Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

**Faculty of Landscape Architecture,
Horticulture and Crop Production Science**

Effect of soil tillage system and straw retention on soil aggregation and water capacity

Jordbearbetningssystemets och halmhanteringens effekter på jordaggregering och markens vattenkapacitet

Emma Lindqvist

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Emma Lindqvist

Supervisor: Linda-Maria Mårtensson, Department of Biosystems and Technology, SLU

Co-supervisor: Vaclovas Bogužas, Institute of Agroecosystems and Soil Sciences, Aleksandras Stulginskis University (ASU), Lithuania

Examinator: Sven-Erik Svensson, Department of Biosystems and Technology, SLU

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Department of Biosystems and Technology

FOREWORD

Agricultural and Rural Management Programme, at SLU, is a three-year university education which comprises 180 credits (ECTS). One of the compulsory elements in this is to implement one's own work to be presented with a written report and a seminar. This Degree Project can e.g. have the form of a smaller trial that will be evaluated or a summary of literature which should be analysed. The effort must be at least 10 weeks full-time (15 credits).

The idea for this study came from Professor dr. Vaclovas Bogužas, Agro-ecosystem and soil sciences institute, Aleksandras Stulginskis University, ASU, Lithuania, who also co-supervised the work.

Warm thanks are expressed to Vaida Steponavičienė (PhD student, ASU) who allowed me to do my Degree Project along with her project; Aušra Sinkevičienė, Aida Adamavičienė and Rita Mockevičienė that helped me with the analyses and guidance in the laboratory in Aleksandras Stulginskis University.

Lecturer, Sven-Erik Svensson, SLU Alnarp, has been the examiner.

Alnarp, October 2015

Emma Lindqvist

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SUMMARY

Arable land supplies food and it is therefore important to develop the production and land-use in a sustainable way. To grow crops for food should be both economical and environmentally sustainable and the soil structure and quality should be taken in consideration when cultivating our land. We need to find new approaches to maintain good soil structure, and minimized tillage systems have many advantages, including costs for the growing of crops, while leaving straw in the fields can reduce erosion and increase the biological activity and humus content of the soil.

The texture has two important physical properties when it comes to indicate the soil quality those are aggregate stability and size distribution. The particle size distribution is the most essential physical property which defines the soil texture, and influences the soil properties the most. These two physical properties mentioned above reflects the resistance of soil erosion, especially in no-tillage system, which is why they are the most important factors when it comes to soil quality.

The soil structure defines which different types of particles that are stored in the soil and it exert control over the physical, biological and chemical processes. It also explains how and where the particles are located, which is important for how suitable the soil is for growing crops. If the soil has a poor structure, it can affect the nutrient availability and the nutrient uptake negatively and increase the power requirement for tillage, increase the nutrient loss and the denitrification, which is negative from an environmental point of view. Organic matter, tillage system, biological activity etc. matters for the aggregate structure in a soil. There are natural structure building processes, such as root development and drying, but there is also structure depleting processes, which basically all the human activities are. A non-cultivated soil generally has a better structure due to the generally higher content of organic matter and less compaction than a cultivated soil has.

Soil structure is being influenced by soil and crop management inputs and has an impact on soil quality. One of the factors that influence the quality is tillage. This input is an important factor and relevant in the point of sustainability, that is why the quality of the soil is depending on the choices of human activities. A soil with higher proportion of clay and humus usually increases the stability of structure and aggregates. Aggregate stability is characterized by the sensitivity to external influence. The essence of aggregate stability is the organic matter, because large parts of plants and roots acts like a barrier and prevent aggregates to break into smaller units with help from decomposing of microorganisms that provides with an adhesive effect. The factors that influences the soil aggregate stability is soil texture, soil structure, the different types of clay minerals, the content and different types of organic matter, cementing agents and which kind of crops that were grown through the history. Permeability is the property of a material that lets fluids to diffuse through the medium without being affected chemically or physically, that is the soil´s capacity to drain off water.

The structure of a soil is influenced in both long and short term of tillage and cultivation measures, which in turn affects the soil physical properties. Vegetation and recycling of organic matter contributes to a better structure and physical environment. Soil

cultivation measures do the opposite, even though tillage contributes to structural stabilization and structural-building processes. If the structure should be improved, the structure-building measures needs to be greater than the structure depleting measures. Adding organic matter can preserve soil structure and increase the crop safety. Measures to improve the structure and provide better conditions for the crops, is to return straw and crop residues to the soil, grow cover crops in the autumn and only apply shallow tillage, which could increase the humus content in the top layer. Increased humus content will give a lower bulk density, increased aggregate stability and increased porosity, which in turn give the soil increased water holding capacity and infiltration capacity. The macro pores is responsible for the soils capillary ability, it provides the plants with available moisture. If the moisture is in the narrow pores, micro pores, the plant roots needs to develop an increased suction force to be able to absorb the moisture. The greatest amount of plant available moisture is found in silty loam soils, while the soil with the least amount is sandy soils because of their inability to bind water due to its larger particles. Heavy rains can also damage the aggregates in the topsoil if the soil is uncovered or unfrozen, which is why organic matter and straw incorporation could prevent damage of this type.

Ploughless tillage and direct drilling gives favourable structure development in the topsoil, and green manure and cover crops are often suggested as effective methods to increase the organic matter, along with reduced tillage system. Though, the experiment at Aleksandras Stulginskis University in Lithuania shows that no-tillage system has the highest level of compaction of the soil compared to deep ploughing system. On the other hand, another experiment in Sweden, with ploughless tillage and straw incorporation, has showed that ploughless tillage system gives a reduced compaction, though; straw treatment are facing problems, such as “straw stops” while cultivating the soil with different tillage methods. If the straw should be incorporated, it needs to be finely chopped and evenly spread evenly over the field.

At Aleksandras Stulginskis University in Lithuania, a long-term field experiment has been running since 1999 in the Experimental Station, Kaunas district. The experiment is made by six different tillage systems: deep ploughing; shallow ploughing; shallow loosening with sweep cultivator and disc harrows; shallow loosening with rotor cultivator; catch crops & green manure incorporation with rotor cultivator; and no tillage. Another factor of this experiment is about straw incorporation and straw removal in the different tillage systems. The soil type of this field is sandy loam. The soil samples have been analysed in the laboratory of Aleksandras Stulginskis University to investigate which impact the different tillage systems and straw incorporation or straw removal have on the soil aggregate stability, soil structure and water capacity. The experiment showed that with straw incorporation in 0-10 cm depth there were less micro aggregates than in the treatment were straw was removed. The aggregate stability was higher in 10-25 cm depth with straw incorporation compared to straw removal. Shallow loosening was the treatment which gave the highest bulk density in both depths, which means that the soil with this treatment was more compacted than with deep ploughing. No-tillage treatment had lower bulk density in the deeper layer, which means that this soil had more porosity. Deep ploughing had a tendency not to be able to hold a high amount of water at 0-10 cm depth, up to -300 hPa, while no-tillage treatment in the deeper layer could hold water the best at lower pressures. In the treatment with shallow loosening, the porosity decreased, while in the no-tillage treatment the porosity increased.

INTRODUCTION

Background

When we grow crops there are many aspects that need to be reviewed, such as e.g. time, labour, fuel consumption and maintenance costs. But it is not just the economic terms of equipment and staff that should be taken into account, but also the soil structure and quality, erosion and soil compaction as some examples. Intensive tillage depletes the land we grow and the soil quality decreases. We need to find new approaches to maintain good soil structure, e.g. with less overpasses and tillage systems that allow the soil to build up a natural protection against conditions such as erosion and structural degrading factors, as an ecological sustainable precaution. A minimized tillage system has many advantages, including lower costs for the growing of crops, as an economical factor of sustainability. It reduces number of passes and degree of compaction of the soil. Moreover, if straw is returned to the fields it can reduce erosion and increase the biological activity and humus content of the soil, which gives a better soil structure, water infiltration and a better nutrient utilization for example.

Arable land is a food supply, and it is therefore important to include the aspect of sustainable development while cultivating our soil. To grow crops for food should be both economically and ecological sustainable, and it is therefore important to cultivate the land to retain a good food supply and social sustainability to meet the consumer's needs and the awareness of a sustainability of today.

At Aleksandras Stulginskis University in Lithuania (ASU), a long-term field experiment was established in 1999 in the Experimental Station, Kaunas district, at 54º52'50 N latitude and 23º49'41 E longitude. The experiment is made by six different tillage systems and straw incorporation, and it hope to prove the effects of intense and reduced tillage systems, and demonstrate the differences in, for example, soil structure between the different treatments. Soil samples are from 2013, when winter wheat was grown, and preceding crop was spring oil seed rape.

Aim

The aim of the experiment is to investigate the differences in structure and organic matter with different tillage systems, and also with straw incorporation or straw removal. We want to investigate if the straw incorporation has a positive effect of the soil, along with reduced soil tillage. The investigation includes soil aggregate stability, water capacity and soil structure. The aim is to make a characterization of soil properties in different tillage systems.

Objective

The objective of the experiments is to prove that with reduced tillage it may be possible to spare the land and its structure, to increase the organic matter content and to improve the quality of the soil. The objective is also to prove that straw incorporation will increase the soil structure and water capacity, better than if the straw has been removed.

Delimitation

The delimitation of this work is that I have not included or calculated any costs of the different tillage systems, this work is focused on soil qualities and no expenses has been included. Because of the limited time in this Degree Project, I and my supervisor at ASU agreed that this work should include the soil structure, aggregate stability and water capacity.

LITERATURE

Soil characteristics

Soil texture

An important characteristic factor of soil is the distribution of particle size, the texture, which has an effect of many properties of a soil *(Eijkelkamp…, n.d.; Dexter, 2003)*. It can be for example the ease of tillage, available moisture, the capillary conductivity of the soil and compaction. It is very important to determine the particle size in order to assess the availability of substances for flora and fauna and the behaviour of substances in the soil, as well as to determine the quality of the ground. *(Eijkelkamp…, n.d.).*

The particle size distribution is the basic and most essential physical property of a soil, which define its texture. The size and its relative abundances influence a soils physical property the most *(Skopp, 2012).* To evaluate the effects of soil and crop management, especially for practices like no-tillage, two important physical properties of a soil has been suggested as indicators of soil quality, these two are aggregate stability and size distribution. They reflects the resistance of soil erosion, especially in no-tillage *(Karlen, n.d.).*

There is a classification system to determine the particle size and give the classification of the soil due to the particle size distribution. Though, the size boundaries can vary between country and discipline, which means that different techniques can be used to determine particle size and the same identical particle may appear to have different diameters in these different measurement equipment *(Skopp, 2012).*

Soil structure and aggregation

The definition of soil structure is the manner in which different types of particles is stored in soil and how they are interconnected in a three dimensional arrangement *(Johansson, 1992)*. Soil structure is the organization of soil particles which exerts control over physical, chemical and biological processes. For example, it controls the root penetration, transport and storage of liquids *(Ghezzehei, 2012; Roland, 2003)*, gases and heat; decomposition and storage of organic matter as well as the soil penetration of the microbial life *(Ghezzehei, 2012).* This applies both to the soil as a whole but also for the detailed layers. In simple terms; it is the soil structure that explains how the soil is constructed *(Johansson, 1992)*, and also the size and location of pores and particles in a soil, which has a great significance for how suitable the soil is for crops to grow *(Ehrnebo, 2003)*. Soil structure can be described as form, stability and resiliency. The form describes the arrangement of solid and void space, arrangement of primary soil particles in hierarchical structures, pore size distribution, total porosity and continuity of pore size. Stability is the ability to keep the arrangement between solid and void space while the soil is exposed to different stresses. Resiliency describes processes like tilt-mellowing, self-mulching and age hardening *(Karlen, n.d.)*. Soil structure must be favourable for the cultivation and aggregates should be shaped and assembled in a way so that the plants' development is not impeded. They can be inhibited if the soil structure is damaged and water and air movement in the soil deteriorates. If the soil is too wet, the plants may suffer from lack of oxygen while in a dry condition they may suffer from drought stress. This can then lead to harvest reduction in adverse conditions. Even nutrient availability and nutrient uptake can be negatively affected if the soil structure is poor, as the plants cannot assimilate the nutrient if the soil structure is poor. Even if there are enough nutrients in the soil, the plants may suffer from nutrient deficiency if the soil structure is not good and the nutrient losses and denitrification may increase. It is not only nutrient deficiency and inhibited development that may occur in poor soil structure, but also increased power requirement for tillage. This may result in lower yields, lower energy efficiency and reduced nutrient utilization, which is also negative for the environment *(Roland, 2003)*.

