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The Effects on soil physical properties of long term soil tillage and soil compaction

Virkning av jordas fysiske egenskaper av langvarig jordarbeiding og jordpakking

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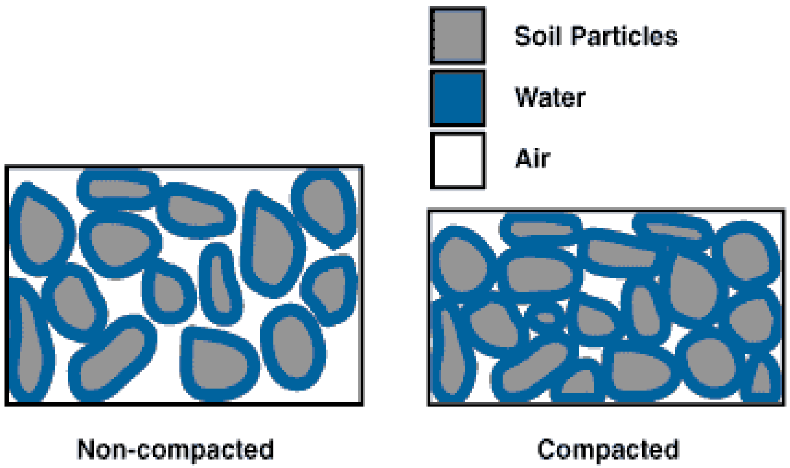
THE EFFECTS ON SOIL PHYSICAL PROPERTIES OF LONG TERM SOIL TILLAGE AND SOIL COMPACTION



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MASTER THESIS IN PLANT SCIENCE (M – PV)

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P R E F A C E and A C K N O W L E D G E M E N T S

The study was conducted at the Department for Environmental Sciences, Norwegian University of Life Sciences (UMB / NMBU), between 2010 and 2014. It was initiated to increase and improve knowledge in identifying and characterizing soil parameters and their effects on crop's development. Furthermore, it shall serve both as a means of soil improvement for its judicious use in cropping systems, and as a beacon's light for further investigation in soil tillage practices and their effects on soil parameters.

I wish to register my profound gratitude to all those who contributed one way or the other to the success of this work. I am particularly grateful and delighted to express my indebtedness to my supervisor, Professor, Dr. Trond Børresen, for giving me the window of opportunity to walk my way through the wonderful world of pedology even when faced with impediments. His excellent supervision, his immense and valuable contributions in both the field and laboratory works when I am lost in the utilization of unfamiliar equipment and gadgets, coupled with the writing techniques when the mind's construction in words becomes a problem were of paramount value.

I must also acknowledge the willingness of Mr. Øyvind Vartdal , the soil physics laboratory technician, for contributing his expertise to the success of this work. In addition, a big thank goes to all staffs attached to the soil science department. I appreciate their good nature towards me during my encounter with them. This will always linger in my mind.

Last, but not the least, my academic pursuit at UMB / NMBU could not have been possible without the humanitarian gesture of the people and government of N O R W A Y. They wholeheartedly granted me and my family political asylum through the UN (United Nations) resettlement program. This granted us the opportunity to recreate our miserable and devastated lives after languishing in refugee camps and slums in Sierra Leone for thirteen and a half years where we nearly met our demise. For this, I am sincerely grateful. Above all, I thank the Almighty G O D for preserving my life.

Ås, 14.08.14

A B S T R A C T

Soil degradation in crop production is becoming increasingly important because of the growing concern it poses on soil functions. Prominent among the degradation factors is soil compaction. It impairs soil productivity by impeding the soil conductivity potential and moisture retention ability, thereby preventing root penetrability and nutrients uptake among other things. This paper is concerned with identifying and characterizing the degree of compaction that may result in deleterious effects on soil physical properties, and the interaction that exists between crop growth and productivity. The above shall be achieved through field and laboratory determination of soil measurements from samples collected on a silty clay loam, and a silty loam soil at the University of Life Sciences (UMB / NMBU) experiment field

Three land preparation practices (Autumn ploughing at 20 – 22 cm depth; Spring ploughing at 12 – 15 cm depth and Spring harrowing at 4 -6 cm depth i.e. without ploughing), stubble cultivation and compaction were the treatments used in a three factorial field trials on a silty clay loam and a silty loam soil to conduct the investigation at the UMB / NMBU experiment field. The three main grain crops produced for the last 20 years were: wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.) and barley (*Hordeum vulgare* L.). Field data collection and standard laboratory procedures were performed using different equipments and gadgets to process the data. These were calculated and statistically analyzed by the ANOVA methods (GLM procedure), (SAS Institute, 1990).

The various treatments did not show much diversity in densification save few tillage applications with stubble cultivation, compaction, and a combined tillage and compaction treatments that were significant S* (i.e. Pr > F) than the others as shown in Tables 2, 4, 8 and 9 in results. Tillage in depths 5-10 cm and 15 – 20 cm showed significant penetration resistant (PR) (Pr > F), and stubble cultivation in depths 10 – 15 cm and 25 – 30 cm also gave significant PR (Pr > F). Fraction 6 – 20 mm exhibited significant aggregate size distribution with tillage application (Pr > F) in Tab.4. Volume % was significant (Pr > F) with compaction application for pF 4.2 in depth 25 - 30 cm, while weight % was equally significant for pF 4.2 in the same depth with the same treatment. The same trend occurred for both pF 4.2 weight % and volume %

for combined tillage times compaction application in the same depths. There was minimal difference in dry matter (DM) % between treatments, as well as water content in grain yield at harvest. However, both grain yield and dry matter % showed significant level (Pr > F) with tillage treatment, but only grain yield gave significant level with compaction treatment.

The maximum bulk density (BD) observed in this trial was 1.60 g / cm^3, which is just slightly above the minimum critical limit of 1.55 g / cm^3 that may restrict root penetration. In this case, any hindrance to root piercing may eminate from the presence of clay minerals, ions bonding and particle density. This implies that a minimum level of compaction resulted from the treatments.

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1. Introduction

1.1 General Introduction

Persistent crops and animals farming has become pervasive worldwide due to population explosion and modernization of farming. This entails crop rotation and heavier utilization of machinery on a given piece of land leading to an increase in soil compaction (Poesse, 1992). Soil compaction (soil densification) is the process of closely packing the soil particles together causing pore spaces and water penetrability to reduce, and increasing soil strength thereby necessitating modification in soil functions (Saone and van Ouwerkerk 1994); (www.finning.ca/Industries/Agriculture/Compaction_Guide.aspx). Warkentin (1995) asserted that compaction changes the soil structure mostly due to the clay content, and rearranges the soil particles based on the different soil functions. These functions are primarily dependent on voids (vacuums), surfaces and both. For instance, vacuum provides major controls on the vital ecosystem soil functions, while the diverse pore sizes and surfaces make provision for the habitats (natural homes) for the several biota, microorganisms and plant roots. In short, the Glossary of Soil Science Terms (GSST) (2013), described soil compaction as "increasing the soil bulk density, and concomitantly decreasing the soil porosity by the application of mechanical forces to the soil".

In order to understand soil compaction, Campbell (1994) suggested that it is more suitable to quantify the alteration that occurs in soil due to mechanical stresses imposed on it thereby increasing its compactness. This can be achieved by utilizing a soil attribute related both to the procedure of concretion and to the understanding of the outcome of the soil status. The most basic and extensively used property suitable for such a measure is the soil bulk density (BD / ρ_b). DeJong-Hughes et al. (2001) attributes soil compaction to the numerous field operations that are practiced on moist or wet soil that make it vulnerable to densification.

The mechanisms involved in soil compaction are a bit difficult to comprehend. Njøs (1978) intimated that numerous literary texts exist on the subject (soil compaction). He cited some examples and prominent among them, which is important to use for this discourse is the one by Barnes et al., 1971. However, in the Nordic countries, Håkansson (1966) examined public writings on soil compaction effect on crops and soils. Soil compaction, as defined by DeJong-Hughes et al. (2001), is the pushing of the soil particles together thereby reducing the larger pore spaces between them, resulting in a reduced rate of both water infiltration and removal from the affected layer. See Figure 1 below.

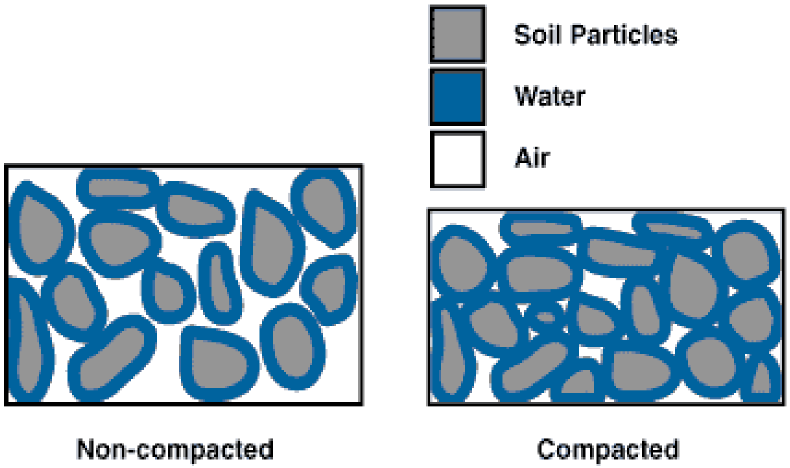

Figure 1. Effects of compaction on pore spaces. (Source: DeJong-Hughes et al., 2001)

In figure 1 above, the non-compacted soil profile (left) has many macro-pores (larger white spaces) which permit rapid infiltration of water through the profile. This is because the larger pores are mainly responsible for the transport of water through the soil profile when wetted. In the compacted soil profile (right), many micro-pores (smaller white openings) decrease water movement resulting into flood and / or runoff, and the restriction of soil-air circulation. The above authors further stated that additional effects of compaction on soil are the reduction of the exchange of gases which may increase aeration-related problems, the increased in soil strength (i.e. the resistance of a soil to be penetrated / sliced by an applied external force), and the lack of organic matter which exacerbates the problem. As a result, plant roots must exert more pressure to pierce the compacted layer; otherwise, they may grow horizontally. Soil engineering defines soil compaction as “the process by which the soil grains are rearranged to decrease void spaces and bring them into closer contact with one another, thereby increasing the bulk density” (SSSA - Soil Science Society of America - 2010).

Soil, generally known as the medium of plants growth, needs careful manipulation in order to maintain moisture to enhance crop production. According to van Straaten (2007), soil is a complicated mixture of weathered mineral matter, organic compounds, water and air that interact in response to biological, chemical, and physical processes. However, when it is poorly managed through the anthropogenic activities of man (i.e. especially through unsuitable agricultural management practices), soil degradation often occurs physically, chemically and biologically, thus posing diverse problems in its productivity. The unsuitable tillage practices are not the only sources of soil degradation, but they are the most common regarded in hampering agricultural production. As such, the judicious use of soil in agriculture is the best way of ameliorating food security and food safety problems worldwide.

Generally, there are many use-potentials of a soil: its capacity to support crop production, road construction, building of houses, and any other uses man makes of it. Consequently, knowing the story of the creation and development of a soil **(genesis)** is essential to be able to preserve it through careful manipulation for successive crop production and other uses (Hillel, 2004). As such, in agricultural production related activities, '**a soil survey report**' of an area is always required to provide all the information needed for the soil of that area (i.e. the genesis, morphology, use-potential, distribution and conservation) (anonymous). This will serve as a guide for land users - particularly extension officers - for efficient agricultural advises and practices.

This dissertation concentrates, although not inclusively, on the physical degradation of soil compaction on crop growth and yield output in the UMB / NMBU research area. Van Straaten (2007) characterizes the effects of compaction as hard setting of soils, desertification, etc. Consequently, the productive capacity of such soil reduces considerably and therefore needs attention. In light of the above, the core objective of this investigation is to '**ascertain the effect of long-term intensive and / or moderate mechanical cultivation on soil physical parameters, and to have knowledge of the interaction that exists between soil compaction and soil tillage in relation to crops growth'.** Furthermore**, 'it is to validate how compaction affects the yield of crops and some of the method(s) used to mitigate the impediment'.**

2. Literature Review

2.1 Background about soil

Before delving into the discourse regarding **“The Effect of Long Time Tillage on Soil Physical Parameters”**, it is important to consider a brief knowledge on the genesis of soil formation, which involves ***factors*** and ***processes*.** Pedologists believe that the factors involved in soil formation ***(i.e. time, climate, organisms, topography, parent material and man)*** vary from place to place and are the controllers of the soil processes because when factors change, the soil so formed also changes. However, the processes ***(i.e. addition, loss / removal, transformation / weathering and transfer / change of location)*** operate in all soils. Hillel (2004) propounded that the physical factors and processes of the soil are of paramount significance. In addition, that these physical factors have serious influence on whether the soil is to be chilly or hot, without oxygen or with oxygen, moist or moisture less, dense or permeable, rigid or flexible, dispersed or aggregated, sealed or porous, saline or without salt, and leached or nutrient rich. The above attributes, in turn, help to decide whether a soil is ideal or not for diverse productions. Consequently, handle a soil carefully and efficiently in its utilization while compensating for reduce fertility, rather than transferring ecological contaminants. The above knowledge regarding soil leads to the coining of diverse explanations about soil seen in section 2.2.

