University of Natural Resources and Life Sciences, Vienna

Universität für Bodenkultur Wien
Department für Nachhaltige Agrarsysteme

Department für Nachhaltige Agrarsysteme
Department of Sustainable Agricultural Systems
Institut für Ökologischen Landbau (IfÖL)
Division of Organic Farming

Freeze-killed versus winter-hardy catch crops before maize in reduced soil tillage systems

Master Thesis by
Julia Fohrafellner, BSc.
Matrikelnr.: 01240617
For obtaining the academic title Master of Science (MSc.)

Supervisors:
Ao.Univ.Prof. Dipl.-Ing. Dr. **Jürgen Kurt Friedel**
Assoc. Prof. **Željka Zgorelec**, PhD (University of Zagreb, Department of General Agronomy)

Vienna, 2019

I give my solemn word that I have completed this work solely and without external help, have not utilized any sources outside those permitted and that the sources used have been given verbatim or quoted textually in the places indicated.

Abstract

Maize has high demands on nutrient supply, previous crops and weed pressure. Moreover, the cultivation of maize comes along with several risks, as soil erosion and nitrate leaching into the environment before and after maize sowing as well as reduced yields as a result of nitrogen deficiency. Possible measures of organic farming to lower these risks are catch crop and undersown crop cultivation and reduced tillage. Therefore, this thesis is coping with the possible effects of two treatments on maize, several soil parameters and weed pressure on organically managed fields. Treatment A consisted of a winter-hardy catch crop mix, which was terminated with the rotary cultivator and undersown crops cultivation along with maize. In treatment B, a freeze-killed catch crops mix, terminated with the cultivator and without undersown crops was tested. To assess possible different effects of the two treatments on the above-mentioned parameters, extensive soil analysis, visual assessments of maize and weed development as well as maize yield elicitation was conducted. Significant differences between the treatments regarding total organic carbon, soil organic matter, bulk density, inorganic nitrogen and nitrate contents of the soil were found. Maize yields and weed pressure did not show significant differences. In terms of the assessed significant differences, treatment A achieved better results in all tested parameters concerning soil health, without reducing maize yields.

Keywords

Catch crop, undersown crops, cultivator, rotary cultivator, maize, yield, weed, soil

Kurzfassung

Mais ist eine Kultur, die hohe Ansprüche an Nährstoffversorgung, Vorfrucht und Unkrautdruck stellt. Weiters geht der Maisanbau mit einigen Risiken einher, wie beispielsweise Bodenerosion und Stickstoffaustrag in Gewässer vor und nach der Mais Saat sowie reduzierter Erträge auf Grund von Stickstoffmangel. Mögliche Maßnahmen des Biolandbaus zur Reduzierung dieser Risiken sind Zwischenfrucht- und Untersaatanbau sowie reduzierte Bodenbearbeitung. Diese Arbeit behandelt daher die möglichen unterschiedlichen Auswirkungen zweier Systeme auf Mais, verschiedener Bodenparameter und Unkrautdruck auf biologisch bewirtschafteten Flächen. System A setzte sich aus einem winterharten Zwischenfruchtgemenge mit Umbruch durch die Fräse und einer Untersaat im Mais zusammen. In System B wurde ein abfrierendes Zwischenfruchtgemenge mit Umbruch durch den Grubber, ohne Untersaat getestet. Um mögliche unterschiedliche Effekte der beiden Systeme auf bereits genannte Parameter zu messen, wurden umfangreiche Bodenanalysen, Bonituren der Mais- und Unkrautentwicklung sowie eine Ermittlung der Maiserträge durchgeführt. Die Systeme unterschieden sich in organischen Kohlenstoffgehalten, Humusgehalten, Lagerungsdichte, mineralisiertem Stickstoff sowie im Nitratgehalt des Bodens. Für Maiserträge sowie Unkrautdruck wurden keine signifikanten Differenzen gefunden. Hinsichtlich der gefundenen signifikanten Unterschiede erzielte System A in allen Fällen die besseren Ergebnisse in Bezug auf Bodengesundheit, ohne Maiserträge zu reduzieren.