The building elements in the soil, the material, consists of primary soil particles that is either composite or secondary particles as an aggregate, humus, dead plant residues etc. *(Johansson, 1992)*. Mineral particles together with the organic material are the building material in the soil, such as walls in a house, and the cavities between are the pores in the soil. The ways in which these materials are arranged, characterize soil structure *(Gustafson-Bjuréus & Karlsson, 2002)*. Soil structure can be described as a spatial arrangement of primary particles, for example, there is single-grained structure and massive structure *(Ghezzehei, 2012)*. If the particles are independent of each other and do not bound to each other, these soils are called single grain structure, such as sandy soils *(Gustafson-Bjuréus & Karlsson, 2002; Johansson, 1992)*. Aggregate structure means that these particles are not independent and therefore are linked and form aggregates, such as clay and silt soils *(Gustafson-Bjuréus & Karlsson, 2002)*. The single-grained structure is particles of sand or silt with little cohesion and is called structure less *(Ghezzehei, 2012)*, and the massive structure is clay with no discernible internal features which is linked in a large mass without cracks or voids visible *(Ghezzehei, 2012; Johansson, 1992)*. This massive structure is found mostly in the topsoil but also in the upper part of the subsoil on a compaction damaged clay soil. Ploughing or disking on a dry loam with such structure can provide so-called clods *(Johansson, 1992)*. Both of these structures is extremes in a total opposite way, and in between these there is aggregates *(Ghezzehei, 2012)*. Aggregates is formed by partly stable particles of different sizes and shapes, such as clay or/and humus, and soil structure is usually described by soil aggregates *(Ghezzehei, 2012; Johansson, 1992)*. These assemblies have typically different sizes, shapes and stabilities, and these properties usually vary with depth. Rough texture, or so-called macro-structure, is the structure we can see and feel. But behind this we find the fine structure, microstructure, which can only be revealed with the physical and chemical analysis methods *(Johansson, 1992)*.

Soil structure is a hierarchical arrangement of soil aggregation *(Ghezzehei, 2012; Karlen n.d.)*, with primary clay particles (smaller than 2 µm), also called colloids, in the lowest order of the hierarchy. These clay particles attracts each other by their identical ion charge and bonds into clay domains, and if these clay domains bonds with sand- and silt particles they will form clusters (2-20 µm) *(Ghezzehei, 2012; Melakari, 2005)*. The colloids are joined together into aggregates which make this structure stable. These soils have negatively charged surfaces and therefore bind positively charged ions to themselves, such as potassium (K^+) *(Ehrnebo, 2003; Melakari, 2005)*. This allows the bonds between the clay particles becomes strong, the particles adheres more strongly to each other than to other adjacent particles *(Kemper & Rosenau, 1986; Melakari, 2005)*, and stability of aggregates is a function which shows the cohesive forces between the particles without breaking from disruptive forces around them *(Kemper & Rosenau, 1986).* This process is called coagulation and is the first stage in aggregate formation. The next step is through dehydration, which pulls the aggregates closer together and the bond becomes even stronger *(Ehrnebo, 2003)*. Silt particles bonds with colloidal particles, such as clay domains, iron- and aluminium oxide and organic colloids. If a soil does not contain colloidal components, it normally cannot form aggregated soil structure *(Ghezzehei, 2012).*

When clusters and silt particles bond with a persistent binding agent, such as humified organic matter, oxides and aluminosilicates, it results is micro aggregates (20-250 µm). Macro aggregates are formed by bonding between micro aggregates and weak bonding agents, such as hyphae of roots and fungi and labile organic matter, which means that the strength and porosity is greatly influenced by soil management practices *(Ghezzehei, 2012).* Macro aggregates can be formed both through desiccation by plant roots, through the permafrost and the organic material *(Ehrnebo, 2003; Karlen n.d.)*. Desiccation occurs when plants take up water from the soil and small soil particles are pulled together tighter. When the frozen ground dries up after a siltation or soil compaction, it provides a more compact structure when cracks are formed in the ground *(Ehrnebo, 2003)*. The macrostructure can also be stabilized by organic material, the aggregates are held together by a fine network of live or partially decomposed roots and fungal hyphae *(Ehrnebo, 2003; Karlen n.d.; Melakari, 2005)*. The material must be constantly renewed because it is subjected to degradation by microorganisms in the soil and therefore the aggregation is especially sensitive to the effects of different cultivation measures *(Ehrnebo, 2003)*. Other processes that make aggregates formation is surface coating of various organic compounds, in particular polysaccharides, which are formed when microorganisms break down organic matter *(Ehrnebo, 2003; Melakari, 2005).* Also earthworms have a positive effect on the structure, when they eat their way through the earth and dig tunnels, earth kneaded then in their guts to aggregate and encapsulated in mucus. Earthworms are also of great importance for the permeability and the plant roots. *(Ehrnebo, 2003; Karlen, n.d.)*. Mechanical soil disturbance, such as soil tillage, usually degrades the weak bonds between micro aggregates and the abundance of macro aggregates is lost *(Ghezzehei, 2012; Melakari, 2005),* while the abundance of micro aggregates increases. The benefit of this process is that micro aggregates contain fine pores, which acts as a water reservoir for the seeds and provides oxygen *(Ghezzehei, 2012).*

To have too high aggregate strength gives a hard overworked soil and an impaired root growth, a lower strength of 8-16 mm aggregate makes it easier to get a good seedbed because the aggregates can more easily fall apart during tillage. A seed bed should preferably have more than 50% aggregate of over 5 mm at its surface. Aggregate strength is high in a soil with a high clay content, while a soil with a high humus content has low strength *(Ehrnebo, 2003)*.

It is more than just the content of organic matter which matters if a soil has aggregate structure, such as tillage, frost heaving, drying up and microbial activity *(Gustafson-Bjuréus & Karlsson, 2002)*. The structure of a soil changes over the years, but may also change over individual years due to human factors or natural phenomena. Frost, root development and drying are examples of natural processes, which act as structure-building. In contrast, human actions are usually structural depleting. The changes are greatest in the topsoil, however, clay soils has greatest variation with time and depth. Soils that have the same mineralogical and textural composition may still have different current structure at any given time *(Johansson, 1992)*. Soils with weak aggregate structure has high sensitivity to external influences, and non-processed soils generally have better structure due to the generally higher proportion of organic material and less compaction than a processed soil has *(Gustafson-Bjuréus & Karlsson, 2002)*.

Soil structure is not really a measurable property, but more of a qualitative concept. How soil acts, therefore, depends more on the characteristics and conditions that the soil structure creates, such as pore system design and aggregates stability *(Johansson, 1992)*. For the soil to be a good environment for roots and plants to grow in, it is important that the ground contains large or relatively large pores, called macro pores *(Johansson, 1992; Kemper & Rosenau, 1986)*. Examples of such can be wormholes, old root canals, stable cracks or voids between the larger aggregates *(Johansson, 1992)*. After growing a crop, the soil contains an abundance of macro pores, and if these will consist is depending on the stability of the aggregates. The higher stability of aggregate a soil has, the lower the degree of erosion will be (*Kemper & Rosenau, 1986)*. If these voids are coherent it can result in a good permeability and high infiltration capacity for water, and also the rapid run at large quantities of water, for example during spring. It also provides a good aeration of the soil and the rapid growth of deep roots even in wet conditions *(Johansson, 1992)*. Macro pores will generally favour the infiltration rate and aeration of the soil (*Kemper & Rosenau, 1986)*.

A soil with good soil structure should have the ability to dissipate excess water, supply plant roots with oxygen, easily processed and withstand external loads such as external pressure or precipitation. This provides the opportunity for good crop establishment and root growth. If excess water cannot be removed, this can damage the crop when the water blocks the pores that would otherwise act as air channels and supply the roots with oxygen. Roots consume large amounts of oxygen, and water blocking these channels may lead to that roots gets hypoxia. These anaerobic conditions can also lead to, among other things, nitrogen losses and leakage of particle-bound phosphorus. A soil with good soil structure gives the roots opportunity to establish themselves through the soil profile, and that it is not clogging during heavy rainfall which causes crusting. At crusting it hinders the plants from getting up through the soil. If the soil is easily worked, farmers can work the soil without excessive energy input, and therefore it is important to optimize these properties of the soil that makes it easy to use *(Ehrnebo, 2003)*. Other properties that also depend on the pore size distribution, which affects the structure, is water retention capacity and air volume at the drain equilibrium, known as field capacity. The water content at wilting point and capacity in plant available or accommodated water is affected by this. It is also important that the soil has a relatively dense network of carrying air pores, especially in the root zone which we find below the growing crop, to provide the crop with gas and oxygen while growing, so called gas exchange and oxygen supply *(Johansson, 1992)*.

Soil structure can easily be influenced by soil and crop management inputs, and that also have an impact on the soil quality. The practices that influence the soil structure may be tillage, fertilization, pest management and different other practices, and all of these are important and relevant for agricultural sustainability. Soil structure is a very important factor for soil quality and is very responsive to human activities. Therefore, it is important to consider all of these practices because management factors that affect soil structure also effect the soil quality *(Karlen, n.d.)*. The structure in the soil is continuously exposed to destructive processes, mainly in the surface layer and topsoil. Increased clay and humus content usually results in increased stability of the structure and the aggregates *(Johansson, 1992).* Aggregate stability is characterized by their sensitivity to external influence. The essence of aggregate stability is organic matter, large parts of plants and roots acts as a barrier and prevents aggregates to be divided into smaller units. When fresh organic matter decomposes, microorganisms secrete polysaccharides and other metabolic waste products that have an adhesive effect, which contributes to a better aggregate stability. Even iron oxides, aluminium oxides and carbonates have an ability to stabilize the aggregates *(Gustafson-Bjuréus & Karlsson, 2002).*

Soil structure is an important characteristic for farmers, since it is one of the main factors which are controlling plant growth by its influence of root penetration, water transport, soil temperature, gas diffusion, among other things. There is a few things that has an influence on the aggregate stability, such as soil texture, soil structure, the different types of clay minerals, organic matter content and which type of organic matter, cementing agents and which kind of crops that has been used through the history. There are some destructive forces, for example mechanical, which can be soil tillage, heavy machinery, treading by animals and other things that can bring the structure of the soil down. The physicochemical forces can be slaking, swelling and shrinkage, dispersion or flocculation. Slaking is a process of structure breakdown that may lead to the formation of a superficial crust under the influence of wetting the soil aggregates. When the aggregates have been wetted, the clay minerals may swell, the cementing agents may dissolve, it may lead to air explosion and/or a reduction in pore water suction. This can also result in a reduction of water infiltration and increase the sediment loss by downward transportation with surface runoff water *(Eijkelkamp…, 2008).*

In order to make a determination of aggregate stability of a soil, it should be exposed to disintegrating forces to represent phenomena that occur in the field. It measures the amount of aggregates in weight, which breaks down into primary particles and aggregates, which usually is made by sieving or sedimentation *(Kemper & Rosenau, 1986).*

Since the aggregate stability has a major impact on plant growth and soil losses, a wet sieving apparatus can be used in order to make a determination with regard to soil conservation, such as erosion, land degradation and to promote sustainable agriculture. The information that this device provides, allows us to understand the sensitivity of the soil for water and wind erosion, and how we can improve soil preparation and customize it according to soil type and crop requirements. It can give us indications on aggregate stability and if that needs be improved, which will allow us to improve the quality of the soil with the help of this information *(Eijkelkamp…, 2008)*.