2.2 What is soil?

From an agricultural point of view, soil is a mixture 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 (SSSA, 2010). It is the cradle for crop growth (Hillel, 2004). 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 (Hillel, 2004). 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 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. Consequently, the bulk density increases while the yield of crops decreases considerably (DeJong-Hughes et al., 2001). Therefore, in its utilization, care is taking to avoid abnormalities resulting in compaction, etc. that will impede soil's normal functions.

2.3 Causes and Effects of Soil Compaction

The causes of soil compaction, as aforementioned in its definition, are due to both natural and anthropogenic influences such as rainfall, trampling by animals and the use of farm machinery for tillage purposes. Hillel (2004) stated that in agriculture, it is due to man's farming activity, coupled with the existing climatic conditions, soil structure, and above all, soil consistency at the time of the cultivation practice. This act, which is termed soil tillage, is the practice of getting soil ready for seedbed, sowing or transplanting, and for crop's growth. Soil tillage falls in two major categories: conventional tillage (i.e. ploughing, harrowing and / or pulverizing soil for cropping) and conservation tillage (i.e. zero tillage, ridge tillage or mulch tillage) (FAO, 2002; FAO, 2002). Based on Hamza[a*] and Anderson[b] (2005) **"both axle load** (i.e. the wt. of farm animal or machine in kg or kN) representing a unit of force, and **ground contact pressure** (i.e. axle load divided by the surface area of contact between the animal or machine and soil in kPa) representing the unit of pressure contribute to true soil destruction. But it is the ground contact pressure that causes soil compaction". The above practices have their merits and demerits but are not detailed in this discourse.

According to Hillel (2004), Lipiec and Simota (1994), the effects of soil compaction on soil physical conditions (structures) are due to many factors. They include a decrease in pore volume, a decrease in air volume (i.e. larger pores / drainable pore volumes also decrease) and an increase in soil bulk density. However,[cf1] particle density remains constant because it is determined by pore volume removal. In this case, available water increases, but might decrease (i.e. when larger pores are reduced to medium or small sizes), and water holding capacity increases. This causes water transport under saturated condition to decrease thus resulting into drainage problem during wet seasons. Subsequently, water transport under unsaturated condition increases. Because of the capillary transport of water, infiltration rate decreases, soil strength increases via both penetrometer resistance and shear strength, root growth decreases due to increase in penetrometer resistance and increased in bulk density, and soil stability may increase in a normal / stable aggregate. Obviously, however, much of the pore spaces are reduced by compaction, but they can never be eliminated (Lipiec and Simota, 1994; http:www.eoearth.org/article/agriculture).

The major activities that affect soil structure are tractor trafficking of any type in agricultural activities and machinery use for cultivation, but with different effects. For example, tractor – operated farm machineries like primary tillage equipment (plough), secondary tillage equipment (harrow), and other machineries employed in other farming activities (i.e. agricultural chemical applications, etc.) result in compaction of soil (Bockari-Gevao, date and year unknown).

There is an increased worry regarding soil firmness in agriculture, as farm tractors and field equipment tend to become bigger and weightier. Soil compaction is connected to the habitual use of the aforementioned farm machineries on moist soils that are vulnerable to degradation. As already said, the soil structure, which regulates the potential of a soil to conduct and hold water needed for nourishment and air transport for plant root activities, is the one most affected. It results in changes in the pore space size, distribution and soil vigor / hardness (http://www.extension.umn.edu./distribution/cropsystems/components/3115s01.html).

Soil compaction causes both beneficial and harmful effects on plant's development. For instance, a slightly firm soil can accelerate seed germination rate due to good seed and moist soil contact. On the other hand, moderately firmed soil could possibly decrease water loss via evaporation thereby restricting soil surrounding the growing seed from moisture stress (http://www.extension.umn.edu./distribution/cropsystems/components/3115s01.html). On the contrary, a firmly compacted soil retards root growth and decreases the area covered / utilized by plant roots. This reduces the plant's water and nutrient up-take potential for vigorous growth. From crop production perspective, the undesirable effect of soil compaction is more felt on soil water flow and storage than directly affecting root development (http://www.extension.umn.edu./distribution/cropsystems/components/3115s01.html; Hillel, 2004).

Njøs (1962) revealed damaging outcome of tractor use in moist soil condition on crop yields of small grains, but intimated beneficial results of rolling with Cambridge rollers to minimize lodging by this investigation. In later finding, Njøs (1976) had a discourse on the long-term outcome of soil bulkiness by tractor traffic on loam and clay loam soils, including the existing influence between them and nitrogen use. In one of the investigations, excess nitrogen use eased the harmful effect on the output of autumn bulkiness but not of spring firmness. Børresen (1993) found out that minimum tillage could possibly result in higher yield output than autumn ploughing mostly in dry early summer years. Njøs (1961) in a laboratory investigation found soil firmness to hamper significant alteration in pore size distribution by decreasing the size of large openings in relation to the size of medium and smaller ones. An increase in the bulk density resulted. Meredith and Patrick (1961) acquired much the same results from their previous experiment.

Free (1953) pinpointed higher bulk density and lesser quantity of larger pores in tractor tracks from earlier row planting. Miller et al. (1963) discovered that traction of agricultural machinery escalates the bulk density of the top soil. According to Bodman (1967), compaction reduces the comparable volume of larger pores and increases those of smaller ones. The biggest orifices are normally the first to experience soil compaction effects (Amaryan and Bazin, 1969). Kubota and Williams (1965), Hartge (1965), Ehlers (1973) and Sommer (1976) made the same assertions. Krϋger (1970) stated, "Soil compaction with tractor traffic or rolling decreased the percentage of pores larger than 50 μm and increased the amount of pores smaller than 10 μm on loamy sand and alluvial meadow soil".

Based on a long-term investigation, Flocker et al. (1958, 1960) proved that compaction escalates the amount, solidness and binding of clods (i.e. aggregates. occurring in cultivated soils). Fergedal (1968) on the other hand, calculated and found less yield output when compaction occurred after moisture stress of the soil in comparison to a moist soil condition. Tveitnes and Njøs (1974) ascertained less air porosity at pF 2 (i.e. moisture at field capacity) and increased percentage of aggregated clods after the bulkiness of grassland in western Norway.

Results obtained from compaction investigations in Denmark showed a considerable yield reduction in barley when four passes of a tractor was applied on two soils of 13 and 15 percent clay respectively in a saturated condition. Tractor passages decreased the volume of larger orifices (> 30 μm) (Rasmussen, 1976).

Wicks et al. (1988), Børresen (1993), Ekeberg and Riley (1997) concluded from their respective long-term field investigations that minimum tillage on numerous occasions gave better results due to additional skills in managing the system and improved soil structure after many years. Furthermore, that the consequence of weather prediction is more advantageous. Blake et al. (1976) after nine cropping years were able to recognize a firmed cultivated channel bottom by the use of a penetrometer measurement. It was revealed that an axle weight of circa 70 KN and a physical ground stress of 2.7 bars presented a soil unable to spontaneously resume its normalcy after collapsing to a depth of 30 – 50 cm. Conversely, the same stress produced resilience below the same depth on a clay soil (Danfors, 1974).

2.4 Soil physical parameters

Soil physical parameters are the ones most affected during mechanical land preparation, for instance with tractor(s). They are those soil attributes that cannot in no way be singled out, or dissociated completely from the general functions of a soil (i.e. soil aggregates, aggregate size distribution, aggregate stability, infiltration rate, moisture release characteristics, bulk density, air permeability, pore volume percent, air volume percent, organic matter content, etc., etc.). They are part of the soil profile contributing immensely to all activities leading to the productive or non-productive functions of the soil. Any agronomic practice that affects any of the soil physical properties mentioned above will definitely affect the normal function of the soil for crop growth. Bengough et al. (2005) stated that many soil physical constrains will impede root development in the field. These involve the resistance of physical processes, water stress, and the lack of oxygen. The stresses operating may vary continually depending on the location of the root in the soil profile, the prevailing soil-water conditions and the degree to which the soil is, per se affected.

3. Materials and Methods

3.1 Location, soil and climate

The research field utilized for this thesis is situated in Ås Kommune, Norway. It is located in an approximately flat sunken area (sinkhole) at the Norwegian University of Life Sciences (UMB / NMBU) between adjoining hills of moraine sources. The site is position at approximately 59º40´ N and 10º46´ E, with an altitude of approximately 65 m above sea level. It was established in 1989 with code number A85. The area is a long time experimental site. For the recent twenty years, grain farming had been the constant crop production practice. As a poorly drained soil in situ due to its location, it was tiled-drained once before 1970, but was again tiled-drained with plastic tubes in 1970, with a spacing of 7 m and a depth of 0.7 to 0.8 m. The field was designed in a way to accommodate the tile-drain at right angle to the main treatments (i.e. soil compaction), and aligned on the borders between the subplots (Njøs, 1978).

3.2 Soil type

Njøs (1978) delineates the source of the soil as "postglacial marine clay in deep layers, and in upper layers of the soil are mixtures of transported and re-sedimented post-glacial clay and some outwash (i.e. materials carried away from a glacier by melt water and deposited beyond the moraine) from surrounding morainic elevations". The soil profile was described according to FAO (Food and Agricultural Organization) (1974) as follows:

"0 – 20 cm AP: Very dark grayish brown (10YR 3/2) *silty clay loam;* moderate, medium and fine sub angular blocky to crumb; many fine and very fine pores; many fine roots; abrupt boundary with 27% available water.

20 – 51 cm BG1: Olive grey (5Y 4/2) *silty loam,* with common medium, distinct yellowish red (5YR 5/6) mottles; moderate coarse prismatic, breaking into moderate to weak medium platy; common worm channels and few, fine pores; common fine roots, Fe and Mn concretions; clear boundary and has 23% available water". Since the maximum soil's depth exploited for this investigation was 30 cm, the limit of the profile description to consider is 20 – 51 cm as above.

"The soil textures of subsequent layers from the top downwards were silty clay loam, silty loam, loam and silty clay. The layer from 51 – 70 cm downward is rather different from the two layers above, especially with regard to the sand content and the ratio coarse sand and medium sand. However, only two parent materials are assumed in the horizon designation. The USDA (United States Department of Agriculture) SOIL TAXONOMY (1974) tentatively classified the soil as a fluventic humaquept" (Njøs, 1978).

3.3 Climate

Climate is one of the external factors involved in the formation of a soil. It encompasses temperature, light and precipitation. Njøs (1978) categorized the climate at the experimental site based on the USDA Soil Taxonomy (1974) as: "(a) frost free season described by a cold early spring, (b) a pre-summer drought that commences from 1 May to 15 July, and (c) a wet autumn from approximately September 10; the infiltration of the frost in most seasons is circa 0.5 m". Information regarding the meteorological data (i.e. monthly mean precipitation (mm) and monthly mean temperature (C°)) of the experimental area from April to September during the period under review (1961 – 2010) are seen in Table 1 (Hansen og Grimenes, Meteorologiske Data for Ås – 2010).

Table 1: Monthly average air temperature (C°) and monthly average precipitation (mm) for the experimental site in Ås (April to September) 1961 – 1990 and 2010 (Source: Hansen og Grimenes, Meteorologiske Data for Ås – 2010).

MONTH	AVERAGE TEMPERATURE (C°)		AVERAGE PREPT. (mm)	
	2010	**1961 - 1990**	**2010**	**1961 - 1990**
APRIL	**5.2**	**4.1**	**35.1**	**39**
MAY	**9.8**	**10.3**	**91.0**	**60**
JUNE	**14.1**	**14.8**	**62.6**	**68**
JULY	**16.9**	**16.1**	**100.7**	**81**
AUGUST	**15.3**	**14.9**	**149.5**	**83**
SEPTEMBER	**10.4**	**10.6**	**93.9**	**90**

In Table 1, the average temperature (C°) increased gradually from April to July 1961 – 1990, and decreased in August and September. The same trends occurred in 2010. On the other hand, the average precipitation (mm) had a gradual increase from April to September 1961 – 1990, but fluctuated in the above-mentioned months in the year 2010.

3.4 Experimental design

The experiment was a tillage trial divided into two blocks. The layout of the experimental field was of a split-split plot design with four (4) replications, and compaction as the treatment on the sub - plots. The individual plot is 3 m* 7.5 m. The treatments included:

i. Tillage cultivation which occupied 135 m^2 of the area (7.5m * 18m);
ii. Stubble cultivation which utilized 202.5 m^2 (i.e. 9 m * 22.5 m), and
iii. Compaction occupying 67.5 m^2 (i.e. 3 m * 22.5 m) of the area respectively.

The trial commenced in 1989 at UMB / NMBU and continued up to date with the following tillage treatments below.

Tillage treatments were:

A: Autumn ploughing (AP), 20 – 22 cm depth with a tractor.

B: Spring ploughing (SP), 12 – 15 cm depth, and

C: Spring harrowing (SH), 4 – 6 cm depth (no ploughing or zero tillage).

Stubble cultivation included:

S0: No harrowing

S1: Harrowed in autumn

Compaction were:

1: In autumn, 1 time track – by – track with tractor;

2: In spring, 1 time track - by- track.

