 1.38 g/cm^3 for the top soil 0-10 cm and 1.34 g/cm^3 for the lower depth 10-20 cm (Table I). Soil BD is increased when heavy and powerful tractor moves on the soil surface pulling tillage tools disc /mould board ploughs and harrows operating beneath the soil producing different effects that may occur simultaneously as the soil is cut, compacted, sheared, lifted and mixed in each pass. Gill and McCreery (1960), reported an estimated pressure of 4 bars is exerted in the soil by ploughshares in each pass. The CT system makes at least 4 passes (one disc plough followed by two to three disc harrows) during its operation, each pass increased the BD of the soil. Conversely, RT had less passes and hence less BD of 1.31 $g/cm^3$for the top soil 0-10 cm and 1.33 g/cm^3 for the lower 10-20 cm induced in the soil (Table I). Reduced tillage is one of the conservation agriculture that leaves 30% of plant residue (from previous crop or other organic material brought to the farm) on the soil surface.

Ogban *et al.* (2001) also found that as bulk density is decreased and infiltration capacity, hydraulic conductivity and SWHC are increased by leaving some plant residue on soil surface. Water is one of the most important component influencing crop yields. The amount and rate of water uptake depend on the plant roots to absorb water from the soil as well as the ability of the soil to supply and transmit water to the roots. This soil ability can be influenced by certain intrinsic properties such as HC, diffusivity and matric suction and Soil and Water Conservation (SWC) (Hillel, 1982). The later, SWC has been shown to be affected by intensity of tillage (Table I). The HC in RT was also slightly higher than in CT indicating a better soil porosity, and distribution of wider pores, better pore geometry and a better water permeability.

Another effect of RT is also to increase SOM which decreases bulk density by altering total soil pore volume. This happens when the organic matter occupies some of the pore space reducing bulk density.

Both the microbial biomass (MB-C and MB-N) were higher in RT (Table II), possibly because less tillage in RT means less disruption of fungal hyphae network in the soil (Balota *et al*., 2003).

Mariangela *et al*. (2009) also observed that a reduction in soil disturbance can stimulate soil microbial biomass resulting in a better quality and increasing yields. This indicates the sensibility of microbial biomass to intensity of tillage of soil. There was also a good correlation between microbial biomass and SOM (Table II). SOM is a source of energy for soil micro-organisms; hence increase in SOM promotes increase in total MB.

Plant roots will penetrate the soil only if the pore diameter is larger than the root diameter or if the root is able to overcome the mechanical impedance (soil strength) to enlarge. Russel (1978) showed that for optimum growth, there must be present sufficient number of continuous pores which exceed the diameter of the roots or which the roots can expand into the soil or displace soil with minimum external pressure. Goss (1977) showed that external pressures of 0.2 and 0.5 bars reduced root extension by 80 and 50%, respectively. Roots need a less compacted less soil strength and external pressure to proliferate and ramify in a soil with less bulk density in order to expose a bigger surface area, given that the primary function of the roots is to continuously gather air, water, and nutrients from soil to increase yield.

The role of microbial biomass in soil fertility cannot be under estimated. Availability of C, N and S nutrients from soil largely mediated through soil microbial community composed of groups of fungal and bacteria (Balota *et al.*, 2003; Balota *et al*., 2004). A soil with high fungal biomass has also low N losses (De Vries *et al*., 2006). The fungal hyphae also entangle soil particles and providing binding agents promoting more soil aggregation and more WSA (Table I).

The effect of RT was also to increase SOM. SOM decreases bulk density by altering total soil pore volume. This happens when the organic matter occupies some of the pore space reducing bulk density. Total SOM then behave like a sponge increasing SWHC (Woomer and Swift, 1994).