Bulk density

Bulk density indicates a soils' compaction and it reflects the soils' ability to function for soil aeration, water movement and to support the soil structure (*Arshad et al, 1996).* Bulk density is calculated in order to understand the relationship between the solid particles and pores *(Gustafson-Bjuréus & Karlsson, 2002).* To calculate the bulk density, the soils' dry weight has to be divided by its volume, which includes the volume of soil particles and the particles pore volume. Bulk density is usually given in g/cm^3. If a soil has too high bulk density it indicates that the soil has low porosity and is compacted, which may cause bad conditions for root development and poor air and water movement. That could result in poor plant growth and cause decreased crop yield (*Arshad et al, 1996).* Soil compaction leads to increased bulk density, which means that the porosity decreases, especially within the macro pores. The macro pores stand for the main air and water transport in the soil profile. The compaction rate shows the percentage difference between the bulk density in the field and after the soil is compacted with a specific pressure (kPa) *(Gustafson-Bjuréus & Karlsson, 2002).* If the soil is compacted the runoff and erosion may increase because of the reduced water infiltration. If the soil has been ploughed or disked on the same depth for a long period of time, it could give a poor bulk density, as well as crop residue removal or limited crop rotation that does not have any variation of root depth or root structure over the years (*Arshad et al, 1996*). It is established in several studies that the bulk density in the topsoil central and lower parts increases at a ploughless tillage system, due to that the tillage depth is less, and these parts are not as loosened as in a ploughing system *(Roland, 2003)*. A solution of the problem with poor bulk density is to decrease the soil disturbance, such as applying reduced tillage system (*Arshad et al, 1996*). Another solution to provide the soil with better bulk density is to increase the soil organic matter (*Arshad et al, 1996; Gustafson-Bjuréus & Karlsson, 2002*), for example by using cover crops, returning of crop residues and apply perennial crops in the crop rotation (*Arshad et al, 1996).* Low bulk density and high humus content are often linked because the humus content has a certain dilution effect as it weighs less than mineral particles *(Gustafson-Bjuréus & Karlsson, 2002; Roland, 2003).* Ideal bulk density varies depending on the soil type, for example soil with sandy soil texture is < 1.60 g/cm^3 (*Arshad et al, 1996*).

Water capacity

Permeability

Permeability is the property of a material that lets fluids, like water, to diffuse through it to another medium, but without the material being affected chemically nor physically itself *(Business Dictionary. n.d.).* Permeability is a soil's capacity to drain off water, and it is measured by a permeability coefficient (K-factor), which is determined by the complex of pores, the structure and texture of the soil, and also the soil solution, such as viscosity and density. The permeability of a soil that is saturated is referred as saturated permeability, and the compactness of the soil along with expansion, contraction, occupation of the absorption complex of minerals affects the permeability of a soil. It is during a geohydrology research that the saturated permeability is determined, and it is important to have an understanding of the prevailing hydrological conditions in order to protect the environment *(Eijkelkamp…, 2013).*

It is important to have good permeability of a soil to excess water to drain off and led it away quickly. The permeability depends largely on the amount of macro pores, such as cracks, degraded roots, passageways and channels from worms' activity, present in the soil. These are also important for the air circulation in order to oxygenate the roots

(Ehrnebo, 2003). Capillarity and permeability largely depends on the pore size and pore volume, e.g. in fine-grained soils, the permeability reduces with the reduced degree of saturation, while in coarse-grained soils, the permeability is influenced mainly by grain size. However, no correlation between grain size and permeability is useful in clayey soils *(Larsson, 2008)*. The permeability of the lower part of the topsoil (25-30 cm), is positively affected by a ploughless tillage system, due to that in a system with ploughing it becomes a plough sole in the transition zone between topsoil and subsoil when the tractor wheels pack the soil *(Roland, 2003)*.

Field moisture

The maximum moisture a soil can hold when a saturated soil drains out the free water from the macro pores to deeper soil layers with gravitational force is called field moisture. It takes various amount of time for the field moisture limit to be reached, depending on the soil type. For a sandy soil it may be achieved within a day, while for a clayey soil it can take seven days or more. There is no common limit of suction force that the field moisture is corresponding to, but pressures between 50 – 500 hPa is often used. Though, in Lithuania, on its loamy and sandy soil, 100 hPa (2.0 pF) is commonly used, which corresponds to 1 meter water column (0.0098 bar), and maximum soil pores that contains water is 30 µm in diameter. Micro pores that has a diameter of 30-2.0 µm in water is called capillary or plant available soil moisture. The quantity of water that remains in the soil in field before the plants is wilthing is called humudity limit. The gravitational water content of the soil depends on the amount and size of macro pores, the capillary force between water and soil and between the water molecules. The greatest amount of available moisture that plants can accumulate is in silty loam, while the least amount is in sandy soils. If the moisture is retained in more narrow pores (micro pores), the plant roots need to develop an increasing suction force to be able to absorb the soil water content. If the moisture remains in <0.2 µm (micro pores), the soil particles suction force becomes greater that the plant root‘s force, and the plants begin to fade. This is when the plant wilthing humidity limit has been reached *(Kadžienė & Feiza, 2012)*.

Water content

Soil water content can be expressed either in a volumetric or gravimetric basis *(Bilskie, 2001)*. The volumetric water content, also called the volume wetness or volume fraction of soil water, is measured by the total volume of soil that is occupied by water in the soil *(Yu et al, 1993)*, the mass of water per mass of dry soil *(Bilskie, 2001)*. To calculate the volumetric water content in a soil, the water in the soil sample has to be divided by the total volume of the sample *(Yu et al, 1993; Bilskie, 2001)*. The water content is measured in $m^3\ m^{-3}$, which means how much of a cubic meter that contains water out of the entire cubic meter of the soil sample. It may also be expressed in percentage *(Measurement Engineering Australia, 2015)*. The gravimetric water content is expressed as the volume of liquid water per volume of soil and it is a ratio of the mass density. To calculate the gravimetric water content in a soil, the volume of water has to be divided by the volume of the soil. The water content shows how much water is present in the soil, which can provide us with information about how much water is stored in the soil profile. With this information we can estimate how much irrigation is needed to reach the right water content in the soil. Gravimetric volume content, volumetric water content, soil bulk density and soil porosity is all connected to each other. To find out how much maximum possible volumetric water content there is in a soil, it has to be calculated as follows: first the gravimetric water content need to be calculated, out of the mass of water divided by the mass of soil. The next step is to calculate the soil bulk density, the mass of dry soil divided by the volume of the soil sample. Then the volumetric water content has to be calculated, the gravimetric water content multiplied by the soil bulk density. The final step is to calculate the soil porosity, which is the soil bulk density divided by the density of the solid fraction (approximated by the value 2.6 g cm^{-3}). The sum of the last step will give a number, for example 0.50 porosity, which means that the maximum possible volumetric water content is half of the sample (*Bilskie, 2001).*

A soil's capillary properties can be displayed through a water retention curve, pF curve, which calculates water transport and leachate formation during unsaturated conditions, as well as soil water retention capacity. The amount of water that is bound in the pores of the soil affects other soil properties, such as resistance and compaction properties. To determine how the retention curve appears for a soil, the soil sample is placed in a pressure chamber on plates or membranes with atmospheric pressure. When the pressure increases the pore water is being pressed out of the soil sample until equilibrium present themselves at the current pressure. The water which remains in the sample is the water that is retained by capillary force, and the remaining water content is determined by weighing *(Ezziyani & Holmén, 2009)*. The soil moisture content depends on the soil type, for example, a saturated coarse, sandy soil cannot hold as much water as a saturated heavy clay soil can. That is due to the fact that a sandy soil has larger particles which take up more place than the particles in a clayey soil. A sandy soil cannot bind water either, that is why a lot of water will drain out as well *(Measurement Engineering Australia, 2015).*

Calculations of water content

To calculate the moisture content, $m^3\ m^{-3}$, in samples with *undisturbed structure*, this formula can be used:
$\mathbf{\Theta_v = M_w/V_t}$ M_w = soil water weight (g),
V_t = sample volume

which is calculated according to this formula:
$\mathbf{M_w = M_{t+a} - M_{s+a}}$ M_{t+a} = total weight of soil sample moist (soil + cylinder),
M_{s+a} = absolute dry weight, in oven 105°C (soil + cylinder)

To calculate the moisture content, $m^3\ m^{-3}$, in samples with *disrupted structure*, this formula can be used:
$\mathbf{\Theta_v = \Theta_m * \rho_b}$ Θ_m = gravimetric soil moisture content
ρ_b = dry soil bulk density

Gravimetric soil moisture content can be calculated with this formula:
$\mathbf{\Theta_m = M_w/M_s}$ M_s = Absolute dry soil weight, in oven 105°C (g)

Dry soil bulk density, $Mg\ m^{-3}$, can be calculated with this formula:
$\rho_b = M_s/V_t$

Influence of tillage- and cultivation measures

The soil structure is influenced in both long and short term of tillage and cultivation measures and thus affects the soil physical properties. Vegetation and recycling of organic matter contributes to better structure and therefore its physical environment, while processing measures does the opposite. However, tillage contribute to structural stabilization and structural building processes *(Johansson, 1992).* Our cultivated soils have largely deteriorated physically just in a few decades, primarily through intensive cultivation of the ground and unilateral modes of operation. In many cases, the return of manure has been low and we use deeper ploughing, which mainly affects the humus content negatively. With increased mechanical stress in the form of heavy machinery and more torque, this has damaged the topsoil and in many cases also the subsoil. These negative factors have together resulted in poor drainage properties and permeability, poor root development, water supply, nutrient utilization, uncertain crop establishment, etc. *(Johansson, 1992).* Tillage may cause sorting of aggregates in the soil, the smaller aggregates tend to sink to the bottom, while the larger rise to the surface of the tilled layer. This means that the continuity of pores decreases in the various layers with tillage and can also create a compacted zone at the base of the tillage layer. Surface tillage may also disrupt earthworm burrow and can reduce crop residue at the ground surface. This may increase the risk of water runoff and soil erosion. *(Karlen, n.d.)*. Tillage can also lead to more rapid degradation of the organic material, resulting in unstable aggregates *(Roland, 2003)*. All operation on the ground will cause increased pressure, especially at high water levels, resulting in degradation of the structure (Johansson, 1992; Sarauskis et al, 2014; Dexter, 2003) and reduction of the pore volume, especially in the coarse pore system (Johansson, 1992; Dexter, 2003). The pores who suffer most are pores larger than 0.03 mm, these pores is an important prerequisite for the draining of water from a water-filled soil against a drainage system at normal depth. If these pores are missing in the topsoil or layers within this, the runoff cannot be done from deeper layers. Therefore, the structure and the pore system in the topsoil have decisive influence on soil drainage. It is particularly important in the spring when a large amount of water must be drained. Drainage is important to promote root development, drying, nutrient utilization and crop safety. Is the drainage flawed, which in many places is currently the case on clay soils, the effect of drainage measures gets worse (Johansson, 1992). One of the best methods to improve soil quality may be reduced soil tillage; however, it is the soil water content that determines what processing methods to be performed in terms of soil structure (Karlen, n.d.).

If the soil structure should be able to be improved or at least maintained, the influence of the structure-building measures needs to be equal or greater than the structure depleting processes, and thereby also contribute to improved soil physical properties. Adding and mixing soil organic matter in the soil seems to have a very small effect on aggregate formation, but can prevent or delay the degradation process. Adding organic material has other positive effects, such as preserving soil structure and increase crop safety. One way to improve the structure and provide better growing conditions, especially on clay soils, is to return the straw and other crop residues to the soil, grow catch crops in the autumn, and only apply shallow tillage. This could increase the humus content of 0.5-1.0% by weight in the top layer, 0-10 cm *(Johansson, 1992).* There are many factors that affect the soil structure, e.g., climate, topography, grain size distribution, cultivation, and so on. An example of a factor that has positive effect on the soil structure is increased humus content. With increased humus content in the soil it gives it a lower bulk density, increased aggregate stability and increased porosity. To till down plant residues in the soil will in the long term give increased humus content, resulting in better soil structure. The greatest negative factor that degrades the soil structure is machine load. For each pass with machines the soil gets more or less compacted *(Roland, 2003: Sarauskis et al, 2014)* and the porosity decreases and channels from worms and roots are destroyed. This means that the permeability and surface infiltration deteriorate, even the gas exchange between soil and the atmosphere deteriorates. This increases the penetration resistance of roots and root growth is inhibited and hampers water and nutrient uptake *(Roland, 2003).*

There are many reports showing that increased proportion of organic matter has positive effects on soil physical properties, such as increased water holding capacity, increased porosity, increased infiltration capacity, increased formation of water-stable aggregates, etc. The risks of erosion, crusting and surface runoff increase at a low percentage of organic matter in the soil, while an increased proportion of organic matter has the effect to improve the structure *(Gustafson-Bjuréus & Karlsson, 2002; Karlen, n.d.)*. Uncovered, non-frozen soil can also cause structural damage to the soil surface, when heavy rain can break aggregates, and pores become clogged. When the soil dries again, a hard crust is forming and makes the surface impenetrable for germinating seeds. It is therefore advantageous to have crop residues and vegetation on the soil surface, to protect the superficial pores from heavy raindrops. *(Roland, 2003)*. Intensive cropping makes the soil more compact and bulk density increases, but decreases with return of organic matter *(Gustafson-Bjuréus & Karlsson, 2002; Roland, 2003)*. Even the pore volume increases with increasing aggregation, humus consists of substances which are fulvic acids, humic acids, humin and polysaccharides, which are very important for the stabilization of aggregates *(Gustafson-Bjuréus & Karlsson, 2002)*.