3: No compactions.

Fertilizer was applied as basal dressing of 500 kg per hectare NPK (Nitrogen, Phosphorus and Potassium) in the ratio: 20: 4: 10 and placed 5 cm deep.

Experimental Design: Split-split plot design with four (4) replications.

	S0			*S1*			*S1*			*S0*		
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*A*
13	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*C*
25	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*	*36*	*B*
2	*1*	*3*	*1*	*2*	*3*	*2*	*3*	*1*	*1*	*2*	*3*	
1	*3*	*2*	*2*	*3*	*1*	*3*	*2*	*1*	*3*	*2*	*1*	
37	*38*	*39*	*40*	*41*	*42*	*43*	*44*	*45*	*46*	*47*	*48*	*A*
49	*50*	*51*	*52*	*53*	*54*	*55*	*56*	*57*	*58*	*59*	*60*	*C*
61	*62*	*63*	*64*	*65*	*66*	*67*	*68*	*69*	*70*	*71*	*72*	*B*
	S1			*S0*			*S0*			*S1*		

Figure 2: Field layout (experimental design) showing treatments: three tillage systems, two stubble cultivation and three compaction systems. Detail of the treatments are explained above. Source: UMB / NMBU Tillage trials, 1989 to present.

3.5 Description of the physical parameters / measurements

To be able to delve into the discourse regarding the topic **"The Effect of Long Time Tillage on Soil Physical Parameters",** there is need to carry out soil physical measurements. These include soil aggregates (i.e. aggregate size distribution and aggregate stability), water release characteristics, bulk density, air permeability, air porosity, penetration resistance, soil moisture retention, etc., etc. The sampling was done immediately after harvesting of the crops, and the methods of sample collection were according to Børresen and Haugen (2003). These are detailed under each physical parameter as they are described below.

a. Soil Aggregates

Soil aggregates occur when individual primary soil particles bond together by clay films, and may become firm by cementing materials such as organic (humus) and inorganic gluing agents (Hillel, 2004). SSSA (2010) defines soil aggregates as the sticking together (cohering) of primary soil particles of the same kind more firmly than to other particles in the same milieu. Both explanations suggest that aggregated soil structure is constructed by binding single grains of soil particles together by means of cementing agents such as: clay fractions (i.e. primary binding agent) and Calcium Carbonate ($CaCO_3$). Other gluing agents include Organic Matter (OM), iron oxide (FeO_2), Aluminum Oxide (AlO_2), and microbial by-products or residues found in OM (i.e. secondary binding agents); or, by disintegration (cracking / splitting) of a massive structure. In short, the presence of gluing substances between the soil particles, the closeness of the particles or the narrower the spaces between the particles, and the higher the specific surface area, the more firm will be the aggregation. Another definition of soil aggregate by NSSGA - the National Stone, Sand and Gravel Association - (1991) states that soil aggregate is "a collective term for sand, gravel and crushed stone mineral materials in their natural or processed states." Aggregation means, "formed in a cluster" (Henderson's Dictionary of Biological Terms - HDBT) (1989). Based on GSST (2013), soil aggregate "is a group of primary soil particles that cohere to each other more strongly than to other surrounding particles". Note that an aggregate can either be a **ped,** (i.e. aggregate formed by natural processes in the course of soil formation) or a **clod** (i.e. aggregate occurring in cultivated soils / fields (Hillel, 2004). **NB** Aggregated soil structures are consider the most desirable soil condition both for plant growth and in the reduction of risk of erosion of an area.

i) Aggregate size distribution

Hillel (2004) explains aggregate size distribution as the separation of soil particles within the structural arrangement of the aggregate when disruptive forces are applied to the original soil in situ, in order to break up the binding agents that hold the soil particles together. Kopec (1995) classified soil particles as sands, silt, clays and organic matter. Particle size analysis is the determination of the various amounts of the different soil separates in a soil sample, usually by sedimentation, sieving, micrometry, or combinations of these methods. Aggregate size distribution, among other things, helps to determine the soil's pore size distribution, and renders the soil vulnerable specifically to wind erosion. Taboada – Castro et al. (2004) suggested that the determination of aggregate size distribution of a soil could be based on the diverse soil management practices that result. **NB** The application of too great a force in order to separate soil particles may lead to the breaking or crushing of the aggregates themselves. Therefore, a successful method of aggregate size distribution is contingent on the techniques made use of in the field for data collection, and the laboratory method(s) involved in the processing of the data.

ii) Aggregate stability

According to SSSA (2010), aggregate stability is a way of evaluating the fraction of soil aggregates, which cannot be easily remove or broking into pieces or crumbled. Hillel (2004) describes aggregate stability as the potential of an aggregate to resist disruptive forces imposed on it (i.e. either mechanically or during cultivation practices), or by the action of moisture which may cause swelling, slaking, and dispersion of clay. "Aggregate stability is also a measure of the proportion of the aggregates in a soil which do not easily slake, crumble, or disintegrate" (GSST, 2013).

b. Penetration resistance

A penetrometer is an apparatus (measuring device) used for evaluating the toughness / firmness of a soil in the field. The soil's resistance to external force is measure in term of the energy increased per unit depth (Hillel, 2004). This method of the measurement of the soil resistance to external forces is an indirect way of evaluating its (soil) strength in the field. As it is not a direct measure of the hardness of the soil per se, but it consists of guidelines and / or variables regarded to be associated to the soil strength (Hillel, 2004). Penetration resistance (or cone index) connotes the force per unit area on a standard ASAE cone necessary for penetration by the cone (GSST, 2013).

According to Davidson (1965), penetrometer use produces comparative measures of the opposition shown by soil to root penetration, and is made distinct as the relationship between the force needed to push a metal cone into a soil versus the basal area of the cone. In the process of using a penetrometer, soil particles are displaced because its use results in fragmenting, compacting and shifting of the soil particles (Børresen and Haugen, 2003). Chancellor (1971) stated that included in the numerous aspects disturbing soil strength are compactness (i.e. denseness), degree of saturation (moisture content) and conditions at the time of compaction. Furthermore, the decay of straw / rubbish and water evaporation can contribute to less soil strength. Many authors, including Zimmerman and Kardos, 1961; Taylor and Gardner, 1963; Taylor and Burnett, 1964; etc., have reported a parlous, although vague, soil strength above which root elongation for various crops is hampered. This is, mostly, in the neighborhood of 2000 – 2500 kPa. Nevertheless, Gill and Bolt (1955) suggested that plant root elongation is contingent on the 'root growth pressure', i.e. the pressure for root growth must be greater than the soil strength.

c. Moisture release characteristics / Soil water characteristics curve

Soil moisture release characteristics, also known as 'the water retention curve' or 'water release curve' is an illustration that describes the link between the soil-water content (by mass or volume) and the soil water metric potential of a plant (SSSA, 2010). Kopec (1995) noted that usually, the size of the particles, their distribution, and their arrangements in relation to each other (structure) determine the soil moisture characteristics (soil water relationship) a particular crop / plant soil will have. Furthermore, that it is the surface area of the soil particle that retains moisture in a specific soil. On the other hand, GSST (2013) suggests soil water characteristic or characteristic curve as "the relationship between the soil-water content (by mass or volume) and the soil-water matric potential. This is also known as the water retention curve or isotherm, and / or the water release curve". Taylor et al. (1966) propounded that any alteration in soil firmness, caused either by compaction or by difference in soil water characteristics could modify root elongation pattern.

d. Bulk density (ρ_b or BD)

Birkeland (1984) defines soil bulk density as the act of measuring soil weight per its bulk quantity (g/cc), mostly stated on an oven-dry (110º) basis. The difference in bulk density is associated with the corresponding amount and fixed relative density of solid organic and inorganic particles and to the fractional volume of voids (pores) in the bulk volume of the soil. Wikipedia (2010) explains bulk density as a large body of numerous materials of primary soil particles, divided by the total sum of the space (volume) they occupy. The total volume includes particle volume, inter-particle void volume and internal pore volume. The bulk density of a soil is determine mainly by the mineral composition of the soil and the extent to which it is compacted. This implies that the more porous a soil is the lower is the value of the bulk density. Another meaning for bulk density is the weight in volume of an individual component of physically slack material such as a powder or soil, to an equal amount of space water occupies, represented in kilograms per cubic meter (kg/m^3) or pounds per cubic foot ($l\ b/ft^3$). It depicts a type of ratio of the density of a substance to the density of a standard (relative density), and is applied mostly in quality control, shipping, and soil analysis (http:www.businessdictionary.com/difination/bulk-density.hotml). A concise meaning by GSST (2013) states that soil bulk density (ρ_b or Bb) is the mass of dry soil per unit bulk volume. The value is express as milligram per cubic meter (Mg/m^3). Campbell (1994) defines soil bulk density or, more exactly, soil wet bulk density as "the mass of soil particles plus the mass of soil water in a unit volume of soil".

Freitag (1971) insinuated that there are various techniques at one's disposal for bulk density evaluation, such as the direct method(s) and the indirect method(s). Nevertheless, none is the more appropriate for all situations. However, the direct methods are employed to ascertain and / or confirm the soil bulk density by either agricultural soil scientists and / or civil engineers (Anon, 1964). Blake and Hartge (1986) evaluated the direct methods, described their speculative base and deliberated about their use in traffic and tillage research. Prominent among them was the core sampling method which is utilized in sampling for the assessment of soil water retention characteristics (pF), air capacity, bulk density, air permeability, etc., etc. The above are detail under each individual sub-topic.

e. Air permeability in soil

Soil air permeability: "(i) Is the ease with which gases, liquids, or plant roots penetrate or pass through a bulk mass of soil or a layer of soil. Since different soil horizons vary in permeability, the particular horizon under question must be designated. (ii) The property of a porous medium itself that expresses the ease with which gases, liquids, or other substances can flow through it, and is the same as intrinsic permeability (k). See also intrinsic permeability, Darcy's law, and soil water" (GSST, 2013). Therefore, soil air permeability describes the rate or ease at which air enters / penetrates a layer of soil (SSSA, 2010).

f. Porosity

Porosity is the portion of the soil solid volume not occupied by water (non-solid volume) over the bulk volume of the sample (SSSA, 2010). In addition, it is a measure of the corresponding pore space in a soil. This implies that when the texture of a soil is coarse, it tends to be less porous than a fine textured soil. Despite the above, there is greater mean individual pore size in the former compared to the latter. But in clayey soils (i.e. mineral soils dominated by clay fractions), there is more irregularity in porosity due to the repeated swelling, shrinking, aggregation, compaction, and cracking depending on climatic changes or agricultural practices (Hillel, 2004).

g. Air (-filled) porosity

Air (-filled) porosity is the portion of the soil volume which air occupies at any given time or under a specific giving condition (i.e. the amount of air present in the soil, or the soil water energy due to its position, and attracted by adhesion and cohesion forces in soil medium) (SSSA, 2010). Hillel (2004) describes air (-filled) porosity as a method used to ascertain the content of air in the soil. This forms the basis of soil aeration, and is connected / associated reciprocally to the degree of saturation.

3.6 Field and laboratory methods

- **Sampling / Pre-treatments methods**

The sampling and pre-treatment methods are all according to Børresen and Haugen (2003)**.** Soil samples were collected as follow: **a)** Samples collected from surface layer down to depth of five centimeter (0 – 5 cm) for the determination of *i - aggregate size distribution* and *ii - aggregate stability by rain simulation.* **b)** Samples collected from surface layer down to depth of 30 cm, at 5 cm intervals (i.e. 0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25-30 cm.) for the measurement of the soil strength against applied pressure vertically into the profile used for finding penetration resistance. **c)** Samples collected from undisturbed soil from 2 cm to 30 cm depth (i.e. 2-7cm, 15-20cm, and 25-30 cm respectively) for the measurements of water retention characteristics, air capacity, bulk density, etc., etc.). and **d)** Samples collected from surface down to 30 cm at three intervals (i.e. 0-10 cm, 10-20 cm and 20-30 cm) for soil moisture determination.

The previously mentioned samples were transferred into the soil physics laboratory upon collection for further processing according to their various needs. The intricacies of each experiment are detailed according to their precepts, etc.

a) Samples collected **from surface layer down to depth five centimeter (0 – 5 cm) for the determination of: i -** ***aggregate size distribution*** **and** ***ii - aggregate stability.***

The soil physical measurement(s) utilized to determine aggregate size distribution was based on the dry sieving method, and aggregate stability was measured with a rain simulator both in a laboratory as detailed by Børresen and Haugen (2003). These techniques are used because they are some of the best ways of investigating the soil's pore size distribution, and the effects they have on the physical parameters after long-term tillage. The particle sizes distribution differ according to the cultural practices applied on sub-plots in each replication. They unveiled diversity in both actual weight of fractions and relative weight of fractions as percentage.

Aggregate(s) (*i.e. i. size distribution and ii. Stability*)

i. Aggregate size distribution

The distribution of aggregate size is a paramount variable needed to determine the soil's pore size distribution. It has an effect on the soil surface erosion especially by wind, and it provides an insight on whether a constructed seedbed has a poor or good quality (Hillel, 2004). Soils favorable for such a venture are those without coarse clods or too much fine materials i.e., approximately half of the aggregated soil should be in the fraction of 0.5 to 5 mm (Børresen and Haugen, 2003). In an effort to distinguish and sort out or categorize soil aggregates to ascertain their sizes distribution, mechanical means are employed which disrupt the original structural arrangements of the soil (Hillel, 2004). Consequently, take care not to use too much force to avoid breaking-up of the aggregates themselves.