Schlagwörter

Zwischenfrüchte, Untersaat, Grubber, Fräse, Mais, Ertrag, Beikraut, Boden

Table of Content

Acknowledgement

First, I would like to thank my supervisor Jürgen Kurt Friedel for his continuous support and constructive critique. Moreover, my sincere thanks go to Gabriele Gollner, for all her patience and time. I also want to thank Benedikt Blankenhorn for his organisational expertise during the field trails. Finally, I want to express my deepest gratitude to my parents, my friends and my partner Michael, for their endless support und motivation.

List of Tables

List of Figures

List of Abbreviations

ANOVA	Analysis of Variance
AGES	Austrian Agency for Health and Food Safety
BOKU	University of Natural Resources and Life Sciences, Vienna
Ca	Calcium
$CaCl_2$	Calcium chloride
CC	Catch crops
FAO	Food and Agriculture Organization of the United Nations
GLM	General Linear Model
K	Potassium
K_{CAL}	Plant available potassium; Calcium-Acetat-Lactat-Method
mL	Millilitre
µL	Microlitre
M	mole
Min	Potential nitrogen mineralization
MPa	Mega Pascal
N	Nitrogen
N_{in}	Inorganic nitrogen
Nt	Total nitrogen
NaOH	Sodium hydroxide

NH_4^+	Ammonium
NH_4Cl	Ammonium chloride
nm	Nanometer
NO_3^-	Nitrate
ÖNORM	National Austrian standard
P	Phosphorus
P_{CAL}	Plant available phosphorus; Calcium-Acetat-Lactat-Method
ppm	Parts per million

1. Introduction

Maize played a minor role in organic agriculture for a long time. This can be explained by its possible negative environmental impacts and challenges in cultivation. As the critical points have been faced and the demand for fodder for cattle is rising (Benke and Martens, 2001 cited from Graß, 2003), maize cultivation in organic agriculture has been increasing in the recent past (Drangmeister, 2011). Nevertheless, maize has high demands on nutrients, previous crops and weed control, and tends to increase soil erosion and compaction. Moreover, maize is sensitive towards unsuitable weather conditions and shows low nutrient uptake capacity during young development stages. Therefore, competition with weeds is high, which can lead to decreased yields and quality (Drangmeister, 2011). Other risks of maize cultivation in conventional systems are:

- Soil covering during the winter months before maize is often missing, which can lead to nitrogen leaching and soil erosion
- Soil erosion and nitrogen leaching after maize is sown
- High contents of nitrogen after maize harvest, therefore risk of nitrogen leaching
- Reduced yields due to nitrogen shortage (Graß, 2003)

Although organic farming generally has less environmental impacts than other agricultural systems (Gomiero et al., 2011) the listed risks can occur (Bein et al. 2001, cited in Graß, 2003). Therefore, solutions for these issues need to be assessed to support an increase in maize cultivation in organic farming. Approaches coming from conventional systems often lead to additional problems when applied in organic agriculture and are restricted. Thus, innovative ideas for organic farming need to be developed, which take ecological and economical aspects into account (Graß, 2003).

One possible measure is the cultivation of catch crops. Catch crops show a high nitrogen fixation capacity and nitrogen conservation during winter months. Moreover, they are effective weed suppressors. As they enrich the soil with nitrogen, built-up of soil organic matter is promoted, which enhanced nutrient availability for following crops (Kolbe, 2004), as maize.

Furthermore, to target some of the problems occurring with maize cultivation, undersown crops can be sown. Undersown crops help protecting the soil from erosion, promote a positive soil organic matter balance, reduce nitrogen leaching potential into the environment, compete with weeds and have a positive effect on the soil structure (Wallner, 2018).

Conservation tillage is an umbrella term of soil tillage methods, which "have the potential to conserve soil and water by reducing their loss relative to some form of conventional tillage" (Carter, 2005, p. 306). These measures can have positive effects on soil erosion, soil organic matter, soil physical conditions as aggregation and nutrient leaching (Carter, 2005).

To gain further knowledge on catch crop cultivation before maize in combination with conservation tillage and undersown crops, this paper investigates the effects and possible differences of a winter-hardy catch crop mix with an undersown crop and a freeze-killed catch crop mix without undersown crop on maize, several soil parameters and weed pressure under reduced soil cultivation.