Mulching may be a method to improve soil quality, by providing soil biota a food source and increase the availability of nutrients for subsequent crops. This allows the surface structural properties to maintain or even be improved. The quantity of biomass, which must be supplied, will obviously depend on soil conditions, cropping sequences, temperature, water regimes and the degree of incorporation. Input must equal the rate of degradation to maintain or increase the soil organic matter level *(Karlen, n.d.)*.

A good root development and large production of root mass along with adequate drying promotes the formation and stabilization of aggregates, and it has also been found that if forage has been grown, it provides a very good environment for aggregate formation and stabilization of these. If forage is used in the crop rotation it may result in higher humus content, stable structure, larger pore volume and more coarse pores, as well as large water and air permeability *(Johansson, 1992).* It has been shown in several studies that perennial crops provide a better soil structure than annuals, forage is one such example of perennial crops. The roots of a forage land give a stable network and advantages of organic matter decomposition in the ground. A forage grassland that is cut at regular intervals gives the best turnover in the root system, while the ground is not subjected to tillage either. It also means that the earthworms may work in peace, and soft leaves and grass is better food for them than straw, because the straw is too large pieces for them. Several studies have shown differences in fauna populations between different cropping systems, which are thought to be due to the addition of organic material such as plant material and animal manure, rather than the supply of fertilizers or chemical pesticides

(Ehrnebo, 2003). Tillage also affects the hydrological conditions in the soil. At seedbed preparation, the soil is smoothed out and the soil gets compacted, soil structure breaks down and runoff increases in comparison with ploughing. It has been shown in Danish trials for the years 1989-1992, that when forage crops or catch crops is cultivated, or if the soil has been ploughed, surface runoff significantly decreases compared to if the land were planted with winter wheat or where the land lay fallow. This is believed to be due to the ability to infiltrate and store water in the topsoil *(Melakari, 2005)*.

In experiments it has been found that the reduced tillage systems, ploughless tillage, and direct drilling gives a favourable structure development in the topsoil, in the same manner as with forage crops. For soil with large ploughing depth, the humus content reduces, which led to soil degradation. For the structurally weak soils, this is a threat to the safety of cultivation. When only reduced tillage is used, it is possible to increase the humus content with 1% in 10 years, and therefore soils with reduced tillage is assumed to have higher humus content than conventionally tilled soils in the long term *(Rydberg & Håkansson, 1991)*.

How the plant residue is treated and handled in the soil determines how effective they are, in terms of the formation of organic material and which influence it has on soil quality. If the soil is processed intensively, there is only a minimal impact on the organic matter, even if crop residues are incorporated into the soil. Green manure and cover crops are often suggested as effective methods to increase the organic matter, but should be used with reduced tillage methods. Plant selection, rotation and frequency of harvesting forms bio pores and can affect the amount of organic matter and its distribution, which also affects soil quality *(Karlen, n.d.)*.

An experiment that was carried out in Aleksandras Stulginskis University, Lithuania, showed that no-tillage system gives the highest soil compaction in the upper layer (0-4 cm) before autumn tillage. This soil has not been cultivated for over 20 years and direct seeding technology has been used. It also showed that autumn tillage led to reduction of soil compaction of the upper layer (0-14 cm), using technologies like deep ploughing, shallow ploughing or deep cultivation. At a depth of 24-34 cm, the soil compaction reduced in deep ploughed soil before and after autumn tillage, while with other tillage technologies the soil compaction increased at this depth *(Sarauskis et al, 2014)*.

Additional data from experiment in Sweden

Experiments have been made during the period 1975-1986 by Rydberg *(1987)* in Sweden, and the experiments are mostly done in the southern and central parts of Sweden, regarding ploughless tillage. The soils in the experiment varied from moraine soil, light clays, stiff clays, organic soil and sandy soils. In the ploughless case, the plough was replaced by 2-3 passes with disc harrows or cultivator at 10-15 cm depth. Otherwise, all tillage occurred in the conventional way, and the straw was basically not removed.

These experiments showed that the soil compaction decreased in a ploughless tillage system. As for straw treatment, there were some "straw stops" in the ploughless case, especially if the preceding crop was autumn-sown cereal. This is why it in most cases resulted in an uneven level of establishment of plants and therefore a lower yield. The recommendations were therefore to keep a low stump and remove the straw, but if the straw is to remain, it should be chopped well and spread evenly on the field, and immediately after harvest being mixed into the topsoil surface layer.

However, there were some abnormal results from some places with structurally weak soils (silty clay loam), which showed a better average yield in ploughless tillage systems if crop residues have been left on the field. This is thought to be due to the straw and that it has impacted the structure stability and water management, and that this had a great impact on the particular place compared to other places *(Rydberg, 1987).*

Weather 2013

Lithuania is characterized by all of the four seasonal weather changes; spring, summer, autumn and winter. The average annual temperature is 6.5 – 7.9° C, and the hottest month of the year is July with an average temperature of 19.7° C and a maximum of 30° C. The coldest month is January with an average temperature of -2.9° C, and the lowest temperature about -30° C. In April-October is the most rainfall recorded, during the summer the precipitation can reach up to 30 mm per day *(Lietuva, n.d.).*

Temperature

The hottest month of 2013, with an average of 24° C, was June. The hottest day of this year was August 8, with a high temperature of 32° C. The coldest month of this year, with an average of -9° C, was January. Also the coldest day was in January, 21st, with a low temperature of -21° C (figure 1) *(WeatherSpark, n.d.).*

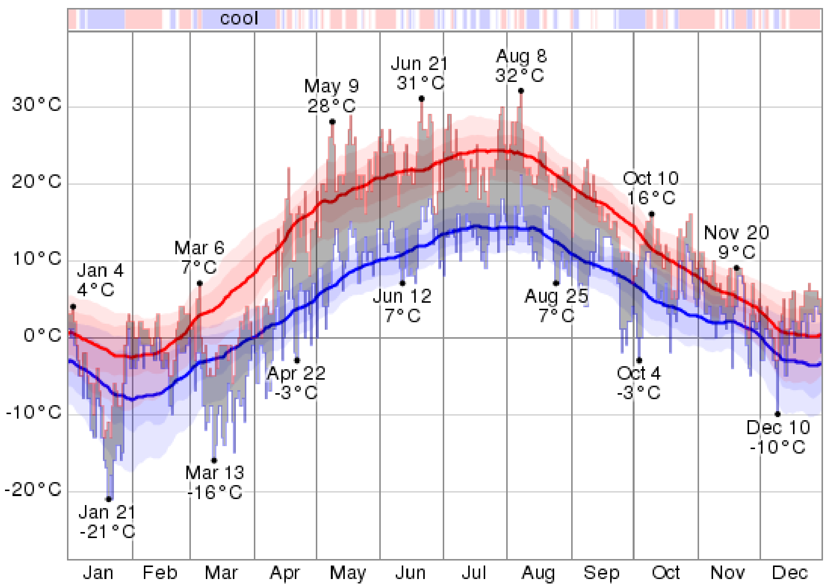

Figure 1. Daily low (blue) and high (red) temperature of year 2013, grey lines between is corresponding average (WeatherSpark, n.d.)

Precipitation

The station provides only with precipitation reports, and not the quantity of liquid precipitation. January 11 in 2013 was the day with most precipitation observations, with 21 hourly weather reports out of maximum 24, where some sort of precipitation took place near the station. January was also the month in 2013 with most precipitation observations, with 277 hourly present weather reports of some sort of precipitation (Figure 2) *(WeatherSpark, n.d.)*.

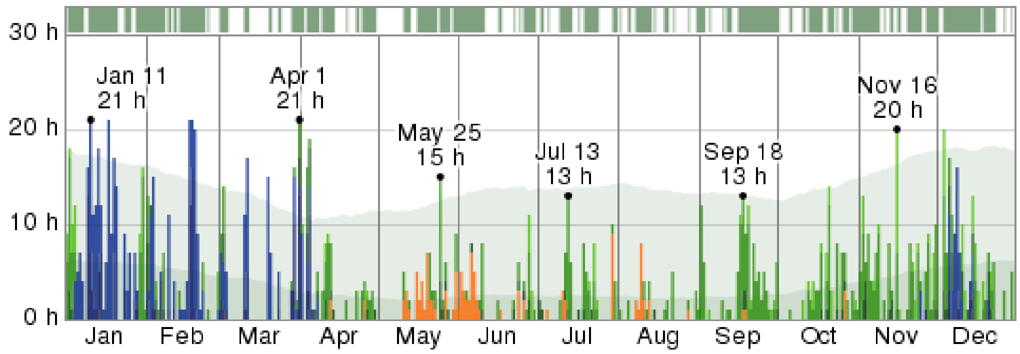

Figure 2. Daily number of hourly observed precipitation reports 2013. Thunderstorms (orange); heavy, moderate, and light snow (dark to light blue); heavy, moderate, and light rain (dark to light green); and drizzle (lightest green). The faint shaded areas indicate climate normal (WeatherSpark, n.d.).

MATERIALS AND METHODS

Experimental design

The experiment was conducted with six different tillage systems: *deep ploughing*, 23-25 cm in autumn (CP); *shallow ploughing*, 10-12 cm in autumn (SP); *shallow loosening with sweep cultivator and disc harrows*, 8-10 cm in autumn (SL); *shallow loosening with rotor cultivator*, 5-6 cm before sowing (SR); *catch crops for green manure incorporation with rotor cultivator*, 5-6 cm before sowing (GMR); *no tillage*, direct drilling (NT).

There were four replications and twelve samples of every tillage system, one sample with straw incorporation and one without from every different system. Totally there was 96 samples (figure 3), and the samples were taken both from 0-10 cm depth and 10-25 cm depth. The experiment was with a split plot design. Two factors were taken in consideration: factor A – straw retention, with straw incorporation (S) and straw removed (R); Factor B – six different tillage systems. The control of factor A was straw removed, which was compared with straw incorporation. The control in factor B, which the other tillage systems were compared with, was deep ploughing (CP). There were also a third factor, the depth of the samples taken, one sample at 0-10 cm depth and one sample at 10-25 cm depth, as mentioned above. All the soil samples were taken from field at the same day. The soil characteristics were sandy loam (Endohypogleyi-Eutric Planosol) with a horizon humus layer of 25 cm and the soil was slightly alkaline: pH - 7.6.

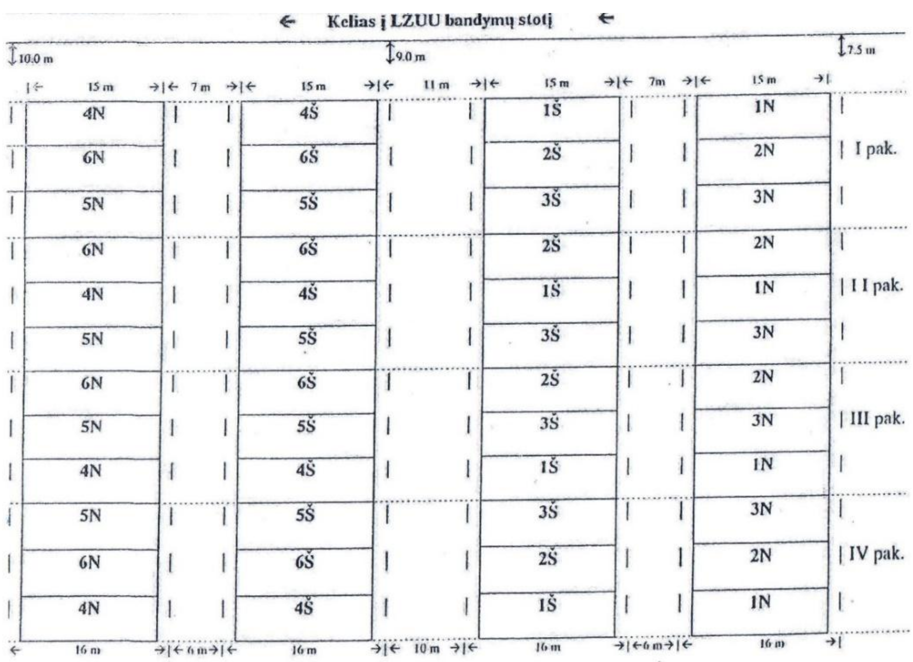

Figure 3. Scheme of investigation. N = without straw, Š =straw. Four replications, twelve samples of each replication.