The requisite materials required for the exercise include soil samples, 2 – liter paper boxes, a trowel and a plastic bucket. Others are a balance, an apparatus consisting of different rotating sieves (20 mm, 6 mm, 2 mm and 0.6 mm respectively) in a container with the frame fitted upon each other (i.e. with the largest sieve on top, and covered by a lid during the sieving process). It is driven by a ½ HK Electro Engine with two lay shafts - one of them with eccentric disk - a transmission system, a frame with guide axles where the sieve container is driven back and forth on a slide bearing, and a stopwatch (Børresen and Haugen, 2003).

▪ **Pretreatment Method(s)**

Preceding the collection of the soil samples for both aggregate size distribution and aggregate stability determination, the 2-litre paper boxes were labelled with experimental code (i.e. A85), and plot number(s), for instance - plot #1, or sub-plots. Soil samples were collected from two major blocks that had two replications each and from 72 sub-plots at five different spots with a trowel. To obtain a representative sample for each sub-plot, mix the soil thoroughly in a bucket. The labelled boxes are filled over with two liters of the mixture. The soil filled boxes (72 in all) were transported to the soil physics laboratory and were immediately opened and left to dry by air at regular room temperature (ca. 28° C).

In the laboratory, the soil samples were air-dried at room regular temperature for 37 days (= 5 weeks and 2 days). The mass and total sample of each labelled box were weighed at least, with 1 g accuracy and total weight recorded. Extremely big clods were broken up, and the content of each box emptied onto the top sieve. Each content sieved for 3 minutes for the fraction sizes segregation process according to the sieve sizes mentioned earlier. At the end of each sieving activity, the fractions were weighed individually and each weight recorded. The laboratory had a ventilation system and a mask worn to prevent dust. Discard all stones found on sieve after sieving because they do not contribute to the soil aggregate. All raw data collected were analyzed and used to determine soil aggregate sizes. They were processed, and the relative weight for each fraction of the aggregate as a percent was calculated to determine their respective weights. Example of the calculation is seen below.

▪ **Formula and / or calculation for relative weight of fractions using plot 1 as an example.**

Relative weight of fraction as percent (Wt. %) = fraction wt. * 100 / Gross wt.

Example Plot 1: Given > 20mm fraction = 60.5 (g); gross wt. (or total wt.) = 1244.5 (g);

Constant =100.

Solution: Relative wt. % (g) = 60.5 (g) * 100 /1244.5 (g) = 4.86 ~ 4.9

The results obtained for the 72 plots were used for the statistical investigations via the ANOVA methods (Analysis of Variance).

ii. Aggregate stability:

Soil is exposed to diverse external forces that if applied, will cause damage to it by dissociating the bindings that hold the aggregates together. In order to enquire how invulnerable or susceptible they are, aggregate stability test by rain simulation is one best way because the adverse actions of water on soil is no exception. For example, raindrops, in addition to run-off water, can provide sufficient energy to detach soil particles and displace them (i.e. erosion effect) (Hillel, 2004). The method of exposing soil samples (i.e. the different fractions) to simulated rain is to ascertain which fraction will better resist the force applied on them. Of the five sieved fractions obtained from the aggregate size distribution exercises, two of these (6-2mm and 2-0.6mm) shall be utilized for the aggregate stability investigation (Børresen and Haugen, 2003).

In addition to the materials used in data collection for aggregate size distribution, the following are essential for the rain simulation exercises. They include: a rain simulator with gadgets, eight sieves with 0.5 mm mesh openings, three ceramic plates (cups), a balance (0.1 g accuracy), drying oven, a stop watch, a wash bottle, plastic funnels, filter papers and soil samples (Børresen and Haugen, 2003).

- **Pre-treatment method(s)**

After calculating the relative weight of each fraction, the air-dried packet of sieved fractions needed for the rain simulation or aggregate stability processes (i.e. 6 - 2mm and the 2- 0.6mm fractions) were transferred into the soil physics laboratory to undergo the rigorous test methods. Clean the sieved soil by picking out all the visible residues or impurities. Two approximately 20 g of soil obtained from each packet were weighed out of the fractions separately (i.e. 20 g * 2 from fraction 6 – 2mm and 20 g * 2 from fraction 2 – 0.6 mm) from each plot of the aggregate size distribution and weights recorded. This implies that 40 g was weighed per fraction and 80 g per plot. These were transferred in packets and labelled parallels one and two respectively (Børresen and Haugen, 2003). They were stored into the rain simulation laboratory for processing. During this period, control the rain simulator before commencing the measuring of stability on the soil samples, because the nozzles discharge can vary from day to day even if their settings are equal.

One can achieve the above by measuring the amount of water discharged from each nozzle. Set the time and pressure you intend to use for the process, and put a plastic bucket under each nozzle to collect the water. For this experiment, the recommended setting includes four Tee-jet 9005E nozzles with distance between sieves and nozzles as 31.5 cm, a water pressure of 1.5 kp/cm² and of 3 minutes duration (Børresen and Haugen, 2003).

Weigh and label individual filter paper and record it. The labelling procedures were as follow: plot number (s), aggregate size (s), parallel number (s) and sieve number (s). To begin the simulation process, put the empty sieves on the rotating disk of the simulator for initial wetting. Start the engine and turn the water on for 3 minutes with time taken by a stopwatch. During the pre-wetting process, check thoroughly to ensure that four nuzzles are functioning properly and that they faced the center pole (i.e. North, South, East and West). Remove the wet sieves and place them on the lab desk to let water drain off for about a minute. Carefully, and evenly pour off the 20 g sample(s) for each parallel on each pre-wetted sieve. Be fast enough in pouring off the samples to prevent the pre-wetting of the aggregates, which could affect the stability of the soil to the simulated rain. Immediately place the loaded sieves on the rotating disk. Start the rotating disk engine and turn on the water for 3 minutes and the time taken with a stopwatch. Ensure that the black meter handle is aligned with the red-stationed handle (pin) at 1.5 bars. Control the water pressure and stopped it after 3 minutes (Børresen and Haugen, 2003).

The soil left on the sieve(s) after the simulation process was washed off carefully (i.e. with water) over into ceramic bowls. The excess water drained carefully to avoid losing the soil particles. Organic particle(s) - plant residues - flow out during the process but this creates no problem. Arrange the labelled and pre-weighed filter papers in each funnel accordingly, and the soil samples from the ceramic bowls emptied over onto each filter paper. Clean the sieves thoroughly and repeat the process until all the samples are treated. Leave them to air-dry for approximately 48 hours at room temperature. After drying, re-weigh the samples together with the filter papers and weights recorded. In order to obtain the net weight of the dry soil, subtract the tare weights of the filter papers from the gross. The net weight is used to compute the aggregate stability for each parallel and fraction as seen in the calculations below. In the examples, find the average of each parallel of the fractions (6 – 2 mm and 2 – 0.6 mm), and deduct the weight of the individual filter paper before performing the necessary mathematical operations.

<u>Examples</u> of calculations for aggregate stability:

▪ **Formula and calculations**: Aggregate stability = (mass of dry soil after rain simulation / mass of dry soil before rain simulation) * 100%.

I am using plot 1, fractions 2 – 0.6 (g) and 6-2 (g) as examples.

Plot 1: Fraction 2 – 0.6 (g): = parallel 1 = 12.75 (g) + parallel 2 = 10.53 (g)

= 23.28 (g) / 2

= 11.64 (g) – Filter paper wt. (1.06) (g)

= 10.58 (g) / mass of dry soil before rain simulation (20) (g)

= .529 * 100%

= 52.9 (aggregate stability).

Fraction 6-2 (g): = parallel 1 = 10.55 (g) + parallel 2 = 11.05 (g)

= 21.60 (g) / 2

= 10.8 (g) – Filter paper wt. (1.06) (g)

= 9.74 (g) / mass of dry soil before rain simulation (20) (g)

= .487 (g) * 100% = 48.7 (aggregate stability).

The results obtained from aggregate stability calculations are used for the statistical investigations via the ANOVA methods (Analysis of Variance).

Total aggregate stability for fractions 0.6-2 mm and 2-6 mm are needed to ascertain the suitability of the aggregates for seedbed preparation. See formula and calculation below and results in Table 4 as total aggregate stability – weight percent.

▪ **Formula and calculation:** Total aggregate stability (wt. %) = fraction 0.6-2 mm + fraction 2-6 mm / 2. Example, using data from Tab. 4, aggregate stability % for tillage application. Given: 0.6-2mm = 61.9; 2-6mm = 65.7.

Solution: Tot. agg. Stability (wt. %) = 61.9 + 65.7 = 127.6 / 2 = 63.8.

b) Samples collected from surface layer down to depth 30 cm, at 5 cm intervals (i.e. 0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25-30 cm) for soil strength measurement against applied pressure vertically into the profile (i.e. finding penetration resistance).

Generally, a penetrometer is an instrument required to measure the soil resistance to penetration. It is composed of a cone installed on a rod, a handle grip and a dial gauge (Børresen an d Haugen, 2003). There are diverse types of penetrometer in use nowadays to measure the soil penetration resistance, but their individual evaluation is affected by the soil moisture content (Børresen and Haugen, 2003). For this exercise, the push-type penetrometer is used. Knowledge acquired in this investigation shall enable users of soil to have concepts about the soil penetration resistance and its physical parameters. These include the bulk density, the degree of compactness, the bearing capacity, the share strength, etc., etc. The requisite material(s) / equipment(s) required, and were used to collect and measure the soil resistance to penetration were: the push-type penetrometer with fixed gadgets, a soil auger, plastic bags, labels, recording ledger and grease pencil (Børresen and Haugen, 2003).

- **Pretreatment Method(s)**

Pre-labelled polythene bags were used to store samples. The smallest cone (i.e. cone no. 1: 1 cm^2 surface) was used to collect data for this exercise. The selection of the cone was based on the soil's penetration resistance, and because less pressure was required in its use. The cone of the instrument was pressed vertically down into the soil at constant velocity of approximately 1 cm / s. Soil samples were collected from 72 sub-plots by taking three sticks of the reading per plot, and six depths at five centimeters interval (i.e. sticks A, B and C respectively, and depths 0-5cm, 5-10cm, 10-15cm, 15-20cm, 20-25cm and 25-30cm). At the time of the penetration test, the soil water content at the experimental site was circa equal to 23-27% in the 0 – 50 cm depth. The labels on each polythene bag were recorded in the ledger including the number of the cone. The data that resulted was used to calculate the penetration resistance of each depth in the sub-plots (Børresen and Haugen, 2003). After measuring the penetration resistance in the field, the data obtained for penetration representing (Force = Newton) were divided by centimeter square (cm^2) and the calculated results ending in N/cm^2. See calculation below.

For this investigation, to obtain the penetration resistance in kilo-Pascal (kPa), find the mean of the data collected from the three sticks for each depth, which represents force (N) and perform the mathematical operations.

The following formula is used for the calculation: **Penetration resistance = Force (N) / surface of cone (cm^2).** Because cone number 1 was used, the surface of the cone in this case stands as 1 cm^2. See calculation below.

▪ **Formula and Calculations: Pen. Resistance = Force (N) / surface area of cone (cm^2).**

Depth 0 – 5 cm: Given: Stick A = 40 N, Stick B = 25 N and Stick C = 20 N; surface area of cone = 1 cm^2

Solution: = 40+25+2 0 = 85 N / 3 sticks (A, B and C) = 28.33 N / 1 cm^2 =28.33 N / cm^2.

NB *To convert N / cm^2 to kPa, you multiply by 10. See example of conversion below.*

Convert 28.33 N /cm^2 to kPa: 28.33 N / cm^2 * 10 = 283.3 kPa.

Results from penetration resistance calculation are used for the statistical investigations via the ANOVA methods (Analysis of Variance).

c) Samples collected from undisturbed soil from 2 cm to 30 cm depth (i.e. 2-7cm, 15-20cm, and 25-30 cm respectively) for various measurements.

Soil samples collected by the steel cylinder method are utilized for diverse measurements. However, for this purpose, they shall be utilized for the characterization of soil water retention characteristic curve (pF) (vol %), porosity (vol %), bulk density (ρ_b or B_D) (g/cm^3), particle density (ρ_s) (g/cm^3), air permeability (cm^3 / min), pore volume (kVf) (vol %), etc., etc. The samples are extracted from three depths (i.e. 2-7 cm, 15-20 cm and 25-30 cm) of an undisturbed soil, and it is very important to take care in the collection process. By so doing, good samples will be obtain to conduct the tests. The appropriate sampling time for the investigation is when the soil water is close to field capacity (Børresen and Haugen, 2003).