1.1. EIP-AGRI Operational Group "BIOBO"

EIP-AGRI (European Innovation Partnership for Agricultural Productivity and Sustainability) is one of five European Innovation Partnerships which was launched in 2012. These partnerships are new approaches of the EU "to help all EU countries to provide their citizens with a more competitive economy, more and better jobs and a better quality of life" (EIP-AGRI, 2018). EIP-AGRI is focused on encouraging the agricultural and forestry sector to be competitive and sustainable (EIP-AGRI, 2018). "It contributes to ensuring a steady supply of food, feed and biomaterials, and to the sustainable management of the essential natural resources on which farming and forestry depend, working in harmony with the environment. To achieve this aim, the EIP-AGRI brings together innovation actors (farmers, advisors, researchers, businesses, NGOs, etc) and helps to build bridges between research and practice" (EIP-AGRI, 2018)

Moreover, new knowledge is not generated only by scientists, but by so called “operational groups”. These groups consist of different actors as, for example, farmers, scientists, businesses and advisors. Together, these actors can work on specific projects in the agricultural and forestry sector and “new insights and ideas will generate and existing tacit knowledge will be built into focused solutions that are quicker put into practice. Such an approach will stimulate innovation from all sides and will also help to target the research agenda” (EIP-AGRI, 2018).

The operational group (OG) BIOBO is dealing with yield performance and soil organic matter build-up by reduced tillage and organic fertilization measures (green manuring and organic fertilizers). The project began in 2016 and will end in 2019. The aim is to assess innovative and reduced tillage methods which fit the farm and its environment and lead to a long-term increase in yield and income. Combined with adapted fertilization, a strategy for yield performance and support of environmental services (as organic matter built-up, increasing water holding capacity, biodiversity and nutrient efficacy, avoiding loss of nutrients and erosion) is formed. The main target group are organic farms, but also conventionally managed farms can profit from the results. Several experiments, each adapted to the farm it is conducted, are set up throughout Lower Austria (Netzwerk Zukunftsraum Land, 2018).

1.2. Importance of Soil Organic Matter in Agriculture

The United States Department of Agriculture (USDA) writes that SOM has several positive effects on soil health. The soil structure improves, surface structure becomes less sensitive to erosion and crusting. Water infiltration increases and therefore surface runoff declines. SOM is able to hold 10 to 1000 times more nutrients and water as the same amount of soil minerals. Moreover, beneficial soil organisms grow in number and activeness at higher SOM levels. This results in positive effects for agriculture for example improved resilience of crops against droughts, as water holding capacity and infiltrations are improved. By associating with minerals, hydrophilic and hydrophobic domains are created, which enables SOM to immobilize pesticides and supress disease organisms, which could lead to reduced demands of pesticides (USDA, s.a., Paul, 2007). Moreover, crop vigour and health improve when soil biological life increases (USDA, s.a.)

Improving SOM content is moreover accompanied with positive changes in soil properties and environmental benefits. This enhancement can be achieved by cultivating cover crops, applying reduced tillage and diverse crop rotations or rotational grazing. Cover crops and residues can contribute to organic matter and nutrient built up in soil, surface residues protect soil from erosion by wind and water and reduced tillage leads to lower organic matter loss (USDA, s.a.).

2. State of the Art

2.1. Soil Quality and Degradation

To sustain environmental quality and agricultural productivity for future generations, it is important to preserve and improve soil quality. Soil quality is defined as "capacity of the soil to carry out ecological functions that support terrestrial communities (including agroecosystems and humans), resist erosion, and reduce negative impacts on associated air and water resources (Karlen et al., 1997 as cited in Weil and Magdoff, 2004). It can reflect the overall condition of the soil, which can be modified by management practises. Increased inputs and technologies in some cases can reduce losses in productivity which are caused by soil degradation. Nevertheless, those inputs do not only lead to economic unsustainability, but also an increased risk for negative environmental impacts (National Research Council, 1993).

The Food and Agriculture Organization of the United Nations (FAO) describes soil degradation as „a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries. Degraded soils have a health status such, that they do not provide the normal goods and services of the particular soil in its ecosystem" (FAO, s.a. (b)) (see figure 1). Poor management practises (as burning, slashing or practises that cause nutrient imbalance) or soil erosion can lead to nutrient depletion of soils, which is one form of soil degradation (FAO, s.a. (a)).