Sampling and analyses

Texture

To start the investigation we needed to collect the 1.0 mm fractions of every soil sample, to be able to analyse further about aggregate stability. To determine the texture of the soil samples, an analytical sieve shaker were used (figure 4). 200 grams of soil was weighed from each soil sample and then poured into the sieve shaker. The sieve shaker divided the sample into different fractions, and every fraction were weighed separately and written down in a protocol. The fractions of 1.0 mm were saved in a plastic bag for further investigation. Samples from both 0-10 cm depth and 10-25 cm depth were analysed and poured into the sieve shaker. It had to be at least four grams of every one mm fraction to be able to do analyses.

Figure 4. Analytical Sieve Shaker.

Soil aggregate stability

To determine the aggregate stability of the soil samples, a Wet Sieving Apparatus (Figure 5) was used. It gave results about the resistance of soil structure against mechanical or physicochemical destructive forces *(Eijkelkamp…, 2008).*
Four grams of 1.0 mm fraction, dry aggregates, of a soil sample was weighed and poured into a sieve in the apparatus, and next sieve is filled in the same way but with four grams of a new soil sample. There were eight sieves, where different soil samples were poured in and moistened for 30 seconds before the process. These sieves were located above a can of 100 ml distilled water. Then the apparatus was started and the soil samples immersed in the water below the cans, and immersed in these for three minutes. The water were running off before the cans were inserted in a convection oven at 110° C, until all the water had evaporated (approximately 24 h). New cans was

inserted below the soil samples, but instead of water, these cans were filled with a solution containing two grams of sodium hexametaphosphate/L of water. The same procedure was repeated and water cans were inserted into the convection oven in the same time as the distilled water *(Eijkelkamp…, 2008).* After one day in the oven until all the water had evaporated, the samples were weighed again, to find out the aggregate stability. The sieves that were filled with distilled water showed how much of non-stable aggregate the soil contains, and the sieves that were filled with chemicals showed how much stable aggregates the soil contains. There was also one sieve that were filled with the chemical but without any process with soil samples, only for control towards the soil samples to have something to compare with (figure 6).

Figure 5. Wet Sieving Apparatus.

Figure 6. Sieves with distilled water, chemical and the control sieve.

Soil type determination

To determine the soil type of the soil samples taken, a Mastersizer 2000 were used (figure 7). It has a technique of laser diffraction to measure the particle size of a soil sample. It measures the intensity of light that are scattered when the laser beam passes the sample and calculate the size of the particles that created the scattered pattern *(Malvern, 2015).*

Figure 7. Mastersizer 2000.

Water displacement

Water displacement was investigated in two kinds of devices; suction and pressure. The apparatus for suction, the sandbox, was equipped with synthetic sand where the soil samples were placed (figure 8). The pressure apparatus was two pressure chamber, one was a bar ceramic plate extractor for pressure up to 0.295 bar (2.48 pF/295 hPa), and the other one was a bar pressure plate extractor for pressure up to 15 bar (4.2 pF/15 000 hPa) (figure 9).

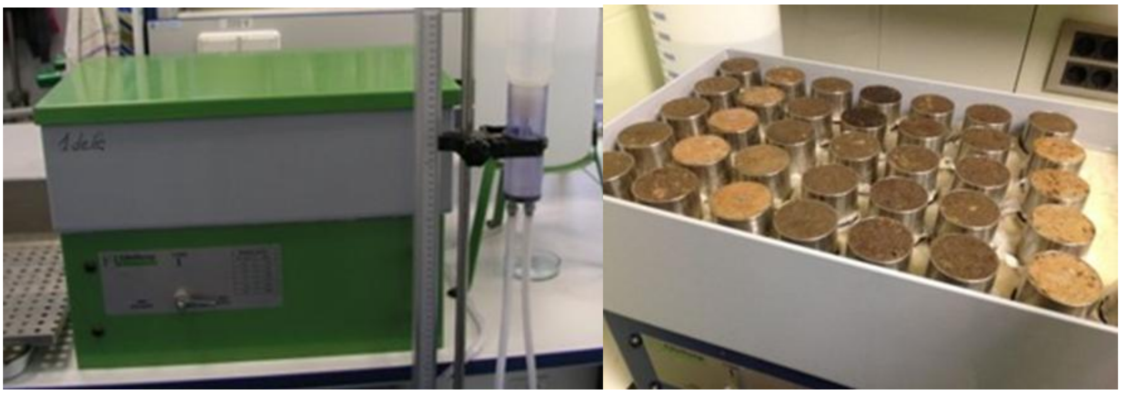

Figure 8. Sandbox for saturation of soil samples.

Figure 9. Bar ceramic plate extractor and Bar pressure plate extractor.

The investigation of water displacement was done in two steps; investigation of soil samples with undisturbed structure, and investigation of soil samples with disrupted structure. The undisturbed soil samples was brought from the field and first placed in the refrigerator with +2° C, and when it was time for the analyses to take place the samples were weighed and placed in cylinders, marked with numbers of the sample. Nylon fabric scraps was attached to the bottom of the cylinders to remove the air, and then we placed them into the sandbox (figure 8), completely saturated. The samples were left in that box with a lid on it for 24 hours, and with 0 cm water column. After one day, the water was lowered to -100 cm water column and left for about 10 minutes until the water in the sandbox were drained out. When the majority of the water had drained out, a suction control adjusted the water level to 0 cm water column again to fill the sandbox with water and it was covered with lid and lowered to -100 cm water column for 3-5 days. After that, we started to analyse. We started at -4 cm water column and set the sandbox at discharge to take out the water. After two days the samples were weighed again, and then put back into the sandbox and set to 0 cm water column to supply with water. The samples were left there for 10-20 minutes, closed the drainage for saturation and then the settings were set on -10 cm water column and the same procedure as with -4 cm water column was done. Then we continued as with -4 and -10 cm water column with -30, -100, -300 and -15 500 cm water column. Then the samples were moved to the bar ceramic plate extractor (figure 9) for analysis with 0.295 bar (-300 cm water column) of pressure, for two weeks. After two weeks, the samples were placed in a permeameter for about two weeks for further investigation about permeability and then placed in an oven for 24 hours and weighed again. The investigation of soil samples with disrupted structure were put in the bar pressure plate extractor for analysis with 15 bar (-15 500 cm water column) of pressure for one month. When the samples were taken out of the pressure chamber, they were placed into cans (figure 10) for weighing (figure 11). After weighing, they were placed in a heating cabinet with 105°C (figure 12) for 24 hours, and then weighed again.

Figure 10. Soil samples in cans.

Figure 11. Scale for weighing of samples.

Figure 12. Heating cabinet.

STATISTICAL ANALYSES

The research data has been handled in two factors variance analysis, ANOVA using a computer program from the program package SYSTAT 10. The difference between the level of probability of the options assessed Fisher‘s LSD test.

Significant differences at * $0.05 \geq P > 0.01$; ** $0.01 \geq P > 0.001$; *** $P < 0.001$; Fisher LSD test vs. control. R – Straw removed (control for factor A), S – Straw chopped and spread, CP – conventional ploughing (control for factor B), SP – shallow ploughing, SL – shallow loosening, SR – shallow rotovating before sowing, GMR – catch cropping for green manure and rotovating before sowing, NT – no tillage, direct drilling.

RESULTS

Soil aggregates

There were no interaction between tillage system and straw incorporation while analysing the results. The analyses of the soil aggregate structure show the percentage of mega-, macro- and micro aggregates in the samples, and it is calculated from the average of all four replications of all the treatments. Mega aggregates are calculated from the fractions bigger than 10 mm, an average of all the replications and treatments. Macro aggregates are calculated from the fractions smaller than 10 mm down to 0.25 mm, the average of those fractions and all the replications and treatments. Micro aggregates are calculated from fractions smaller than 0.25 mm, the dust, an average of all the replications and treatments (table 1).

The results showed that the only significant difference between the different treatments were in micro aggregates with straw incorporation in 10-25 cm depth, compared to the treatment where straw had been removed. The significance was 95% in this comparison. This means that straw has an influence in soil aggregation when it comes to micro aggregates in the deeper layer (10-25 cm).

These analyses did not show any significant difference between using different tillage systems or in different experiment depth of them, even though there was some tendencies. For example, it is shown in table 1 that in factor A (straw retention) there is more mega aggregates in the deeper layer with straw incorporation than with straw removed, but almost the same amount in the topsoil. When it comes to macro aggregates, there was a very small difference between the depth and straw retention.

In factor B (tillage systems), it is shown in the table that when it comes to mega aggregates, the biggest difference was found in SP, and NT, in 0-10 cm depth. In both of the cases the mega aggregates decreased compared to CP. The biggest difference between tillage systems in 10-25 cm depth was found in SL, and NT. Also here the mega aggregates decreased compared to CP. When it comes to macro aggregates in 0-10 cm depth, the biggest difference was found in SL, the macro aggregates decreased in this case compared to CP. Only in SP it was shown to have an increased amount of macro aggregates in 0-10 cm depth, compared to CP. In all of the different tillage systems in 10-25 cm depth, there was higher amount of macro aggregates than in the control, the biggest difference was found in SL and NT. When it comes to micro aggregates in 0-10 cm depth, all of the different tillage systems had a higher amount of micro aggregates than in the control, except for SL. The biggest difference was between control and NT in this depth. In 10-25 cm depth, there was only higher amount of micro aggregates in SR and NT, where the biggest difference was in shallow rotovating.

Table 1. Percentage of fractions on the average from all replications per factor. Significant differences at * 0.05 ≥ P > 0.01; Fisher LSD test vs. control

	Depth, cm	Soil aggregates		
		Mega >10 mm	Macro 0.25–10 mm	Micro <0.25 mm
R	0-10	18.24	71.17	10.59
	10-25	22.87	68.07	9.06
S	0-10	17.38	72.79	9.83
	10-25	26.43	66.26	7.31*
CP	0-10	18.23	72.63	9.14
	10-25	30.28	61.67	8.06
SP	0-10	14.46	76.10	9.44
	10-25	26.63	66.28	7.09
SL	0-10	20.79	66.26	8.23
	10-25	21.48	70.52	8.00
SR	0-10	17.37	72.06	10.57
	10-25	25.69	64.76	9.55
GMR	0-10	17.17	70.94	11.89
	10-25	22.76	69.83	7.41
NT	0-10	14.12	73.89	11.99
	10-25	21.06	69.92	9.02

Aggregate stability

There were no interaction between tillage system and straw incorporation while analysing the results. In the results of soil aggregate stability there were only one significant difference shown, in straw incorporation in 10-25 cm depth (figure 13). The significance of the result was 99.9%. The results showed that the soil aggregate stability was higher in 10-25 cm depth with straw chopped and spread, than in the sample from straw removed. In the deeper layer (10-25 cm), straw incorporation increased the soil aggregate stability by about 16 % compared to the treatment where straw was removed. These analyses do not show any significant difference between using different tillage systems or in different depth of them, and no difference between straw incorporation and straw removal in 0-10 cm depth. The highest difference is between CP and SP, even though it is not a significant difference.