The following equipment(s) / material(s) were utilized for a successful extraction of the samples: ***1) In the field***: 180 steel cylinders (100 cm^3) with one sharp edge and plastic lids for both ends, hammer, hammer union, knife, pinch bar, furring strip, metric ruler, spade, pencil, recording forms, and 5 transport boxes that could contain 36 cylinders each. ***2) In the laboratory***: a balance, drying oven and air pycnometer(s), air pressure system with reduction valves and pressure gauge, calibration cylinder with steel disks, 100 cm³ cylinders, pF cylinders, bandage, rubber bands, distilled water, sandboxes and pressure cooker (pressure chamber) with pressure plates (Børresen and Haugen, 2003).

▪ **Pre-treatment Method(s)**

1) In the field**:** The data was collected from 36 sub-plots selected on an experimental field that had been in use since 1989 – 2013. The following tillage practices were routinely applied for the past 20 or more years: autumn ploughing (10 – 20 cm depth), spring ploughing (12 – 15 cm depth) and spring harrowing but no ploughing (4 – 6 cm depth). The samples were collected immediately after harvesting of the crops, or when the soil water content is close to field capacity, (i.e. the soil profile's ability to retain moisture after the process of internal drainage has ceased). The following depths were used for the sample collection: 2 -7 cm, 15 – 20 cm and 25 – 30 cm respectively (Børresen and Haugen, 2003).

According to Børresen and Haugen (2003), use a spade to carefully clear the soil surface and dig down to the desired soil depth. In this case, 2 cm of top soil was cleared on each selected spot on the selected sub-plots in order to have a smooth and undisturbed soil surface. Triplicate measurements were made with steel cylinders, and two soil samples taken at 2-7 cm depth on each plot. This was achieved by removing the plastic lids off the cylinders. Two cylinders were placed in the hammer union with the sharp ends out of the union; they were hammered down in the soil until each was 0.5 cm deeper than the surface. A pinch bar or a spade was used to dig out the cylinder containing the soil body depending on the convenience to prevent disturbance of the soil within the cylinder. The samples were cleaned and cut with a knife to make the end faces plane. This was accomplished by holding the soil-filled cylinder in one hand and the end face cut with the knife. Take care during the cleaning process to avoid breakage of the sample. When the cleaning of one end face is completed, put on a plastic lid and clean the second end face, then the second plastic lid is put on it. Soil was cleared from the same pit down to 15 cm depth, and two more samples collected at 15 – 20 cm and the aforementioned cleaning process conducted on them. Subsequent clearing was done in the same pit down to 25 cm and a cylinder was used to collect a third sample at 25 – 30 cm depth. The later collections was treated just as the first two sets. This implies that five samples were collected per plot, with 180 samples collected in all from the 36 sub-plots.

i. Each cylinder has a number. Record them on the required form including the sampling place, plot number(s), etc. indicated for convenience in the area identification. Put the completed samples from the 36 selected sub-plots in the transport boxes that could contain 36 cylinders each. They included: sub-plots 1, 2, 3, 13, 14, 15, 25, 26 and 27 from block one, replication I. Sub-plots 10, 11, 12, 22, 23, 24, 34, 35 and 36 from block one, replication II. Sub-plots 40, 41, 42, 52, 53, 54, 64, 65 and 66 from block two, replication III; and sub-plots 43, 44, 45, 55, 56, 57, 67, 68 and 69 from block two, replication IV. They were all stored in five transport boxes (5 boxes) and taken to the soil physics laboratory.

ii. Take care in choosing places for sample collection on the sub-plots to prevent disturbance, for instance, tractor wheel tracks, wet sports or holes. In the process of collecting a sample, if a stone was hit a new spot will be located in the same sub-plot for the collection to avoid disturbing the soil and to collect sample equal to the size of the cylinder.

***2) Laboratory procedure(s*):** Upon transporting the samples to the soil physics laboratory, the soil-filled cylinders were weighed and weights recorded on soil chats for ease of identification, then placed in soil boxes and kept in the lab. There are various laboratory procedures that follow to ascertain air, pF2 (vol %), tare weight (g), actual soil weight (g), weights in pFs (1.3 – 3) (i.e. 0.002 Bar) to (1Bar) and soil gross wt. (g) all under water content. The net dry wt. (g) is also found in the lab. In addition, pF 4.2 (15 Bar), oven dry wt. (g) and tare of box (g) are inclusively found to complete the data needed for further computations.

***i. Actual weight*:** The weight of the soil-filled cylinder taken before the lab work (sandbox methods) commences was the actual weight (g) in the field.

ii. pF 1.3 (0.002 Bar): In the lab, the **pF 1.3** process starts with the **sandbox method.** Begin by cutting a white shirting (cloth) and placed it at the sharp edge of each soil-filled cylinder replacing the plastic lid, and the other side remaining without cover. Cut a large piece of the same cloth to fit in the sandbox. Spread it in and add a little distilled water (1 cm) to keep the shirting moist. Set in 36 soil-filled cylinders and leave overnight. The next day, add more distilled water into the sandbox until it levels up with the soil-filled cylinders and leave overnight for saturation.

The next day, connect a suction pipe (plastic tube) and open the valve of the tube to collect excess water draining out with a glass or plastic flax. Cover the flax with polythene to prevent evaporation. Pierce a hole in the polythene to create passage for the drainage tube, and use rubber ban to hold the polythene in place. Take daily readings until drainage stabilizes, then close the drainage valve, remove samples and reweigh them. . The saturation process takes 4 days. The results (weights) (g) are recorded for pF 1.3 (0.002 Bar). Immediately put the samples in little water to keep it saturated waiting for the pf 2 process. The process continues until all the samples go through it.

iii. Field Capacity pF 2 (0.1 Bar): The field capacity is obtained by the use of the pressure cooker (pressure chamber) methods. Each cooker has three-pressure plates. The cookers are connected to a big glass tube that contains water of ca. 1 meter height (i.e. from the bottom up to the red mark at the top of the tube). The pressure valves are opened for the cookers to supply air and movement occurs in the big glass tube as bobbles. This continues until the pressure stabilizes. A glass jar with funnel is placed under the rubber tube (channel) to drain water. This data is recorded every day for approximately four to five days or until equilibrium is reached.

The pressure in the glass tube that is trying to push out the water is the same as the height of 1 meter of water, which is equivalent to 0.1 bar, i.e. the pressure difference measurement and is the same as **field capacity**. A small tube in the big glass can be used to regulate 2 or 3 cookers at the same time depending on the connection, and they have the same pressure. Too much and long bubbling is not good, but bubbling occasionally is a good method for stabilization. When reading the data, make sure there is correct pressure in the tube. To estimate the correct pressure, the air pressure must be stable at the bottom of the small tube but not be too high in the big one. The pressure gauge should always read between 3 – 5 points.

NOTE: The pressure in both the big glass tube and the pressure cooker is higher than room pressure. With the pressure plate, there is a wire-mesh above the rubber at the bottom of the plate. Between the plate and the rubber, the pressure is the same as in the room, while the other portion has the same pressure as in the cooker. There is a membrane tube (rubber tube) connected at the bottom if the pressure plate extending out of the chamber into the room. The room pressure is the same as the point where the membrane tube is connected. The pressure that pushes water out of the chamber through the tube operates just as the pressure in the small tube that pushes water down in the big glass tube causing bubbles. The process ends when drainage equilibrium is attained. The samples are weighed in grams and recorded as **pF 2 (0.1 Bar) or water at field capacity.**

The samples at field capacity were processed in two different ways to: **a-** measure the air volume at pF 2 (vol %) by an air pycnometer and **b-** measure the pressure difference at air permeability (20 cm) (cm^3 / min) also by the use of air pycnometer (See procedures below).

▪ ***Air, pF 2 (vol %):*** The processes involved in measuring the air volume percent at pF 2 are: test the apparatus to ensure that the gadgets are functioning properly. Put a soil-filled cylinder in the soil chamber and compress the soil in the chamber by use of the pressure nub. Close the ventilation pipe and immediately turn the nub connecting the ventilation tube to the soil chamber clockwise at 180°. Wait until 1.000 registers on the pressure indicator then quickly turn the nub clockwise again at 180°. Take the reading from the pressure indicator at a point of interval between a brief pause of number registration and resumption. Repeat the above processes on the same soil-filled cylinder and find the average of the two readings. Look on an already tabulated chart for the reading and the number adjacent the reading represents the air volume percent at pF 2. All the other soil-filled cylinders under-go the same processes to attain air volume percent.

▪ ***Air pressure difference:*** With respect to measuring the air pressure difference i.e. air permeability (20 cm) (cm^3 / min), the following are essential: Put a soil-filled cylinder in the soil chamber and compress the soil in the chamber by use of the pressure nub. Read the pressure difference on the apparatus and record it as air permeability.

iv. pF 3 (1 Bar): After obtaining air, pF 2 (vol %) and air permeability (20cm) (cm^3 / min), then the process leading to pF 3 commences. Put the soil-filled cylinders back into the cooker's chambers and increase the pressure to 1 bar. This should register constantly on the nanometer because it is easier to adjust when pF is above 2 and up to the 5 mark. Make sure that the needle in the nanometer is always on the 1 bar for the pF 3 process. The process continues until equilibrium is reached as in **pF 1.3 (0.002 Bar)**. The cylinders are reweighed and weights (g) recorded as pF 3.

v. ***Gross Dry weight:*** The soil-filled cylinders that have provided pF 3 weights are put into the oven to dry for at least 48 hours at 105° C. They were removed after the stipulated time, reweighed and weights recorded as gross dry weights (g). "All weighing of the soil samples (pF-cylinders) are done with two red lids. Tare weights of the cylinders also include two red lids" **(**Børresen and Haugen, 2003).

vi. pF 4.2 (15 Bar): The process gearing towards pF 4.2 analysis commences with grinding of the samples according to parallel per sub-plots, i.e. all parallels from 2- 7 cm, 15- 20 cm and 25 – 30 cm are ground and mixed according to sub-plots. Arrange numbered rings on two pressure plates (i.e. 21 rings per each plate plus 2 colored rings used as standard by which the rest shall be judged). Fill each ring at ¾ level with the mixed soil samples according to plots. The rings used as standards were filled in the same manner with soil samples. Saturate the samples in the rungs with distilled water. Cover the cookers and leave for 24 hours. Twenty-four hours is ideal for this sample because it is small. However, the required time should be 48 hours for saturation. Make sure that all cooker covers are tightly screwed on with bolts and nubs. Employ a foot-bound wrench to tightly secure the cooker's cover at approximately 20 ft. lbs. This will ensure the uniformity of pressure in the cooker and avoid leakage. Open the pressure valve at 15 bar after 24 hours of saturation and permit drainage for circa 10 days or until it reaches equilibrium. The samples are removed, put in numbered boxes and weighed (g), and weights recorded as pF 4.2 (15 Bar).

vii. Oven dry weight (g): The oven dry weight was obtained by further drying of the samples after the end of the pF 4.2 process. The samples were put in boxes, as already mentioned, and stored in the oven with the boxes opened. Regulate the oven at 105° C and start the drying process. This will last for 24 hours. Reweigh the samples and record them as oven dried weight (g). The data collected from air, pF 2 (vol %) representing air volume up to oven dried weight (g) i.e. data of sampling, are calculated and used for data of analyzing. See the example of the calculations for data of analyzing below.

<u>Examples</u> of formulae and calculations using data from plot 1.

Available water (ϴ): Water, pF 2 (vol %) – water, pF 4.2 (vol %)

= 37.2 – 14.47 = 22.73 (ϴ) (vol %).

Actual Water content (ϴ) (vol %): Gross raw weight in field – Gross dry weight

= 316.0 – 276.0 = 40 (ϴ) (vol %).

Water at pF 1.3 (ϴ) (vol %): Gross raw wt. at pF 1.3 (ϴ) (vol %) – Gross dry weight

= 322.1 - 276.0 = 46.1 (Ɵ) (vol %).

Water at pF 2 (Ɵ) (vol %): Gross raw wt. at pF 2 (Ɵ) (vol %) – Gross dry weight

=313.2 – 276.0 = 37.2 (Ɵ) (vol %).

Water at pF 3 (Ɵ) (vol %): Gross raw wt. at pF 3 (Ɵ) (vol %) – Gross dry weight

=311.9 – 276.0 = 35.9 (Ɵ) (vol %).

Net Dry weight (g): Oven dry weight (g) – Tare of box (g)

= 27.09 – 18.51 = 8.59 (g).

Pore volume or water vol. at saturation (vol %): Air vol (%) pF2 + Water vol. (pF2)

=13.7 + 37.2 = 50.9 (vol %).

Dry bulk density (ρ_b) (g /cm³): a- Gross dry wt. (g) – Tare wt. (g) /100 (cm³)

= 276.0 (g) – 149.3 (g) / 100 (cm³) = 126.7 (g) / 100 (cm³)

= 1.267 (g) / cm³).

OR

b- Net dry wt. (g) / 100 (cm³)

= 126.7 / 100 = 1.267 (g) / cm³).

Particle density (ρ_s) (g / cm³): a- Gross dry wt. (g) – Tare wt., (g) / Volume of solid (vol %)

=276.0 (g) – 149.3 (g) / 49.1 (vol %) = 126.7 / 49.1

= 2.58 (g) / cm³).

OR

b- Net dry wt. (g) / Volume of solid (cm³)

=126.7 (g) / 49.1(vol %) = 2.58 (g) / cm³).