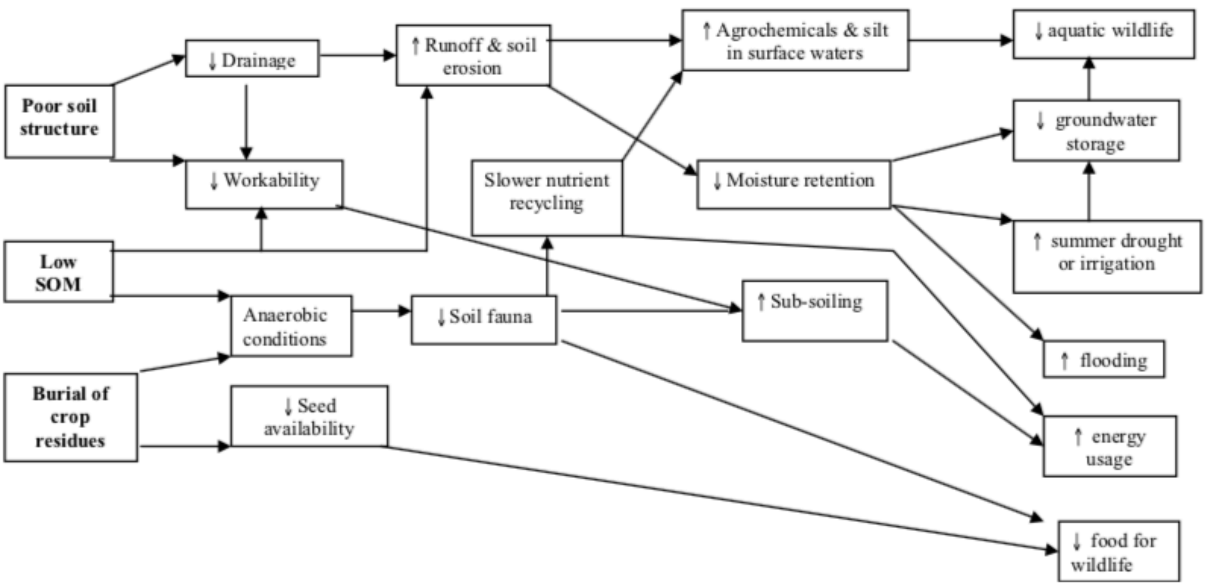

Figure 1: Processes through which degraded soils affect the environment (Source: Holland, 2004).

2.2. The Role of Nitrogen and Soil Organic Matter in Soil

2.2.1. Nitrogen

"No other element essential for life takes as many forms in soil as nitrogen (N), and transformations among these forms are mostly mediated as microbes" (Paul, 2007, p. 341). Depending on their oxidative state, N takes nine different forms in soil. It mainly occurs as nitrate (NO_3^-), nitrogen dioxide (NO_2), nitrite (NO_2^-) nitric oxide (NO), nitrous oxide (N_2O), dinitrogen (N_2), ammonia (NH_3), organic N (R-NH_3) and ammonium (NH_4^+) (Paul, 2007). Organic forms in soil are amino sugars, amino acids or nucleic acids. Ammonium accounts for the smallest fraction and is bound to clay minerals (Bot and Benites, 2005).

N_2 is the most abundant form of N but unusable for most organisms. Through biological N_2 fixation (BNF), N_2 is transformed into organic N. This metabolic process can only be done by prokaryotes of the domains Bacteria and Archaea. Nevertheless, symbiotic associations have developed between prokaryotes and legumes. N_2 fixating prokaryotes gain energy from the photosynthetic activity of the plant, whereas the plant can use the additional N in case of N limitation. Bacteria like rhizobia form such relationships with legumes by the formation of nodules. Rhizobia are abundant bacteria in soil, which penetrate legume roots by infecting their root hair, entering through the lateral root emergence or by penetrating root primordia (Paul, 2007).