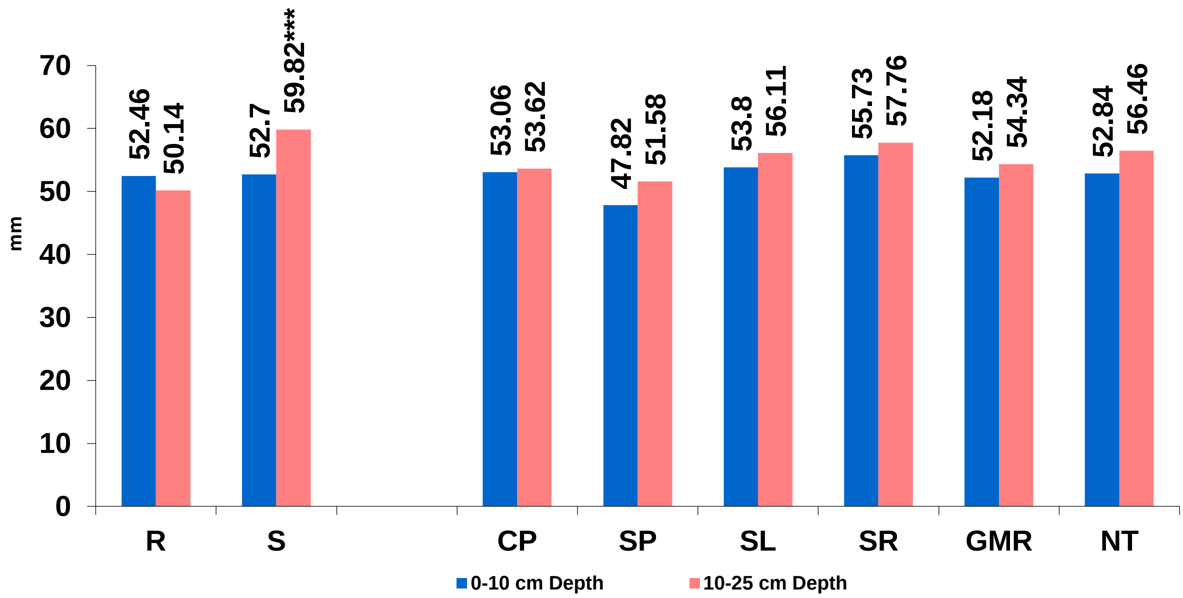

Figure 13. Effect of tillage systems, straw incorporation and green manure combinations on soil aggregate stability (mm). Significant differences at *** $P < 0.001$; Fisher LSD test vs. control.

Bulk density

The results of bulk density of the soil samples showed that there were no significant difference between straw incorporation and straw removed (factor A) in 5-10 cm depth (figure 16) or in 15-20 cm depth (figure 14). The difference between these two treatments was small and it showed that straw incorporation had no influence in the soil's bulk density.

The results of factor B (tillage systems) in 5-10 cm depth (figure 15), showed one significant difference, the bulk density increased in SL compared to CP. The significance was 95 %.

According to the results, NT had the same bulk density as CP. SP and SR had a decreased bulk density compared to CP. GMR had an increased bulk density, though there were no significant differences shown.

The results of factor B in 15-20 cm depth showed two significant differences, in SL and in NT (figure 15). In the treatment with SL, the bulk density increased compared to CP, and the significance was 95 %. In the treatment with NT, the bulk density decreased compared to CP, and the significance was 95 %.

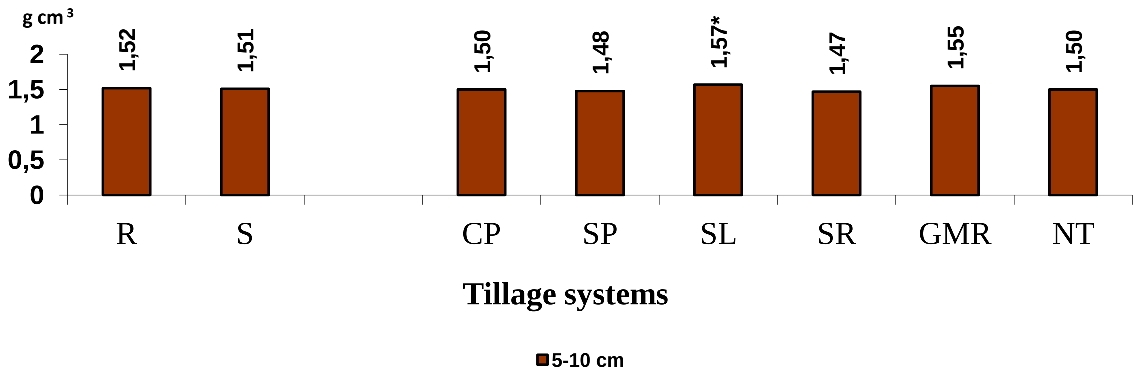

Figure 14. Bulk density, g/cm^3, 5-10 cm depth. Significant differences at * 0.05 ≥ P > 0.01; Fisher LSD test vs. control.

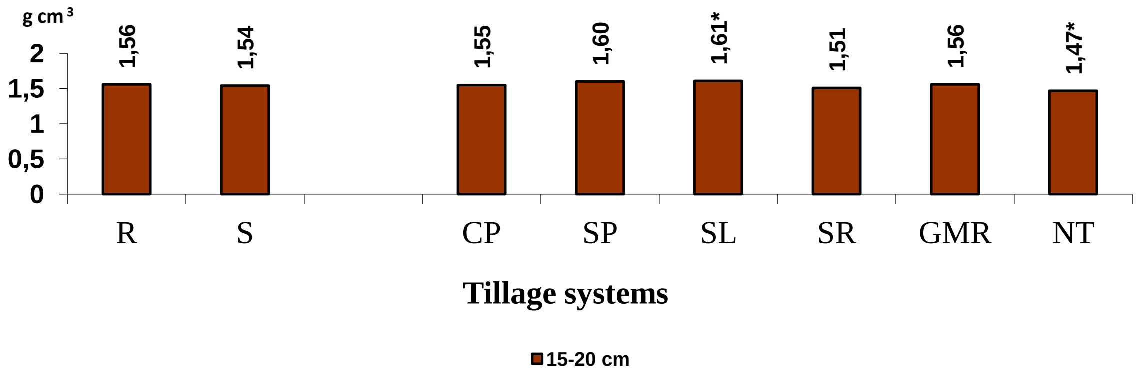

Figure 15. Bulk density, g/cm^3, 15-20 cm depth. Significant differences at * 0.05 ≥ P > 0.01; Fisher LSD test vs. control.

Gravimetric water content in field

The results of gravimetric water content in field in 5-10 cm depth (figure 16), showed no significant difference between straw incorporation (factor A), neither with different tillage systems (factor B). The results showed only small tendencies of variation between the different treatments. With straw incorporation (factor A) the water content decreased compared to the treatment where straw was removed, but no significance. In factor B (tillage systems), there were also small differences, such as increased water content in the treatments with SP, GMR and NT compared to CP, though there was no significance in either of the treatments.

The results of gravimetric water content in field in 15-20 cm depth (figure 17), showed that there was a significant difference between straw incorporation and straw removed (factor A). It showed that with straw incorporation the soil moisture decreased compared to the treatment straw removed. The significance was 95 %, which showed that the straw incorporation had an influence of gravimetric water content in field. The results of different tillage systems (factor B) in 15-20 cm depth, showed a significant difference in GMR with 95 % significance. It showed that in this treatment the gravimetric water content in field decreased compared to CP.

Other tendencies of differences, without significance, showed that no tillage system increased the gravimetric water content in field, but in all the other tillage systems it decreased.

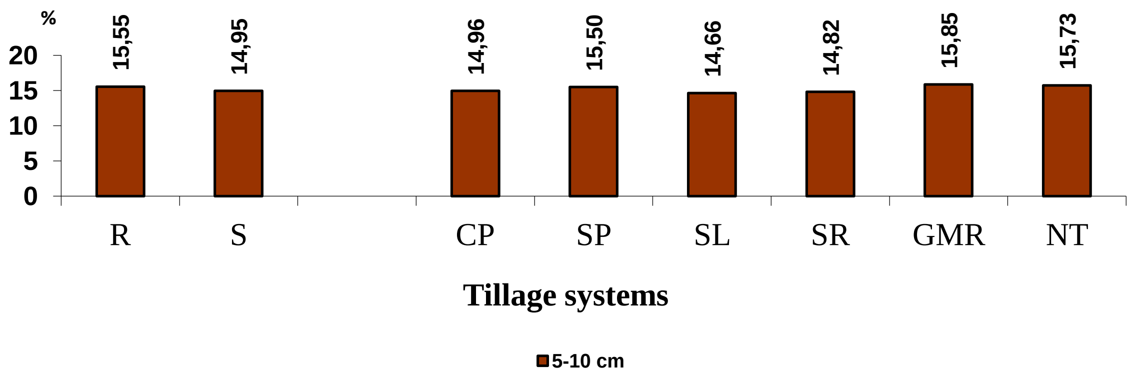

Figure 16. Gravimetric water content in field %, 5-10 cm depth.

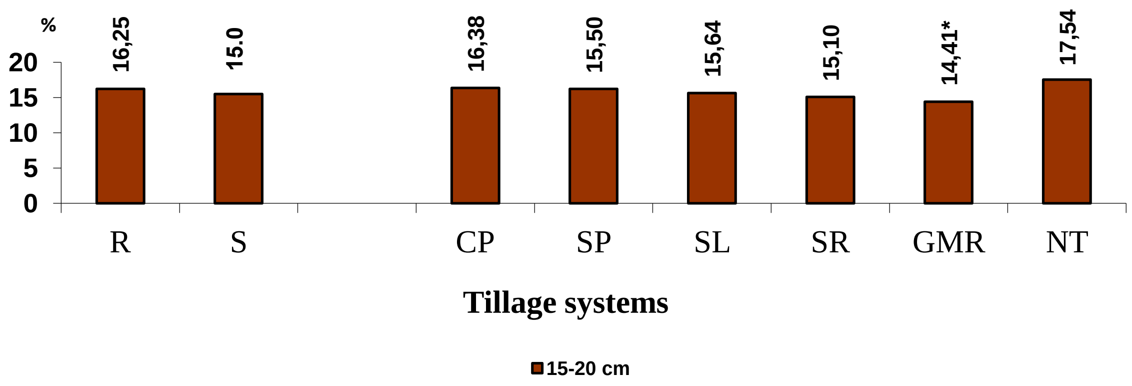

Figure 17. Gravimetric water content %, 15-20 cm depth. Significant differences at * $0.05 \geq P > 0.01$; Fisher LSD test vs. control.

Gravimetric water content in samples

The results of gravimetric water content in soil samples in 5-10 cm depth (table 2), showed that there was no significant difference between straw incorporation and straw removed (factor A), neither in different tillage systems (factor B) compared to CP. The only tendencies in factor A were that with straw incorporation the water content was higher than in the treatment were straw has been removed. In factor B the results varies in the different treatments. In GW-4, SP was the only treatment with higher water content compared to CP. In GW-30, both SP and SR had higher water content than CP. In GW-100, SL was the only treatment with lower water content than CP, all other treatments had higher content. In GW-300, all of the treatments had higher water content than CP. In GW 15500, only SP had a higher water content compared to CP, all of the other treatments had lower content. None of the mentioned differences had any significance.

The results of gravimetric water content in soil samples in 15-20 cm depth (table 3), showed no significant difference in factor A (straw incorporation). The results showed that in all the samples the straw incorporation had a higher water content compared to the treatment without straw, though it was not significant. In factor B (tillage systems), it showed a difference in NT in GW-4, GW-10 and GW-30 with 99 % significance, and a difference in NT in GW-100 with 95 % significance, compared to CP. In all of the mentioned significant differences, the water content was higher in NT compared to CP. In the other two samples, GW-300 and GW-15500, the water content in NT was also higher than in CP, though it was not significant.

There are some tendencies of difference in the other tillage systems as well, though they are not significant. For example, SP showed a higher water content in all the samples compared to CP. SL showed a lower water content in all the samples but one, GW-300, where the content was higher than in CP. SR showed a higher water content in all samples but one, GW-15500, compared to CP. GMR showed a lower water content in all of the samples but two, GW-100 and GW-300, compared to CP.