Volume of solid or Material vol. (Vol %): 100 – Pore volume (vol %)

= 100 – 50.9 = 49.1 (vol %).

Water, pF 4.2 (Weight %): pF 4.2 (15 BAR) (g) – Dry wt. (g) / Dry wt. (g) – Tare wt. (g) * 100

= 28.07(g) – 27.09(g) / 27.09(g) – 18.51(g) * 100

= .98(g) / 8.58(g) = .1142191142 * 100 = 11.42

Water, pF 4.2 (vol %): Water, pF 4.2 (wt. %) * Bulk density (ρ_b) (g /cm³)

$$= 11.42 * 1.267 = 14.46 \sim 14.47.$$

Air permeability (20 cm) (cm^3/min): K: V * 2.59 / 20

$$K = 240 * 2.59/ 20$$

$$= 240 * 1.1295 = 31.1\ (10^{-8}\ cm^2).$$

Legends: K = Air Permeability**; V =** Airflow through the soil (cm^3/min)**; 2.59** = given constant**; 20** = pressure in cm water column.

d) Samples collected from surface to 30 cm depth at three intervals (i.e. 0-10 cm, 10-20 cm and 20-30 cm) for soil moisture determination (Mass wetness).

Soil samples collected from undisturbed soil by the use of a steel auger are used for different soil measurements. However, for this purpose, they are used to investigate soil moisture content. This measurement says something about the water content difference in each individual plot of the experimental area. It entails using the results to find the mass of water and the percent rate in each sub-plot.

Many tools and materials are required to collect samples that are used for the measurement of soil moisture content. However, for this experiment, the following are needed: a steel auger, a grease pencil / marker for labelling, polythene / plastic bags (depending on amount of samples to be taken) and a bucket (i.e. for fieldwork); **for laboratory use**: petri dishes, electric oven, and a balance / a scale (Børresen and Haugen, 2003).

▪ **Pre-treatment Method(s)**

Polythene bags were labelled in preparation for both field and laboratory works. A steel auger was used to collect a stick from each sampling plot at three depths (i.e. 0 – 10cm, 10 – 20cm and 20 – 30cm respectively) from the seventy-two sub-plots. These were stored in the pre-labelled polythene bags according to depths and plots then transported to the soil physics laboratory (Børresen and Haugen, 2003).

In the laboratory, empty petri dishes were weighed, and both the weights and numbers on them recorded separately. The samples were transferred in the pre-weighed dishes according to plot numbers and soil profile depths. The soil-filled dishes were weighed, and the weights recorded as box plus wet soil weight (g). These were oven dried with the boxes open for 24 hours at a temperature of 105° C. After drying, they were re-weighed and weights recorded as box plus dry soil weight (g). The dried soils were transferred back into the polythene bags and the boxes cleaned and stored (Børresen and Haugen, 2003). The data was used to calculate **a)** weight of water in grams in each plot as water content i.e. weight of water (g), and **b)** the percent of water. See example of calculation(s) below.

▪ **Formulae and Calculations:**

a) Mass of water (wt. of water) (g) = Gross raw wt. – Gross dry wt. Plot 1, depth 0 – 10 cm is used as an example.

Plot 1: (Depth 0 – 10). **Given**: Gross wet soil wt. g + box g = 38.94 g, Gross dry soil wt. g + box g = 36.14 g. ***Soln:*** Mass of water = 38.94 g – 36.14 g = 2.8 g.

b) Percent water = Mass of water g / Gross dry wt. g – tare of box g * 100

Plot 1: (depth 0 – 10). **Given:** Tare wt. = 17.90 g, Gross dry soil wt. g + box g = 36.14 g, wt. of water = 2.8 g and constant = 100. ***Soln:*** Percent water = 2.8 g / 36.14 g – 17.90 g * 100 = 2.8 g / 18.24 g * 100 = 15.3509.

The results for the calculation of mass of water (g) and percent water collected from three depths of the seventy-two plots are used for the statistical investigations via the ANOVA methods (Analysis of Variance).

3.7 Yield

Crop yield is the harvested produce resulting from a cultivated plant grown on a small scale for consumption, or on a large scale for commercial purposes. The increase or decrease in yield is dependent on the degree of soil compaction and the soil type. Busscher et al. (2002) stated that less yield could be obtained even in soils that are incompletely re-compacted but capable of increasing soil strength in a year or less. Generally, tilling soil without reducing / removing compaction causes might not improve yield. Ellis (1990) revealed that grain yield exhibited less reaction to sub-soil tillage in wheel tracks despite the noticeable decrease in penetration resistance. Nevertheless, a noteworthy yield increase resulted when both the dense layer and wheel tracks were dislodged. Yields for the year 2010 were harvested with combined harvester on a plot size of 5.5m * 2m = 11m^2. At the end of this investigation, data on grain yield (GY) and dry matter percent (DM %) for 2010 were collected and used for the calculation of water content in grain at harvest. The formula for calculating water content in grain is shown below and results recorded in Table 9.

- **Formula: Water content in grain yield =** 100% - Dry matter (DM)

Example Given: Grain yield (GY) = 400.6; Dry matter (%) = 85.1; Constant = 100.

Soln.: Water content in grain yield = 100 – 85.1 = 14.9

3.8 Statistical Analysis

The statistical investigations were conducted by employing the ANOVA methods (Analysis of Variance) (GLM procedure), (SAS Institute, 1990). Means differences were assessed by an LSD trial. For parameters that had more than a sample per plot, computation was based on the means per plot preceding the statistical analyses (Børresen, 1999).

4. Results

The changes that occur in soil structure due to the anthropogenic activities of man were thoroughly examined in this trial. Three tillage practices in autumn and spring against stubble cultivation and compaction were utilized with densification as main treatment on the sub-plots. All results obtained from calculations of the raw-data were statistically analyzed by the ANOVA methods (GLM procedure), (SAS Institute, 1990). Compaction results from the various methods employed in this investigation were insignificantly not different except for a few. The individual analysis showed that compaction between treatments was negligible, and that very few tillage practices with stubble cultivation, compaction, and the combination of both tillage and compaction treatments had some effect on the soil structure more than the others as detailed in Tables 2 to 8 respectively.

In Table 1, the average temperature (Cº) showed gradual increment for the months of April to July 2010, and then gradually declined for August and September. The same trend of upward average increase occurred in years 1961 – 1990 (from April to July) and subsequently declined gradually in August and September. In contrast, while average precipitation (mm) fluctuates from April to September in 2010, it showed a gradual steady increase from April to September, 1961 – 1990.

Table 2: Penetration Resistance (kPa) in different depths for different tillage systems, compaction and treatments, and the significant interaction amongst them.

Depth(s):	0 – 5 (cm)	5 – 10 (cm)	10 - 15 (cm)	15 – 20 (cm)	20 – 25 (cm)	25 – 30 (cm)
Tillage: AP:	956.3	1906.9	1881.5	2012.5	2692.8	3665.3
SP:	934.7	1243.1	1894.4	2563.9	2691.7	2830.6
SH:	1154.2	3055.6	3184.7	2822.2	2609.2	2668.1
Level of Sign: Pr. > F	IS	S *	IS	S *	IS	IS
Stubble Cult: SO:	1006.0	2032.4	2189.8	2484.3	2644.3	2867.6
S1:	1024.1	2104.6	2450.7	2448.2	2685.2	3241.7
Level of Sign: Pr. > F	IS	IS	S *	IS	IS	S *
Compaction: 1:	929.2	1991.7	2217.6	2462.5	2622.2	2986.1
2:	1022.9	2129.2	2437.5	2550.0	2730.6	3016.7
3:	1093.1	2084.7	2305.6	2386.1	2641.4	3161.1
Level of Sign: Pr. > F	IS	IS	IS	IS	IS	IS
Til.* Comp: AP*1	795.8	1987.5	1752.9	1958.3	2604.2	3400.0
AP*2	1006.3	1787.5	1720.8	2020.9	2637.5	3337.5
AP*3	1066.7	1945.8	2170.8	2058.3	2836.7	4258.3
SP*1	879.2	1145.8	1737.5	2620.8	2658.3	2820.8
SP*2	970.8	1333.3	2162.5	2641.7	2775.0	2983.3
SP*3	954.2	1250.0	1783.3	2429.2	2641.7	2687.5
SH*1	1112.5	2841.7	3162.5	2808.3	2604.2	2737.5
SH*2	1091.7	3266.7	3429.2	2987.5	2779.2	2729.2
SH*3	1258.3	3058.3	2962.5	2670.8	2445.8	2537.5
Level of Sign: Pr. > F IS		IS	IS	IS	IS	IS
Til.*Stub: AP*S0	943.1	1908.3	1886.1	2155.6	2746.7	3286.1
SP*S0	902.8	1163.9	1580.6	2525.0	2633.3	2836.1n
SH*S0	1172.2	3025.0	3102.8	2772.2	2552.8	2480.6
AP*S1	969.4	1905.5	1877.0	1869.5	2638.9	4044.4
SP*S1	966.7	1322.2	2208.3	2602.8	2750.0	2825.0
SH*S1	1136.1	3086.1	3266.7	2872.2	2666.7	2855.6
Level of Sign: Pr. > F IS		IS	IS	IS	IS	IS

Legend: AP: Autumn Ploughing; SP: Spring Ploughing; SH: Spring Harrowing; S0: No Harrowing; S1: Harrowed in autumn; 1: Compaction in autumn; 2: Compaction in spring; 3: No compaction; S*: Significant; IS: insignificant.

In Table 2 above, autumn ploughing (AP), spring ploughing (SP) and spring harrowing (SH) at depths 5 – 10 cm and 15 – 20 cm showed significant levels of resistance (S*) to penetration with tillage treatments (i.e. Pr > F). On the other hand, depths 10 – 15 cm and 25 – 30 cm exhibited significant levels of penetration resistance (S*) with no harrowing (S0) and harrowed in autumn (S1) with stubble cultivation treatment (i.e. Pr > F). All other treatments had diverse differences to penetration, but they were very insignificant (IS).

Table 3: Water Content in weight percent in different depths for diverse tillage systems, compaction and the significance of treatments amongst them.

Tillage / Depth(s):	0 – 10 cm	10 – 20 cm	20 – 30 cm
AP:	19.6	19.6	20.5
SP:	19.3	21.2	22.0
SH:	22.5	21.4	23.2
Level of Sign : Pr. > F	IS	IS	IS
Stub. Cult: SO:	21.2	20.8	22.2
S1:	19.8	20.7	21.7
Level of Sign: Pr. > F	IS	IS	IS
Compaction: 1	19.5	21.4	22.8
2	21.7	20.1	21.7
3	20.3	20.7	21.3
Level of Sign: Pr. > F	IS	IS	IS
Til.*Comp AP * 1	16.5	20.0	20.6
AP * 2	23.5	18.6	20.8
AP * 3	18.9	20.3	20.2
SP * 1	19.2	22.5	22.5
SP * 2	19.4	20.4	21.7
SP * 3	19.3	20.8	21.9
SH * 1	22.7	21.8	25.3
SH * 2	22.1	21.4	22.6
SH * 3	22.7	21.0	21.8
Level of Sign: Pr. > F	IS	IS	IS
Til. * Stub: AP* SO	21.2	19.0	20.4
SP * SO	19.4	22.4	21.7
SH * SO	22.8	21.0	24.4
AP * S1	18.1	20.2	20.7
SP * S1	19.2	20.1	22.4
SH * S1	22.2	21.7	22.0
Level of Sign: Pr. > F	IS	IS	IS

Legend: AP: Autumn Ploughing; SP: Spring Ploughing; SH: Spring Harrowing; S0: No Harrowing; S1: Harrowed in autumn; 1: Compaction in autumn; 2: Compaction in spring; 3: No compaction; S*: Significant; IS: insignificant.

Table 3 shows that there are diversities shown in the water content in the different soil depths, but this does not give significant level of water with any of the treatments. This implies that at all levels of the treatments; there is insignificant (IS) level of water content in weight percent.

Table 4: Aggregate size distribution (weight %) and Aggregate stability (Weight %) for different tillage systems and compaction treatments.