Conventional tillage caused a reduction of soil organic carbon (Table II). Use of the disc plough inverts the soil and buries crop residues, and cause sudden decomposition plant residues by microbes which use the SOM as a source of their energy causing immobilization reducing the quantity of SOM (Haynes, 1986; Jansen and Kucey, 1988). Conventional tillage increases aeration in soil accelerating oxidation of SOM which causes destruction of SOM and reduces microbial biomass by removing their source of food from top to deeper unfavourable layers (Thierfelder and Wall, 2011). Johnson (1998) reported that the original SOM content can be reduced to 50% in one or two seasons when soil is inverted through CT. This is because when the plant residues are mixed into a warm and moist soil or when the soil is inverted, the plant residues break down rapidly often too fast for crop to use the released nutrients and most of it is lost through leaching. Organic carbon sources include undecomposed plant residues and microbes to stable compounds that becomes SOM. In Kenya, major sources of organic matter include animal manure (farmyard manure) and crop residues, but few farmers use FYM because of bulkiness, difficulty in

TABLE II - EFFECT OF TILLAGE PRACTICE AND DEPTH ON SOIL CARBON AND MICROBIAL PROPERTIES

Till practice and depth (cm)	Soil organic matter SOM (%)	Microbial biomass –N (mg/kg)	Microbial Biomass –C (mg/kg)	Mass –C (mg/kg)
CT(0 -10)	3.6	0.22	2.6	2.6
CT(10-20)	3.3	0.21	1.8	1.8
RT(0 -10)	4.8	0.26	2.7	2.7
RT(10-20)	3.5	0.23	3.0	3.0

handling as well as its unavailability (Adebayo and Ajayi, 2001). Unfortunately, some farmers see plant residues at planting as a nuisance with some feeding to livestock, burning or burying it. Others have challenge to produce and retain enough CR given low yields and competition with livestock (Rusinamhodzi *et al*., 2015).

Reduced tillage increased ($p \leq 0.05$) soil organic C (Table II). This was attributed to the fact that RT leaves crop residue cover on the soil surface at planting time which creates surface roughness for controlling soil loss through erosion (Biamah, 2000). Where crop residues are left on the soil surface, there is reduction of soil temperatures, splash, crusting and compaction there is less activity of the soil organisms and soil fauna that slowly decompose the materials to make soil organic matter and release important nutrients such as N, P, S and K to plants. Increase in SOM was correlated with increased structure WSA and associated with porosity important in relation to root proliferation gas exchange and water retention, SWHC at pF 4.2 and increased microbial biomass (Table II). The organic matter also improves soil quality and fertilizer use efficiency by producing carbonic acid which dissolves minerals into soil for plant uptake (Azraful *et al.*, 2007) and by enhancing CEC in soils and reducing aluminium toxicity and P- fixation sites in acid soils with Al, Fe and Mn oxide mineralogy.

Maize grain yields were found to be higher ($P \leq 0.05$) in 2016 and 2017 (Table III). On average, RT had better yields than CT.

TABLE III - EFFECT OF TILLAGE INTENSITY ON MAIZE GRAIN YIELD ON A MOLLIC ANDOSOL

Tillage	2016	2017	2018	Mean
Conventional (CT)	6.31a	6.41a	6.24a	6.3
Reduced Tillage (RT)	7.29b	6.17a	7.93b	7.1
Mean	6.8	6.3	7.1	6.7
CV (%)	13	17	19	
$LSD_{(0.05)}$	0.4	0.42	0.5	

Values having the same letter within a column are not different (p=0.05)

This increase was also attributed to increased soil water content, higher soil organic matter that had accumulated up to the third year (Table I) associated with plant residue management in reduced tillage. Rockstrom *et al*. (2007) and Chivenge *et al*. (2011), observed that yields can be doubled by adding organic matter, preventing soil erosion and increasing water retention in soils. SOM excrete some physiologically active compounds such as fulvic and humic acids which plants take up and use as auxines and other hormones promoting growth and increasing yields (Table II)