Table 2. Gravimetric water content in samples, 5-10 cm depth

Tillage systems	Depth, cm	Gravimetric water content					
		GW-4 cm water column height, 3,93 hPa	GW-10 cm water column height, 9,82 hPa	GW-30 cm water column height, 29,46 hPa	GW-100 cm water column height, 98,20 hPa	GW-300 cm water column height, 294 hPa	GW-15500 cm water column height, 15221 hPa
R	5-10	28.09	27.69	27.01	24.50	20.98	12.11
S	5-10	29.17	28.50	27.60	24.93	21.66	13.13
CP	5-10	29.17	28.41	27.09	24.21	20.89	12.91
SP	5-10	29.93	28.99	27.68	24.74	21.31	13.22
SL	5-10	27.01	26.60	26.05	24.04	21.17	12.83
SR	5-10	29.61	29.21	28.55	25.49	21.56	12.37
GMR	5-10	27.43	27.04	26.60	24.69	21.42	12.19
NT	5-10	28.65	28.33	27.83	25.13	21.55	12.21

Table 3. Gravimetric water content in samples, 15-20 cm depth. Significant differences at * 0.05 ≥ P > 0.01; ** 0.01 ≥ P >0.001; Fisher LSD test vs. control

Tillage systems	Depth, cm	Gravimetric water content					
		GW-4 cm water column height, 3,93 hPa	GW-10 cm water column height, 9,82 hPa	GW-30 cm water column height, 29,46 hPa	GW-100 cm water column height, 98,20 hPa	GW-300 cm water column height, 294 hPa	GW-15500 cm water column height, 15221 hPa
R	15-20	26.75	25.23	24.25	22.30	19.10	11.58
S	15-20	27.01	26.42	25.38	23.37	19.77	12.21
CP	15-20	26.28	25.54	24.26	22.58	19.53	11.68
SP	15-20	24.75	24.24	23.46	22.12	19.04	11.89
SL	15-20	25.06	24.66	23.93	22.55	19.77	12.13
SR	15-20	28.10	26.68	25.57	22.76	19.49	11.52
GMR	15-20	26.69	25.51	24.56	22.64	18.10	11.91
NT	15-20	30.43**	28.31**	27.12**	24.34*	20.69	12.22

Volumetric water content in field

The results of volumetric water content in 5-10 cm depth (figure 18), showed that there were no significant difference between straw incorporation and straw removed (factor A), neither in different tillage systems compared to deep ploughing (factor B). The only tendencies in factor A was that in the treatment where straw had been removed; the water content was higher than in the treatment with straw incorporation. In factor B the results were similar in all tillage systems, except in GMR, where it showed to have higher water content than in CP, but no significance proven.

The results of volumetric water content in 15-20 cm depth (figure 19), showed no significant difference between straw incorporation and straw removed (factor A).
The results of tillage systems (factor B) showed a significant difference in GMR, with 95 % significance. This treatment had lower water content than CP. Also SR showed close to significance difference with its low water content compared to CP, though it is not significant. The other treatments was similar to CP or slightly higher, but without significance.

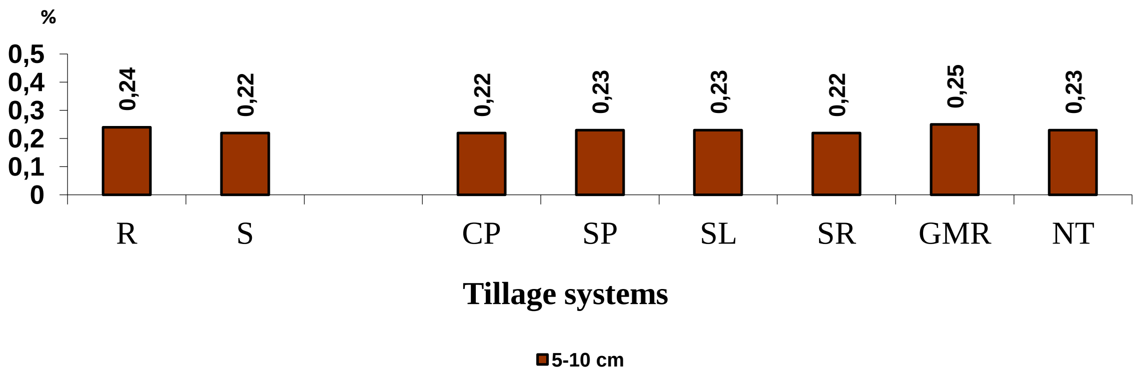

Figure 18. Volumetric water content in field %, 5-10 cm depth.

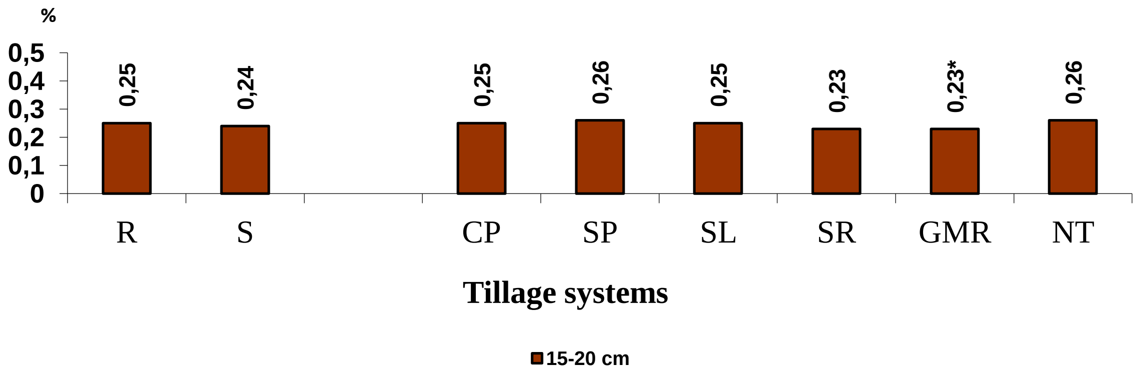

Figure 19. Volumetric water content in field %, 15-20 cm depth. Significant differences at * $0.05 \geq P > 0.01$; Fisher LSD test vs. control.

Volumetric water content in samples

The diagram in figure 20 shows the water holding capacity of the soil samples in 5-10 cm depth. The results of volumetric water content in the soil samples in 5-10 cm depth (table 4), showed that there were no significance between the treatments in factor A (straw retention), neither in factor B with the different tillage systems compared to CP. The results showed that the values were similar between the treatments in factor A and between the treatments in factor B, which means that the different treatments do not have an influence on the water holding capacity in the soil in this depth, though the diagram in figure 22 shows that CP had a tendency of having the lowest water holding capacity of all treatments up to -300 hPa, but with no significance.

The diagram in figure 21 shows the water capacity of the soil samples in 15-20 cm depth. The results of volumetric water content in the soil samples in 15-20 cm depth (table 5), showed no significance between treatments in factor A (straw retention). In factor B the results showed a 99 % significant difference between NT and CP in Qv-4, and 99.9 % significant difference between NT and CP in both Qv-10 and Qv-30. The water holding capacity in NT was significant higher than in CP in all of these samples mentioned, which means that NT had an influence on the water holding capacity in the soil at this depth. The other tillage systems had similar values as CP.

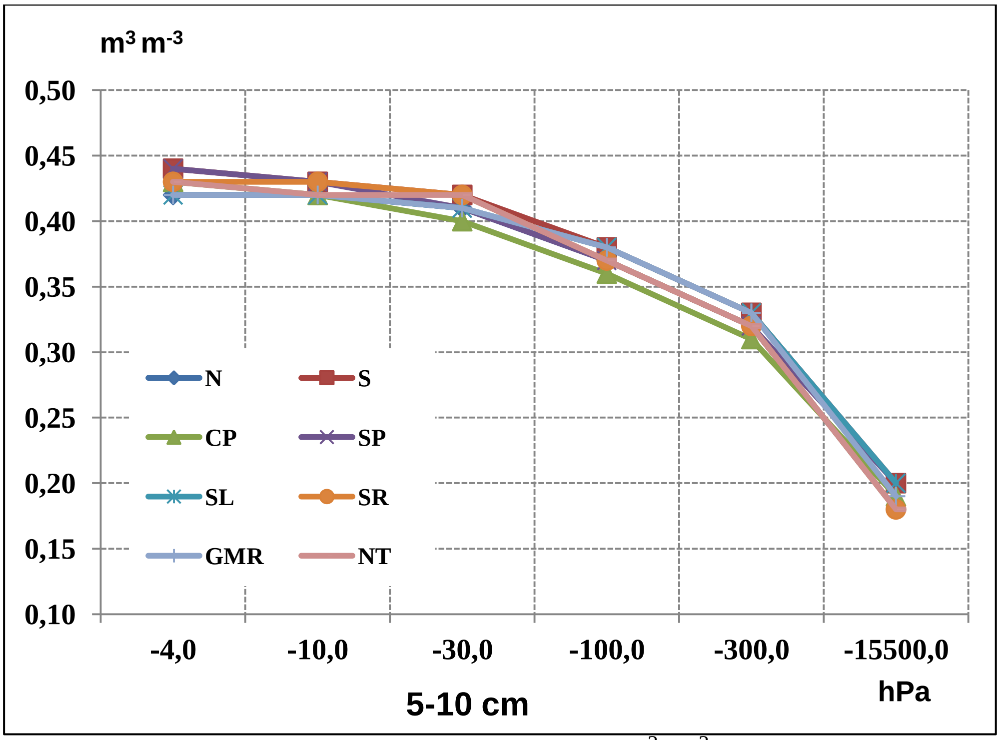

Figure 20. Volumetric water content in samples $m^3\ m^{-3}$, 5-10 cm depth.

Table 4. Significance in volumetric water content in samples, 5-10 cm depth

Tillage systems	Depth, cm	Volumetric water content					
		Qv-4 cm water column height, 3,93 hPa	Qv-10 cm water column height, 9,82 hPa	Qv-30 cm water column height, 29,46 hPa	Qv-100 cm water column height, 98,20 hPa	Qv-300 cm water column height, 294 hPa	Qv-15500 cm water column height, 15 221 hPa
R	5-10	N.S	N.S	N.S	N.S	N.S	N.S
S	5-10	N.S	N.S	N.S	N.S	N.S	N.S
CP	5-10	N.S	N.S	N.S	N.S	N.S	N.S
SP	5-10	N.S	N.S	N.S	N.S	N.S	N.S
SL	5-10	N.S	N.S	N.S	N.S	N.S	N.S
SR	5-10	N.S	N.S	N.S	N.S	N.S	N.S
GMR	5-10	N.S	N.S	N.S	N.S	N.S	N.S
NT	5-10	N.S	N.S	N.S	N.S	N.S	N.S

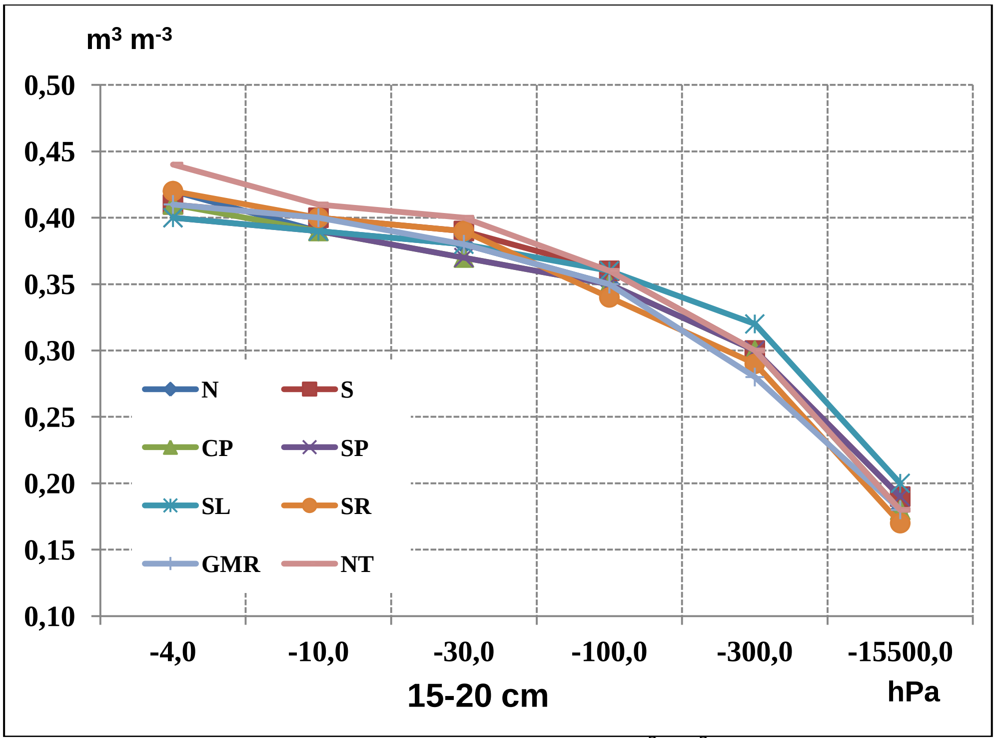

Figure 21. Volumetric water content in samples m^3 m^{-3}, 15-20 cm depth.