Surface: 0 – 5 cm	Aggregate size distribution (%)					Ag. Stability (%)		Tot. Ag. Stability (Wt. %)
Fraction(s):	>20 mm	6 – 20 mm	2 – 6 mm	0.6–2mm	< 0. 6 mm	Fraction (2 – 6 mm)	Fraction (0.6– 2mm)	(2 – 6 mm) + (0.6 – 2 mm)
Tillage: AP	3.6	16.3	34.0	28.6	17.1	65.7	61.9	63.8
SP	11.8	36.8	27.2	14.5	8.6	73.2	75.0	74.1
SH	10.7	30.1	29.8	19.9	9.1	78.0	78.0	78.0
Level of Sign: Pr. > F	IS	S*	IS	IS	IS	IS	IS	--
Stub. Cult: SO	8.4	27.7	30.3	21.2	11.6	72.2	72.3	72.3
S1	9.0	27.8	30.4	20.8	11.7	72.3	70.9	71.8
Level of Sign: Pr. > F	IS	IS	IS	IS	IS	IS	IS	--
Comp: 1	9.4	28.0	30.6	20.3	11.2	70.3	70.6	70.5
2	8.7	26.9	30.5	21.4	12.2	73.5	72.7	73.1
3	8.0	28.3	29.9	21.2	11.5	73.0	71.5	72.3
Level of Sign: Pr. > F	IS	IS	IS	IS	IS	IS	IS	--
Til.*comp: AP*1	4.3	17.0	34.4	27.6	16.3	66.4	62.4	64.4
AP*2	2.7	14.8	33.8	30.0	18.5	62.8	60.1	61.5
AP*3	3.9	17.0	33.7	28.2	16.6	67.7	63.1	65.5
SP*1	10.5	37.1	28.4	14.8	8.8	71.0	74.9	73.1
SP*2	13.0	36.1	27.8	14.3	8.5	77.8	77.0	77.4
SP*3	12.0	37.3	25.4	14.4	8.6	70.8	73.0	71.9
SH*1	13.5	29.9	29.0	18.6	8.7	73.6	74.6	74.1
SH*2	10.4	29.9	29.7	19.9	9.4	79.9	81.0	80.5
SH*3	8.2	30.6	30.6	21.0	9.3	80.5	78.4	79.5
Level of Sign: Pr. > F	IS	IS	IS	IS	IS	IS	IS	--
Til.*Stub:AP*SO	3.6	15.9	33.4	28.9	17.6	66.7	64.8	65.8
AP*S1	3.6	37.1	26.2	14.2	8.3	64.6	58.9	61.8
SP*SO	12.5	30.0	31.2	20.5	8.8	71.3	72.7	72.0
SP*S1	11.1	16.6	34.6	28.3	16.7	75.0	77.3	76.2
SH*SO	9.0	36.6	28.2	14.8	8.9	78.7	79.4	79.1
SH*S1	12.3	30.2	28.4	19.2	9.5	77.3	76.6	77.1
Level of Sign: Pr. > F	IS	IS	IS	IS	IS	IS	IS	--

Legend: AP: Autumn Ploughing; SP: Spring Ploughing; SH: Spring Harrowing; S0: No Harrowing; S1: Harrowed in autumn; 1: Compaction in autumn; 2: Compaction in spring; 3: No compaction; S*: Significant; IS: insignificant.

In Table 4, there are differences observed in aggregate size distribution for the different fractions for all treatments. However, fraction 6 – 20 mm was the only one that showed significant (S*) weight percent with tillage treatment (i.e. Pr > F). All the others showed insignificant (IS) differences to the treatments. Aggregate stability also showed minimal differences for the two fractions (i.e. 2 -6 mm and 0. 6 – 2 mm) but there was no significant stability percentage observed.

However, the sum of the fractions (i.e. 2 – 6 mm plus 0.6 – 20 mm) showed that the weight percent of the aggregates are ideal for seedbed preparation because the average sum of both fractions is greater than 50 % with all the treatments.

Table 5: Bulk density (g /cm³), Particle density (g/ cm³) and Available water (ϴ) (vol %) in three depths for different tillage and compaction treatments.

	Bulk density (ρ_b) (g /cm³)			Particle density (ρs) (g/ cm³)			Available water (ϴ) (vol %)		
Depth(s):	2 -7 cm	15–20 cm	25–30 cm	2 – 7 cm	15–20 cm	25–30 cm	2-7 cm	15–20 cm	25–30 cm
Tillage: AP	1.23	1.30	1.50	2.61	2.62	2.63	25.7	27.9	23.9
SH	1.22	1.40	1.51	2.55	2.54	2.75	25.9	24.3	23.1
Sig: Pr > F	IS	IS	IS	IS	IS	IS	IS	IS	IS
Compaction: 1	1.21	1.30	1.50	2.62	2.60	2.62	26.9	25.3	23.5
2	1.20	1.40	1.55	2.50	2.52	2.70	22.8	24.7	22.6
3	1.30	1.35	1.50	2.62	2.70	2.80	27.8	28.3	24.5
Sig: Pr > F	IS	IS	IS	IS	IS	IS	IS	IS	IS
Til.*Compact: AP*1	1.24	1.24	1.51	2.62	2.60	1.50	24.5	27.8	24.8
AP * 2	1.24	1.40	1.60	2.61	2.62	2.70	24.6	24.7	21.7
AP * 3	1.22	1.32	1.40	2.60	2.70	2.70	28.2	31.3	25.4
SH * 1	1.20	1.40	1.51	2.61	2.60	2.74	29.3	22.9	22.2
SH * 2	1.20	1.42	1.30	2.40	2.42	2.71	21.0	24.7	23.4
SH * 3	1.32	1.40	1.60	2.70	2.64	2.81	27.4	25.3	23.6
Sig: Pr > F	IS	IS	IS	IS	IS	IS	IS	IS	IS

Legend: AP: Autumn Ploughing; SP: Spring Ploughing; SH: Spring Harrowing; S0: No Harrowing; S1: Harrowed in autumn; 1: Compaction in autumn; 2: Compaction in spring; 3: No compaction; S*: Significant; IS: insignificant.

In Table 5, there is no level of significant effects in the bulkiness, particle density nor available water content observed in the different depths when the various treatments were employed. Nevertheless, there were steady minimal incremental bulkiness shown in weight with respect to the bulk density as we move vertically downward. Particle density showed fluctuating weight increments for all treatments. Available water also exhibited fluctuating increment in all the treatments with no significant level of available volume of water.

Table 6: Pore volume (vol %), Air, at pF2 (vol %) and Air Permeability (10^{-8}cm2) in three depths for different tillage and compaction treatments.

	Pore volume (vol %)			Air, at pF2 (vol %)			Air Permeability ($10^{-8}cm^2$)		
Depth(s):	2 – 7 cm	15–20cm	25–30 cm	2–7 cm	15 – 20 cm	25 – 30 cm	2–7 cm	15–20cm	25 – 30 cm
Tillage: AP	52.8	50.3	43.9	13.6	7.8	6.4	39.3	38.0	22.0
SH	53.0	47.9	45.4	13.0	6.4	5.4	19.1	37.4	10.0
Sig: Pr > F	IS	IS	IS	IS	IS	IS	IS	IS	IS
Compaction: 1	53.9	50.0	45.0	13.1	9.0	6.0	13.6	64.8	13.0
2	50.4	47.8	42.5	14.5	6.0	5.7	30.3	10.7	14.9
3	54.5	49.6	46.4	12.3	6.4	6.1	43.7	37.6	20.1
Sig: Pr > F	IS	IS	IS	IS	IS	IS	IS	IS	IS
Til.*Compact: AP * 1	52.8	52.1	43.5	14.6	10.5	6.2	19.5	94.6	15.5
AP * 2	52.7	48.0	40.7	14.7	6.8	6.9	20.8	11.1	20.8
AP * 3	53.0	50.9	47.5	11.6	6.2	6.2	77.2	8.5	29.8
SH * 1	54.9	48.0	46.5	11.7	7.5	5.8	7.8	35.0	10.4
SH * 2	48.2	47.6	44.4	14.4	5.2	4.5	39.9	10.4	9.1
SH * 3	55.9	48.3	45.4	13.3	6.7	5.9	9.8	66.2	10.4
Sig: Pr > F	IS	IS	IS	IS	IS	IS	IS	IS	IS

Legend: AP: Autumn Ploughing; SP: Spring Ploughing; SH: Spring Harrowing; S0: No Harrowing; S1: Harrowed in autumn; 1: Compaction in autumn; 2: Compaction in spring; 3: No compaction; S*: Significant; IS: insignificant.

In Table 6, pore volume percent showed decreasing differences in the different depths for all the treatments as we move vertically downwards, and they were not significant (IS). Air, at pF2 volume percent exhibited similar trends, with depth 2 – 7 cm giving the highest air pressure with all treatments. They were however not significant. Air permeability exhibited fluctuating differences in airflow with the various treatments in the various depths. Nevertheless, with an unimaginable high number of air penetration under both compaction treatment and the combination of both compaction and tillage treatment in depths 2 – 7 cm and 15 – 20 cm respectively (see colored figures in Table). However, there were no significant effects (IS) shown.

Table 7: Moisture at pF1.3 (vol %), pF2 (vol %) and pF3 (vol %) in three depths for different tillage and compaction treatments.

	pF1.3 (vol %)			pF2 (vol %)			pF3 (vol %)		
Depth(s):	2 - 7 cm	15 - 20 cm	25-30 cm	2 – 7 cm	15 - 20 cm	25-30 cm	2-7 cm	15 - 20 cm	25 - 30 cm
Tillage: AP	48.3	45.5	39.3	39.3	42.5	37.6	36.7	39.4	34.9
SH	45.1	45.2	41.4	40.1	41.7	40.1	35.0	38.7	36.7
Sig: Pr > F	IS	IS	IS	IS	IS	IS	IS	IS	IS
Compaction: 1	48.4	45.7	41.5	40.9	41.1	39.1	37.4	38.7	36.6
2	42.8	44.7	37.9	36.1	41.9	37.0	32.4	38.9	33.7
3	49.0	45.5	41.7	42.3	43.3	40.5	37.7	39.6	37.1
Sig: Pr > F	IS	IS	IS	IS	IS	IS	IS	IS	IS
Til. * Comp: AP * 1	48.7	45.7	40.1	28.2	41.6	37.3	37.1	39.2	35.5
AP * 2	48.1	43.5	35.0	38.1	41.2	34.1	36.0	38.7	31.6
AP * 3	48.2	46.6	43.0	41.6	44.8	41.5	37.0	40.5	37.7
SH * 1	48.1	45.7	43.0	43.5	40.7	41.0	37.7	38.2	37.7
SH * 2	37.5	45.5	40.8	34.0	42.5	39.9	28.7	39.2	35.9
SH * 3	49.3	44.4	40.5	43.0	41.5	39.5	38.5	38.7	36.6
Sig: Pr > F	IS	IS	IS	IS	IS	IS	IS	IS	IS

Legend: AP: Autumn Ploughing; SP: Spring Ploughing; SH: Spring Harrowing; S0: No Harrowing; S1: Harrowed in autumn; 1: Compaction in autumn; 2: Compaction in spring; 3: No compaction; S*: Significant; IS: insignificant.

In Table 7 above, there were minor differences in moisture content in volume percent in the different depths with respect to pF 1.3 (0.002 BAR), pF 2 (0.1 BAR) and pF 3 (1 BAR) respectively for all the treatments, but these differences showed no significant result on the effect of the moisture content. Even at field capacity (i.e. pF2 or 0.1 BAR) where the soil profile is expected to retain moisture after internal infiltration has stopped, moisture content is not much different from the others.

Table 8: Moisture at pF4.2 (Volume %) and pF4 2 (Weight %) in three depths for different tillage and compaction treatments.

	pF 4.2 (Vol. %)			pF 4.2 (wt. %)		
Depth(s):	**2– 7 cm**	**15-20cm**	**25-30 cm**	**2–7 cm**	**15-20 cm**	**25-30 cm**
Tillage: AP	**13.5**	**14.6**	**14.4**	**11.0**	**11.2**	**9.8**
SH	**14.2**	**17.2**	**17.0**	**11.7**	**12.5**	**11.5**
Sig: Pr > F	**IS**	**IS**	**IS**	**IS**	**IS**	**IS**
Compaction: 1	**13.9**	**15.7**	**16.8**	**11.5**	**12.1**	**11.4**
2	**13.2**	**17.1**	**14.3**	**10.9**	**12.3**	**9.6**
3	**14.5**	**15.0**	**15.9**	**11.5**	**11.2**	**11.0**
Sig: Pr > F	**IS**	**IS**	**S***	**IS**	**IS**	**S***
Til. * Comp: AP * 1	**13.8**	**13.8**	**15.0**	**11.1**	**11.1**	**10.0**
AP * 2	**13.5**	**16.5**	**12.1**	**10.9**	**12.1**	**8.1**
AP * 3	**13.3**	**13.6**	**16.0**	**11.0**	**10.4**	**11.4**
SH * 1	**14.0**	**17.6**	**18.6**	**12.0**	**13.1**	**12.7**
	12.9	**17.7**	**16.5**	**11.0**	**12.4**	**11.1**
SH * 3	**15.6**	**16.4**	**15.9**	**12.0**	**12.1**	**10.6**
Sig: Pr > F	**IS**	**IS**	**S***	**IS**	**IS**	**S***

Legend: AP: Autumn Ploughing; SP: Spring Ploughing; SH: Spring Harrowing; S0: No Harrowing; S1: Harrowed in autumn; 1: Compaction in autumn; 2: Compaction in spring; 3: No compaction; S*: Significant; IS: insignificant.

In Table 8, both pF 4.2 vol % and wt. % showed significant (S*) difference at the 25 – 30 cm depth with compaction application (i.e. Pr > F). The trend remains the same in both pF 4.2 vol % and wt. % with the application of both tillage and compaction treatments (Tillage * Compaction) simultaneously. The other depths showed some differences in treatments but they were insignificant (IS).