CONCLUSION AND RECOMMENDATION

Intensive soil disturbance by conventional tillage CT for decades has contributed to soil degradation and soil fertility decline in the central Rift. The traditional high powered disc and mould board plough have previously served the farmers well over decades by digging deep in the soil inverting it and burying the plant residues producing a fine soil tilth they so much deserved for the seed bed. But over the recent years there seem to be doubts about the suitability and sustainability of the system given the rate and evidence of soil fertility decline and degradation that has occurred. The CT done mainly by hired tractors who give no regard to such factors as terrain or slope (so as to plough along the contour) and soil depth (so as not to destroy the soil profile) may have contributed to soil degradation. Soil moisture availability is another issue that has emerged as it becomes clear that water deficit is now a major constraint to crop productivity as climate change become increasingly evident in the central rift. To arrest this situation a widespread adoption of conservation tillage RT is suggested. This study have shown that it is possible to increase yields by increased management of crop residues which increase organic carbon and hence SOM. Organic matter supplies N, P, C, S and maintains CEC that is crucial to supply of micro nutrients and block P-fixation sites in highly weathered acidic soils which forms a big percentage of our land.

It can be concluded that RT improved soil quality attributes, soil structure, soil moisture content, soil organic matter creating an environment for a better more open and continuous network of soil pores. This condition enhances a better root density and creates favourable and delicate balance of the soil necessary for microbial biomass and plant growth.

Because RT was found to increase MB-C which is a main indicator of soil quality, the practice is useful for sustainability and integrity of ecosystems and is recommended for the area and other areas with soils developed from volcanic ash and which are crucial to food security in Kenya. The success of RT will depend on efficient management of weeds and also plant residue management so as to give initial good crop establishment that is associated with use of CT. Phasing out the traditional CT will not be easy as currently, mould board and disc ploughs for CT land preparation are the most accessible and the fact that this is the only land preparation method framers have are accustomed to. It will also depend on availability of RT tools such as chisel plough, harrows, jab planter, ox seeder, tractor based rippers and seeders as well as zero till drills.

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REFERENCES

Adebayo, K. and Ajayi, O.O. (2001). Factors determining the practice of crop livestock integration in the derived savannah and forest zones of Nigeria ASSET Series A 1: 101-107.

Anderson, J. M. and Igram, J. S. I. (1993). Tropical Soil Biology and Fertility. A handbook of methods, CAB International, Wallingford, UK. Pp 68-71.

ASTM (American Society for Testing Materials, (1958). ''Procedures for Soil Testing''. Philadelphia, Pennsylvania.

Azraful, H. A Qadir, I. and Mahmood, N. (2007). Effect of integrated use of organic and inorganic fertilizer on fodder yield of sorghum (*Sorghum bicolor L.*). *Parkstan Journal*, 27: 322-329.

Balota, E. L., Colozzi-Filho, A., Andrade, D. S. and Hungria, M. (1998). Biomassa microbiana e sua atividade em solos sob diferentes sistemas de preparo e sucessão de culturas. *Revista Brasileira de Ciência do Solo*, 22, 641-649.

Balota, E. L., Colozzi, A. F., Andrade, D. S. and Dick, R. D. (2003). Microbial Biomass in soils under different tillage and crop rotation systems, *Biology and Fertility of Soils* 38:15-20.

Balota, E .L, Colozzi, A. F., Andrade, D. S. and Dick, R. D. (2004). Long term tillage and crop rotation effects on microbial biomass and C and N mineralization in a Brazillian Oxisol. *Soil and Tillage Research,* 77:137-145

Biamah, E.K. (2000). Conservation Tillage Initiative (CTI) for Kenya. A conceptual frame work. Kenya Conservation Tillage Initiative Regional Land Management Unit (RELMA) Nairobi, pp4-6, 16.

Blake, G.R. and Hartage K.H. (1986). Bulk density. In methods of soil analyses PART 1, and 2. Klute, A, edit., Agron. No.9, pp 363-382.