N is essential for the growth and development of plants. It is mostly responsible for the development of morphological traits in legumes and cereals and the biochemical and physiological processes in plants. Some of those biochemical functions are essential for the formation of cell wall, nucleic acids, chlorophyll, enzymes and other cellular components (Harper, 1994 as cited in Fageria, 2014, p. 5).

Some forms of N formed by microorganisms also act as pollutants and risk human and environmental health (described in detail in Chap. 3.3.). Many times, this pollution occurs far from the initial formation of the hazardous molecules (Paul, 2007).

2.2.2. Soil Organic Matter

The most complex and yet, not well understood component of soil, is SOM (Carter, 1996). SOM content can vary from around 800 g kg^{-1} in some Histosols to 2 g kg^{-1} in deserts. Agricultural soils usually have a content of 10 to 40 g kg^{-1} in the A horizon (Bot and Benites, 2005). By effecting biological, chemical and physical properties of soil, it has direct impact on microbial and plant growth. Moreover, it is the greatest source of the plant nutrients nitrogen, phosphorus (P) and sulphur (S). In association with secondary minerals as i.e. clay, it creates soil structures by forming aggregates, which promote aeration, water infiltration and water storage. A balanced soil structure enhances plant growth and offers habitat to soil microorganisms (Paul, 2007). These microorganisms feed on SOM and break it down. Thereby, excess nutrients like N, P and S are released in forms usable for plants. By breaking down carbon structures and producing new ones or using carbon for their own biomass built-up, soil biota are the most important players in nutrient cycling in soil (Bot and Benites, 2005). SOM concentrations and turnover directly influence productivity (Paul, 2007).

2.3. Soil Organic Matter Formation

SOM consists of dead plant and animal material as well as living soil fauna, soil microorganisms and decomposition by-products. Fresh residues, which will decompose to smaller SOM fractions, consist of manures, crop residues, roots, insects, earthworms and dead micro-organisms. Those residues, especially the ones from crops, contain high amounts of complex carbon compounds. Carbon atoms are linked to each other and form, combined with other atoms like hydrogen, nitrogen, phosphorus and sulphur, molecules like amino acids, simple sugars, long carbon chains or carbon rings (Bot and Benites, 2005), which are sources for plant nutrition.

In this thesis, instead of the classic "humification model", the by (Lehmann and Kleber, 2015) proposed "soil continuum model" is used to describe the formation of SOM (see figure 2). In this concept, "organic matter exists as a continuum of organic fragments that are continuously processed by the decomposer community towards smaller molecular size" (Lehmann and Kleber, 2015, p.62). Larger organic compounds are broken down and form smaller molecules with increased polar and ionizable groups, which leads to increased water solubility. Simultaneously, reactivity towards mineral surfaces is rising, thus molecules are protected against further decomposition. This adsorption can be followed be desorption, abiotic or biotic degradation or exchange reactions with other organic compounds. Microbes are involved in this decomposition process, as they deposit "microbial cells, cell debris, exopolysaccharides, and root exudates on mineral surfaces " (Lehmann and Kleber, 2015, p.62).