Table 9: Grain yield (GY), Dry Matter Percent (DM %) and Water Content in Grain at Harvest (2010)

	Grain	Dry Matter %	Water Content
Tillage: AP	400.6	85.1	14.9
SP	369.1	85.2	14.8
SH	377.7	85.3	14.7
Level of Sign: Pr > F	S*	S*	
Stub. Cult: S0	380.5	85.2	14.8
S1	384.4	85.2	14.8
Level of Sign: Pr > F	IS	IS	
Compaction: 1	376.8	85.3	14.7
2	377.2	85.2	14.8
3	393.4	85.2	14.8
Level of Sign: Pr > F	S*	IS	
Til. * Comp.: AP * 1	392.5	85.1	14.9
AP * 2	403.1	85.0	15.0
AP * 3	406.1	85.2	14.8
SP * 1	361.0	85.3	14.7
SP * 2	359.7	85.2	14.8
SP * 3	386.5	85.1	14.9
SH * 1	376.8	85.4	14.6
SH * 2	368.7	85.3	14.7
SH * 3	387.6	85.3	14.7
Level of Sign: Pr > F	IS	IS	
Til.*Stub:AP*S0	403.8	85.1	14.9
SP *S0	367.1	85.2	14.8
SH * S0	370.8	85.3	14.7
AP * S1	397.3	85.1	14.9
SP * S1	371.2	85.2	14.8
SH * S1	384.6	85.3	14.7
Level of Sign: Pr > F	IS	IS	

Legend: AP: Autumn Ploughing; SP: Spring Ploughing; SH: Spring Harrowing; S0: No Harrowing; S1: Harrowed in autumn; 1: Compaction in autumn; 2: Compaction in spring; 3: No compaction; S*: Significant; IS: insignificant.

Grain yield (GY) and Dry matter percent (DM %) for the year 2010 were collected and recorded in Table 9. The individual results showed that both GY and DM % differ between treatments negligibly. This was reiterated from the results obtained from calculating the water content in grain yield at harvest for the various treatments, which exhibited minimal differences. However, both GY and DM % gave significant level of confidence (Pr > F) to tillage treatment, but only GY exhibited significant level of confidence (Pr > F) to compaction treatment.

Arvidsson* and Håkansson (2014) in their result stated that winter and spring crops have completely different growth situations because winter crops exhibits early growth due to cooler weather conditions than spring crops. Consequently, the effect of compaction on winter and spring crops differ due to environmental instead of botanical variations. Edling and Fergedal (1972); Voorhees (1987) suggested that crops are more vulnerable to soil densification under very moist situation than dry.

5. Discussion

The effect of different treatments on soil penetration resistance (kPa) in different depths is shown in Table 2. Tillage application showed significant effect on penetration resistance in depths 5-10 cm and 15-20 cm than the other treatments. In addition, stubble cultivation gave a notable soil strength resistance in the 10-15 cm and 25-30 cm depths respectively. The combined effects of both compaction, together with tillage and compaction treatments did not exhibit any remarkable resistance to penetration, despite their disparity in the result.

The unanticipated penetration resistancs (S*) shown at shallow depths of 5-10 cm with tillage treatment and 10-15 cm with stubble cultivation may be as a result of the formation of larger lumps of soil (Schulte-Karring, 1976) which were dispersed during tillage of the silty clay loam with 27 % available water. On the other hand, the significant penetration resistannce (S*) shown in depths 10-15 cm and 25-30 cm with stubble cultivation may be ascribed to the less effect of the tillage application on the subsoil.

The effect of standard wheel tractor used for land preparation is quite distinct. According to Van Huyssteen and Weber (1980), the initial traction of tractor wheels on top of a loose soil produces increased soil strength to an appreciable depth of 45 cm. This is shown in Tab. 2 in depths 5 – 10 cm and 15 – 20 cm with tillage cultivation. An additional pass over the same soil will affect the 0-15 cm depth only. This is also evident in Tab. 2 in depth 10 – 15 cm with stubble cultivation. The trampling impact of the tractor tires was also revealed in the difference in the soil surface. This implies that slight drop of 10 – 15 cm in the surface level of a profile during tillage means the same mass of clod was densely packed into a small amount thereby increasing its bulk density and strength. They, (Van Huyssteen and Weber, 1980) further stated that the restriction of deep root elongation resulted because of shallow soil tillage. To surmount re-densification, Schulte-Karring (1976) and Van Huyssteen and Saayman (1980) recommended subsoil loosening under field condition from track to track to an appreciable depth of 55cm.

Based on erosion evaluation on one-half of Norway's roughly 0.7 million hectares of cultivable land area, Børresen[1] and Riley[2] (2006) rated 17 % as highly eroded places while 6 % as very highly eroded land. They linked the soil removal process to tillage practices in autumn which makes soil at risk by water, particularly during snowmelt period. Since 1980, the outcome of different land preparation techniques on soil weathering (particularly erosion) have been evaluated in Norway (Lundekvorn, pers. Comm.), with autumn ploughing (i.e.the traditional common practice) as reference. The result suggests that for erosion risk averse, all tillage operations should be avoided in autumn. And for good cropping output, direct drill, for example, with winter wheat, which usually reduces erosion problems is feasible (Børresen and Riley, 2006).

Børresen (1993) suggested that higher aggregate stability could be as a result of higher OM content application. Harris et al. (1965) also indicated that OM creates ideal feeding condition for both micro- and macro-organisms (particularly earthworms), causing benificial effect on aggregate stability. It is evident that mechanical land preparation affects soil physical condition. However, direct drilling and minimum tillage occassionally result in higher bulk density, lower total porosity, lower air porosity at 10 kPa and higher available water content as compared to ploughing (Rydberg, 1987; Maikie Dawson and Morrice, 1988; Rasmussen, 1988). Furthermore, Schønning (1988), Riley (1983) and Riley and Ekeberg (1989) stated that redused air permeability resulted after minimum tillage practice.

Horn et al. (1995) categorised soils vulnerable to densification into three as: 1. “Sandy soil with single-grain structure” which moderately yields to soil densification, but does not result in serious destruction of the soil physical attributes / qualities. Tilling can restore such soil to its former structure. 2. “Soils of silt origin such as silty loams containing less collodial substances” and are readily compressed by outside forces / pressures. And 3. “Intermediate and fine-grained textured loam and clay soils” which resist machine-driven stress at low amount of water, but highly vulnerable to severely imposed pressure at high water availability.

According to observations from the various data analyzed, bulk density and penetration resistance are synonymous, in that, the consequences of bulk density are the same as those of penetration resistance. For instance, soil strength increases as bulk density increased (Taylor and Gardner, 1963), and as it (bulk density) increases, penetration resistance increased. Taylor and Gardner (1963) further vouched that penetration resistance is contingent on soil moisture content, soil suction, air-filled porosity and soil bulk density. It is known that an increase in soil strength will result in the decrease of the quantity of roots penetrating the said soil. Taylor and Gardner (1963) observed that root piercing through soil strength higher than 30 kg / cm^2 ceases except for a few soil-type. Taylor and Gardner (1963) and Taylor et al. (1966) reported similar outcome with cotton roots, which did not pierce soil strength higher than 30 kg / cm². But, they propounded that root elongation could be hampered by other factors limiting root penetration such as moisture content and bulk density when soil strength is below 30 kg / cm².

Bulk density in this investigation (see Tab. 5) ranges from 1.20 – 1.60 g / cm³. Blake (1965) asserted that bulk densities in the neighborhood of 1.55, 1.80 and 1.85 g / cm³ could restrict root elongation of most crops in clay loam, loam, sandy loam and loamy sand soils respectively. When soil strength increases, the number of successful root growth lessened in a specific soil. Nizami and Zia (1990) suggested a critical limit of 1.75 g / cm³ for bulk density that restricts root penetration. Veihmyer and Hendrickson (1948) reported similar results for root piercing in sandy soils. Nevertheless, Blake (1965) warned that modification of the critical limit of densification for diverse soils might emanate from clay minerals, iron cementation and particle density.

Because soil compaction primarily reduces soil pores (or soars soil densification), causing soil porosity increase (or reducing bulk-density) is an ideal practice of lessening / getting rid of the problems (Hamza[a,*] and Anderson[b], 2005). They suggested several ways of solving soil compaction problems: 1. Organic matter application to maintain soil water, which helps soil to recover compaction effects; 2. Controlled traffic may create and retain root zone for plant growth by concentrating compacted soils in the trafficked lane (Braunack et al., 1995); 3. Sub-soil tillage (deep ripping) gets rid of densification, destroys hard pans and mitigates hard setting soils (Whitehead and Nichols, 1992), and 4. Plant roots penetration occurring as daily (diurnal) changes in root diameter loosens and disintegrates any dense soil layer surrounding them.

The maximum bulk-density observed in this trial is 1.60 g / cm³, which is slightly above the minimum critical limit of 1.55 g / cm³ that restricts root penetration. Any hindrance to root piercing in the soils (i.e. silty clay loam and silty loam) at the experimental site may be due to the presence of clay minerals, iron cementation and particle density. In Table 5, it is observed that a minimum critical limit of 1.55 g / cm³ for bulk density, which may restricts root penetration, was attained in depth 25 – 30 cm with compaction treatment in spring (i.e. 1 * track by track with tractor). On the other hand, a maximum bulk density of 1.60 g / cm³ was attained in depth 25 – 30 cm with both autumn ploughing plus compaction in spring, and spring harrowing without compaction. These results could restrict plant roots piercing in silty clay loam and silt loam with circa 23 – 27 %

available water, thus hampering yield (Blake, 1965), even though there was no significant effect shown in the above depth according to the analysis in the results.

6. Summary / Conclusions

The premise that a specific change in soil strength, whether by tillage practices or not, results in specific root-growth pattern, if other developmental factors are not scarce (Taylor et al., 1966) is hereby submitted. Data to assess the above theory were collected and evaluated in relation to different depths through penetrometer resistance evaluation; aggregate size distribution and stability analysis; soil moisture determination and retention probe with respect to soil compaction and it related hindrances, and bulk density and it related measurements were all employed.

There are many factors affecting soil physical properties during long-term employment of mechanical cultivation on a specific piece of land. This action results in a soil with poor physical condition. As such, "there is a change in the volume of a given mass of soil otherwise refreerd to as a change in porosity" (Roa-Espinosa, unknown date) – thereby initiating the compaction process. Soil compaction can inhibit crop growth and reduce agricultural output in many ways. Despite the fact that understanding the occurrence and reduction of compaction in soil are important, it is note-worthy to associate them with crop yield output.

In this investigation, the various methods used to assess the soil's physical condition showed negligible results among treatments save few. For instance: **a)** Tillage in depths 5 – 10 cm and 15 – 20 cm exhibited significant penetration resistance (Pr > F), and stubble cultivation in depths 10 – 15 cm and 25 – 30 cm gave significant penetration resistant (Pr > F); see Tab. 2 in results. **b)** Tillage application gave significant aggregate size distribution percent (Pr > F) with fraction 6 – 20 mm; see Tab. 4 in results. **c)** Compaction application showed significant volume percent (Pr > F) for pF 4.2 in depth 25 – 30 cm, and significant percent (Pr > F) for pF 4.2 in the same depth. With the application of both tillage and compaction treatments, pF 4.2 volume percent showed significant result (Pr > F) in depth 25 – 30 cm, and pF 4.2 weight percent gave similar outcome (Pr > F) at the same depth; see Tab. 8 in results. **d)** The sum of aggregate stability for fractions 2 – 6 mm and 0.6 – 2 mm gave total weight percent greater than 50 with all the treatments. This indicates that the aggregates are ideal for seedbed preparation; see Tab. 4 in results.

Considering the above summaries, one may argue that the treatments herein utilized, if applied to ameliorate compaction problems, should be used in conjunction with other processes relevant in creating soil with good physical condition because no specific remedy has been shown ideal for compaction reduction. Roa-Espinosa (unknown date) described soil with good physical condition as "containing 50 % solid materials, 25 % water and 25 % air". This concords with the total aggregate stability obtained in weight percent shown for both fractions (2 – 6 mm and 0.6 - 2 mm) in Tab. 4 in results. Alternative measures to improve soil physical condition could be the use of OM as recommended by Børresen (1993), and butteressed by Harris et al., (1965) which results in positive effect on aggregate stability. Avoid subsoil compaction by reducing wheel loads which imposes stress on sub-soil layers (Berisso et al., 2012), and minimize evaporation by utilizing straw or mulch on or near soil surface to boost grain output on the average (Børresen, 1999).

In these investigations on a silty clay loam and a silt loam soil at UMB / NMBU, the treatments (i.e. tillage, stubble cultivation and compaction) in autumn and spring gave few differences in the results as shown in Tables 2 – 8. The yield was no much different especially GY, DM % and water content in grain at harvest. This could be as a result of the resistant of the above mentioned soils to spring harrowing and spring plowing in shallow depths at low water content. The sum total of aggregate stability increased thereby creating ideal soil for seedbed preparation.

One could conclude that to improve the productive capacity of the experimental site, minimum tillage and no ploughing, couppled with straw cultivation in spring seems to be a suitable practice for the silty clay loam and the silt loam soil at the site. Furthermore, a more integrated research work needs to be done by pedologists, agricultural engineers and agronomists aimed at altering the existing tillage practices. In light of the above, new land preparation methods based on climatic conditions, soil types, varietal adaptation and the inclusion of local knowledge into low-input farming systems may result and be introduced to farmers. Perhaps, with such integrated knowledge, compaction problems shall be ameliorated, crop yields improved and farming systematized.

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