Brade, F.G. (1986). Conservation tillage as a means of reducing rosion of erodible land. National workshop on ecological disasters in Nigeria: Soil erosion, Owerri, Nigeria. 8-12 sept 1986. Federal ministry of Science and technology, Lagos, Nigeria, pp189-196.

Brookes, P. C., Landman, A., Pruden, G. and Jenkinson, D. S. (1985). Chloroform fumigation and release of soil nitrogen; a rapid extraction method to measure microbial biomass nitrogen in soil. *Soil Biology and Biochemistry,* 17: 837-842.

Chivenge, P., Vanlauwe, B. and Six, J. (2011). Does combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis *Plant Soil* 342 1-30

De Vries, F.T., Hoffland, E., Van Eekeren N., Brussaard L. and Bloem, J. (2006). Fungal/ bacterial ratios in grassland with contrasting nitrogen management, *Soil Biology and Biochemistry* 38, pp.2092-2103.

Elliot, E.T. (1986). Aggregate structure and carbon, Nitrogen and Phosphorous in native and cultivated soils. SSSA J 50 pp 627-633.

FAO, UNESCO, (1990). Food and Agricultural Organization- United nations Scientific and Cultural Organization. Soil Map of the World, Revised legend. World Soil Resources Report 60, Rome, ITALY.

Feng, Y., Motta, A.C., Reeves, D.W., Burmester, C.H., Van Santen, E., and Osborne, J.A. (2003). Soil microbial communities under conventional till and no- till continuous cotton systems. *Soil Biol. Biochem*. 35 (12), 1693-1703.

GenStat 5 Committee, (1993). GenStat 5 release 3 Reference manual. Oxford University. Press, Oxford, UK.

Gill, W.R. and McCreery, W.F. (1960). Relation of size of cut to tillage tool efficiency. *Agr. Eng*. 41, 372-374, 381.

Goss, M.J. (1977). Effects of mechanical impedance on root growth on barley (*Hordium vulgare* L.). I. Effects on elongation and branching of seminal root axes. *J. Exp. Bot.* 28: 27-36.

Hargrove W.L. and Thomas G.W. (1981). Effect of organic matter on exchangeable aluminium and plant growth in acid soils. In Stelly, M. (ed) *Chemistry in the soil Environment*. MadSoc. ison, Winscosin USA: American Society of Agronomy.

Hue, N.V., Craddock, G. and Adams F. (1986). Effects of organic acids on aluminium toxicities in sub soils. *Soil Science Society of America J.* 50: 28-34.

Haynes, R.J. 1986. The decomposition process, mineralization, immobilization, humus formation and degradation. In Haynes, R. J. (ed) *Mineral Nitrogen in the Plant –Soil system*. Orlando, Florida, USA, Academic Press.

Herman, M. (1990). Effect of tillage systems and crop sequence on rhizophere microflora of winter wheat. *Soil Till Res* 15: 297-306.

Hillel, D. (1982). *Introduction to soil physics*. Academic Press (Harcourt Brace Javonovich, publishers) pp. 176-196.

Jansen, H.H. and Kucey R.M.N. (1988). C, N, and S mineralization of crop residues as influenced by crop species and nutrient regime. *Plant and Soil* 106: 35-41.

Johnson, L.O. (1998). Dry land farming in LAMP/SCAPA. Why dry land farming? A paper presented at Conservation Tillage Work shop, Machakos, Kenya, 23-26 November, RELMA, Kenya. Kirchhoff, F. and Basnet, B.B. (1989). Soil Physics Laboratory manual. Department of Agriculture, The University of Queensland, St. Lucia, Old 4072

Lal, R. (1986). Effects of six years of continuous no till on puddling systems on soil properties on soil properties on rice (*oryza sativa*) yield of a loamy soil. Soil Till. Res 8:181-200

Mahasi, M. Maling'a, J.N., Tuey, D.K. and Kamunndia, J. (2003). Crop production handbook of Kenya. Kenya Agricultural Research Institute (KARI), Nairobi, Kenya.