Table 5. Significance in volumetric water content in samples, 15-20 cm depth. Significant differences at ** P 0.01 ≥ P >0.001; *** P < 0.001; Fisher LSD test vs. control

Tillage systems	Depth, cm	Volumetric water content					
		Qv-4 cm water column height, 3,93 hPa	Qv-10 cm water column height, 9,82 hPa	Qv-30 cm water column height, 29,46 hPa	Qv-100 cm water column height, 98,20 hPa	Qv-300 cm water column height, 294 hPa	Qv-15500 cm water column height, 15 221 hPa
R	15-20	N.S	N.S	N.S	N.S	N.S	N.S
S	15-20	N.S	N.S	N.S	N.S	N.S	N.S
CP	15-20	N.S	N.S	N.S	N.S	N.S	N.S
SP	15-20	N.S	N.S	N.S	N.S	N.S	N.S
SL	15-20	N.S	N.S	N.S	N.S	N.S	N.S
SR	15-20	N.S	N.S	N.S	N.S	N.S	N.S
GMR	15-20	N.S	N.S	N.S	N.S	N.S	N.S
NT	15-20	**	***	***	N.S	N.S	N.S

Pore structure

The results of pore structure in 5-10 cm depth (table 6), showed that there was no significant difference in factor A (straw retention), which means that straw incorporation had no influence on the pore structure at this depth. In factor B (tillage systems), the results showed a significance in both SL and in GMR in the 30-100 µm pores, a 99 % significance that there were less amount of this pores in these two tillage systems compared to CP. Another significance was shown in SL, SR and in NT in 100-300 µm pores, all of these tillage systems had a lower amount of this pore size compared to CP, with a significance of 95 %. GMR also had a lower amount of this pore size compared to the control, with a singificance of 99 %. The result of the total porosity in all the tillage systems gave a significance at SL of 95 %. This system had the lowest total porosity compared to the contol.

The results of pore structure in 15-20 cm depth (table 7), showed that there was no significant difference in factor A (straw retention), which means that straw incorporation had no influence on the pore structure at this depth. In factor B (tillage systems), the results showed a significance in GMR, with 99.9 %, a higher amount of 10-30 µm pores than CP. Another significance was shown in both SR and NT, with 99.9%, both of the systems had higher amount of 30-100 µm pores than the control. SL showed a significance of 95 %, with lower amount of 100-300 µm pores. NT showed a significance of 95 %, with a higher amount of 300-750 µm pores. The result of the total porosity in all the tillage systems gave a significance at SL of 95 %, The SL system had the lowest total porosity compared to the contol. NT gave a significance at total porosity as well, with 95 % significance. The NT system had the highest total porosity compared to the control.

Table 6. Pore structure, 5-10 cm depth. Significant differences at * 0.05 ≥ P > 0.01; ** P 0.01 ≥ P > 0.001; Fisher LSD test vs. control

Tillage systems	Depth, cm	Pore structure							
		<0.2µm	0.2-10µm	10-30µm	30-100µm	100-300µm	300-750µm	>750µm	(Total porosity) $m^3\ m^{-3}$
R	5-10	0.183	0.133	0.053	0.037	0.010	0.006	0.006	0.428
S	5-10	0.198	0.128	0.049	0.040	0.013	0.010	0.006	0.431
CP	5-10	0.194	0.118	0.049	0.042	0.019	0.011	0.001	0.434
SP	5-10	0.196	0.119	0.050	0.043	0.019	0.013	0.000	0.442
SL	5-10	0.196	0.124	0.040	0.031**	0.009*	0.006	0.000	0.406*
SR	5-10	0.182	0.134	0.057	0.045	0.009*	0.006	0.011	0.444
GMR	5-10	0.185	0.140	0.050	0.029**	0.006**	0.005	0.000	0.415
NT	5-10	0.182	0.139	0.054	0.040	0.007*	0.005	0.009	0.436

Table 7. Pore structure, 15-20 cm depth. Significant differences at * 0.05 ≥ P > 0.01; *** P > 0.001; Fisher LSD test vs. control

Tillage systems	Depth, cm	Pore structure							
		<0.2µm	0.2-10µm	10-30µm	30-100µm	100-300µm	300-750µm	>750µm	(Total porosity) m3 m-3
R	15-20	0.181	0.116	0.050	0.030	0.015	0.023	0.003	0.411
S	15-20	0.188	0.115	0.056	0.030	0.015	0.009	0.008	0.420
CP	15-20	0.181	0.119	0.047	0.026	0.020	0.011	0.013	0.416
SP	15-20	0.190	0.114	0.049	0.021	0.013	0.008	0.002	0.396
SL	15-20	0.192	0.117	0.045	0.021	0.011*	0.006	0.000	0.392*
SR	15-20	0.174	0.120	0.050	0.042***	0.016	0.021	0.006	0.430
GMR	15-20	0.186	0.095	0.071***	0.029	0.014	0.018	0.000	0.412
NT	15-20	0.179	0.123	0.054	0.040***	0.018	0.030*	0.001	0.446*

CONCLUSION

According to the literature study I have made, I make the conclusion that if the soil structure should be improved, or at least maintained, the structure-building measures needs to be equal or greater than the structure depleting measures. That is why adding organic matter can help to preserve soil structure and increase the safety in crop production. To improve the structure, the straw should not be removed and it will provide better conditions for the crops, and also give the soil a better protection by covering the bare soil. Another suggestion is to grow cover crops in the autumn and only apply shallow tillage. According to Johansson *(1992)*, this could increase the humus content in the top layer, and if the plant residues is being tilled down, it will in long term increase the humus content and result in better soil structure. The greatest negative factor of soil degradation is heavy machine load. Every pass we make over the field, the soil get more or less compacted and the porosity decreases, which is why a reduced tillage system should be applied.

Ploughless tillage and direct drilling gives favourable structure development in the topsoil, like forage crops, with its good root development and stabilization of aggregates. According to Rydberg & Håkansson *(1991)*, it is possible to increase the humus content with 1% in 10 years if only reduced tillage system is used. Green manure and cover crops is often suggested as effective methods to increase the organic matter, along with reduced tillage system. Though, experiment at Aleksandras Stulginskis University in Lithuania has showed that no-tillage system has the highest level of compaction of the soil compared to deep ploughing system. On the other hand, experiment in Sweden has showed that ploughless tillage system gives a reduced compaction, though, there are problems with the straw treatment with too much organic material while cultivating the soil with different tillage methods. If the straw should be incorporated, it need to be chopped finely and spread evenly over the field.

The aim of this investigation was to prove the differences between different tillage systems and with straw incorporation compared with when straw was removed. Our results showed that the soil had higher aggregate stability in 10-25 cm depth with straw incorporation than with straw removal. Though, there were some tendencies, without significant difference, that shallow ploughing would decrease the soil aggregate stability compared to deep ploughing. In some of the other tillage systems the aggregate stability actually increased, but also here without any significant difference. When it comes to the aggregate structure, the results from our experiment showed that the only significant difference was in the micro aggregates. In 0-10 cm depth with straw incorporation we found lower content of micro aggregates than where straw was removed. Also in this result we found some tendencies of difference, but without significant differences. For example, there were higher amount of mega aggregates in 10-25 cm depth with straw incorporation than were straw was removed. Mega aggregates decreased in 0-10 cm depth in treatments of shallow ploughing and no tillage compared to deep ploughing, and in 10-25 cm depth the amount decreased in shallow loosening and no tillage. Among the results from macro aggregates, shallow ploughing increased the amount in 0-10 cm depth compared to deep ploughing, while it in 10-25 cm depth the amount increased in all of the different tillage systems compared to deep ploughing. The results from micro aggregates showed a tendency to increase the amount in 0-10 cm depth in all tillage systems, except for shallow loosening, the biggest increase was shown in no tillage. In 10-25 cm depth, shallow rotovating increased the amount of micro aggregates the most.

We also analysed bulk density in the soil, and the results showed that there were no significant difference between straw incorporation and straw removed in neither of the depth. In 5-10 cm depth there was shown one significance, shallow loosening increased bulk density compared to deep ploughing, and in 15-20 cm depth shallow loosening had an increased bulk density also here compared to deep ploughing. No tillage had a decreased bulk density in this depth compared to deep ploughing. This means that shallow loosening has an influence in both of the depths and gives a higher bulk density than the deep ploughing, and no tillage had an influence in the deeper layer with a lower bulk density. With a higher bulk density in the soil means less porosity and the soil has a higher compaction than with the deep ploughing system.

The results from gravimetric water content in field (soil moisture) showed no significant difference in 5-10 cm depth in either straw retention or tillage systems. But in 15-20 cm depth the straw incorporation decreased the soil moisture compared to the treatment where straw was removed. In the different tillage systems, catch crop for green manure decreased the soil moisture compared to deep ploughing. This means that straw incorporation and the green manure and catch crop treatments had an influence on soil moisture and they cannot hold as much water as the control of both of the factors. The results of gravimetric water content from soil samples analysed with different hPa showed that there was no significant difference in straw retention, neither in different tillage systems in 5-10 cm depth, but in 15-20 cm depth the treatment with no tillage showed that in four of the six analyses it had significant difference to have higher water content, and in the other two analyses it was also shown to be higher but not a significant difference. Higher water content means that the soil can hold more water under these pressures.

The results of volumetric water content in field showed no significant difference in 5-10 cm depth in either straw retention or tillage systems. But in 15-20 cm depth one significant difference was shown, catch crop for green manure had a lower water content compared to deep ploughing, which means that the soil with this treatment cannot hold as much water as deep ploughing. No significance was shown in straw retention on this depth either. The results of volumetric water content from soil samples analysed with different hPa showed that there was no significant difference in straw retention, neither in different tillage systems in 5-10 cm depth, but in 15-20 cm depth the treatment with no tillage showed that in three of the six analyses it had significant difference to have higher water content, which means that soil with no tillage can hold more water under these pressures.

The results of the pore structure in 5-10 cm depth showed that shallow loosening and green manure and catch crop had lower amount of 30-100 µm pores, and all tillage system except shallow ploughing had a lower amount of 100-300 µm pores than deep ploughing. In the total porosity it showed that shallow loosening had the lowest porosity compared to deep ploughing. The results in 15-20 cm depth showed that green manure and catch crop had a higher amount of 10-30 µm pores, and shallow rotovating and no tillage had higher amount of 30-100 µm than deep ploughing. Shallow loosening had a lower amount of 100-300 µm pores, and no tillage had a higher amount of 300-750 µm pores than deep ploughing. The total porosity showed that shallow loosening even in this deep had the lowest porosity, but it also showed that no tillage had the highest porosity comapred to deep ploughing. According to the literature I have studied, a low amount of the pores larger than 3 µm in the topsoil decreases the ability to drain the run-off water from the deeper layer in the soil. According to the results we got, shallow loosening seems to decrease the porosity of the soil, and this soil could have problem to drain out excess water. No tillage shows a higher porosity, which is a good property due to the air and water infiltration.

Our results did not prove all of the mentioned benefits of straw incorporation and reduced tillage system when it comes to aggregate stability and aggregate structure as we would have hoped for. Though, when it comes to water capacity, we got some significant differences which is interesting. We had expected to find other differences between the different tillage systems and that it would show a significant higher beneficial advantage with reduced tillage system and straw incorporation. My own conclusions is that to be able to handle the increasing population of the Earth and the demand of food supply, we need to take better care of the soil that we have, and reduce the stress for the soil to achieve sustainability in the agriculture. I also think that there has to be more investigation and experiments made to draw any specific conclusions about this experiment, I think it is not enough investigation to make any strong decisions about if this results is reliable or not. There could be a lot of other benefits with reduced tillage systems and straw incorporation, such as erosion and biological activity that would give the soil a better soil structure that is not taken in consideration in this investigation. I thought that this investigation and all the experiments would have shown some differences between the different tillage systems, due to all the literature I have read, but our analyses did not give us any indication of better soil structure or aggregate stability with reduced tillage system. Though, I think that it is beneficial to use reduced tillage system to spare the land we have and to create a more sustainable agriculture management. The disadvantages with a reduced tillage system could be about weeds, when deep ploughing is not applied it is harder to control the weeds without using more pesticides. With deep ploughing, a lot of the weeds can be tilled down and controlled better than in a system without ploughing.

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