Malik, R. K. (1996). Herbicide resistant weed problems in developing world and how to overcome them. Proceedings of the second International World weed Science congress, Copenhagen, pp 665-673.

Marenya, P.P., Kassie, M., Jaleta, M., Rahut, D.B. and Erenstein O. (2017) Predicting minimum tillage adoption among smallholder farmers using micro-level and policy variables. *Agric Econ* 5, 12 (2017)·

Mariangela, H., Julio, C.F., Osvaldino, B., Glaciela, K. and Rosinei A.S. (2009). Soil microbial activity and Crop sustainability in a long term experiment with three soil tillage and two crop rotation systems *Applied Soil Ecology,* 42, (3) 288-296.

Mwangi, H.G., Akuja, T.E., Kamwaga, J.N., Njuguna M.N. and Nafuma L.S. (2008). Soil profile based tillage practices for wheat in central Rift valley area of Kenya. *Journal of applied Bioscience*. 11: 570-575.

Nichols, M. L. (1929). Methods of research in soil dynamics as applied to instrument design. Ala. Agric. Exp. Stn. Bull. 229, Agric. Eng. (1932), 13 279-285.

Ogban, P. I., Ekanem, T. P. and Etim, E. A. (2001). Effect of mulching methods on soil properties and growth and yield of maize in SE Nigeria. *Trop Agric*. (Trinidad) 78(2):82-89.

Okalebo, J.R., Gathua, K.W. and Woomer, P.L. (2002). Laboratory methods of soil and plant analyses. A working manual. 2nd Ed., pp 84-85.

Resck, D. V. S. and Silva, J. E. (1990). Soil organic matter dynamics under different tillage systems in the cerrados region in BrazilIn *proc. 14th, international congress of soil sciences*. Kyoto, Japan, ISS.

Rockstorm, J., Lannerstand, M. and Falkenmark, M. (2007). Assessing the water challenge of a new green revolution in developing countries *PNAS 104*(15): 6253-6260.

Russel, E.W. (1978). *Arable agriculture and soil deterioration*. Pp 216-227. 11th Intern. Cong. Of Soil Sci. Edmonton, Alberta.

Rusinamhodzi, L., Wijk, M.T.V., Corbeels, M., Rufino, M. C. and Giller K. E. (2015). Maize crop residue uses and trade-offs on small holder crop livestock farms in Zimbamwe: Economic implications of intensification. *Agric. Ecosys. Environ*. 214, 31-4.

Seybold, C. A. Herrick, J. E. and Brejda, J. J. (1999). Soil Resilience: A fundamental component of soil quality. *Soil Science*, 164 (4), 224-234

Simpson, R. T., Frey, S. D. and Six, J. (2004). Preferential accumulation of microbial carbon in aggregate structures of no tillage soils. *Soil Sc. Soc Am J* 68: 1249-1255.

Six, J., Feller, C. and Denef, K. (2002). Soil organic matter, biota and aggregation in temperate and tropical soils- effects of no tillage. *Agronomy 22*: 755-77.

Smedema, L.K. and and Rycroft, D.W. (1983). *Land drainage* Batsford Academic and Education Ltd., London.

Thierfelder, C. and Wall, P. (2011). Reducing the risk of crop failure for smallholder farmers in africa through the adoption of conservation agriculture. In: Bationo, A., Waswa, B., Okeyo, J., Maina, F., Kihara, J. (eds). Innovations as Key to the Green Revolution in Africa. Springer, Dordrecht.

Wada, K. (1985). The descriptive properties of Andosols. *J. of soil science 2:* pp173-229.

Wolf, B. and Snyder, G. H., (2003). Sustainable soils: The place of organic matter in sustaining soils and their productivity. The Haworth Press, New York, NY; London, Oxford.

Woomer, P. L. and Swift, M. J. (eds) (1994). *The Biological Management of Tropical Soil Fertility*. John Wiley and sons Baffins Lane, Chisester, West Sussex PO19IUD, UK.