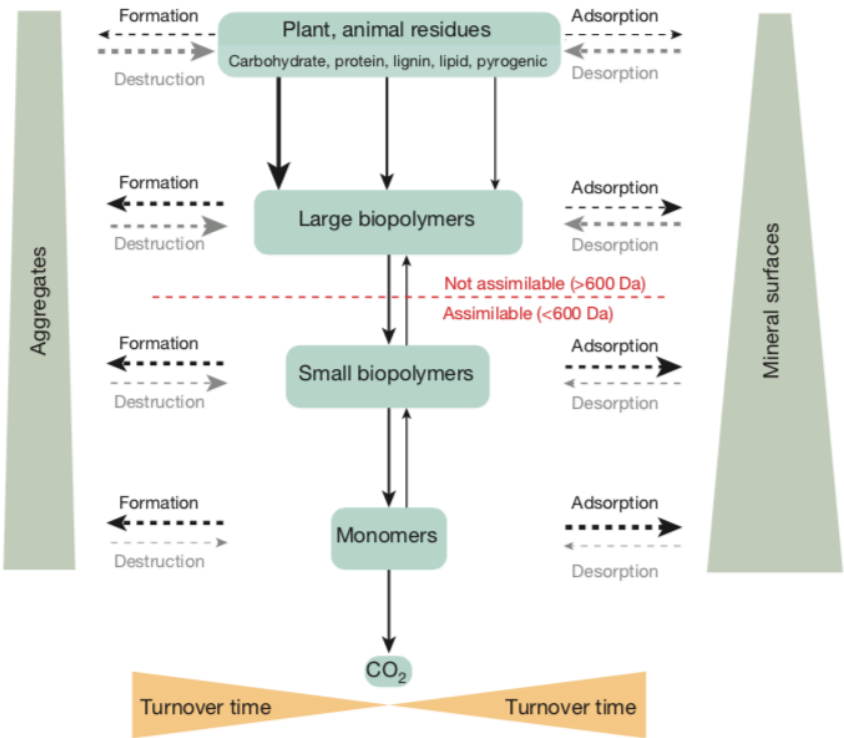

Figure 2: The soil continuum model. Dashed arrow lines denote mainly abiotic transfer, solid lines denote mainly biotic transfer; thicker lines indicate more rapid rates; larger boxes and ends of wedges illustrate greater pool sizes; all differences are illustrative. All arrows represent processes that are a function of temperature, moisture and the biota present (Source: Adapted from Lehmann and Kleber, 2015).

2.4. Leaching of Nitrogen

Reactive N entering the environment has several effects. By adding N through fertilizers and domestic legumes into the system to achieve greater yields, humans have created a higher productivity within agriculture (Galloway et al., 1995). It is estimated that, due to human activities, the global N fluxes of reactive N (including N_2O, NO_3^-, NH_3, NH_4^+ and NOx) have doubled (Vitousek et al., 1997).

In numbers, 180 Tg N are put into agroecosystems each year, of which fertilizer accounts for approximately 120 Tg and agricultural BNF for 60 Tg N (Fowler et al., 2013). Nevertheless, storage of N in terrestrial ecosystems is limited, reactive forms can be accumulated in biomass or SOM (Galloway et al., 1995). 44-54 % of added N are taken up by crops, the remaining N is lost into the environment through leaching into ground and surface waters (together a loss of 32–45 Tg $year^{-1}$) and denitrification into the atmosphere (a loss of 26–60 Tg $year^{-1}$) (Smil, 1999). This inefficient use of N fertilization represents a great problem and risk, which need to be addressed (Tonitto et al., 2005). Negative effects on the environment are i.e. pollution of drinking water, eutrophication of surface water and oceans, ozone destruction in the stratosphere or ozone precursor in troposphere (Paul, 2007).

2.5. Reduced Soil Cultivation Methods

Tillage affects the built-up and loss of SOM through physical disturbance of soil and the incorporation of plant residues. By disrupting soil through cultivation, water content, aeration and microclimate are affected. These have impact on soil biota abundance and activity and the biological processes they influence. Conventional tillage methods reduce microbial diversity and therefor reduce resilience and stability of soil (Paul, 2007). Inverting soil with ploughs has been, until quite recently, the commonly used tool in agricultural cultivation. This inversion can, when continually used, lead to the degradation of the soil structure and further, to the development of fine particles with low SOM content. Consequently, soil moisture cannot be retained, which leads to anaerobic conditions that can cause a decrease in nutrient recycling. These processes can cause several environmental problems (Holland, 2004).

Conservation tillage (CT) can be defined as "a tillage or tillage and planting combination that retains a 30 % or greater cover of crop residue on the soil surface" (Carter, 2005, p. 306). It "involves soil management practices that minimise the disruption of the soil's structure, composition and natural biodiversity, thereby minimising erosion and degradation, but also water contamination" (Anonymous, 2001 as cited in Holland, 2004, p. 1f) (see figure 3). The main types of conservation tillage are mulch tillage, ridge tillage, zone tillage and no-tillage (Carter, 2005). Other techniques are cover cropping or incorporation of crops residues into the top soil, which can be described as conservation agriculture methods. Conventional tillage on the other hand, "defines a tillage system in which a deep primary cultivation, such as mouldboard ploughing, is followed by a secondary cultivation to create a seedbed" (Holland, 2004, p.2).

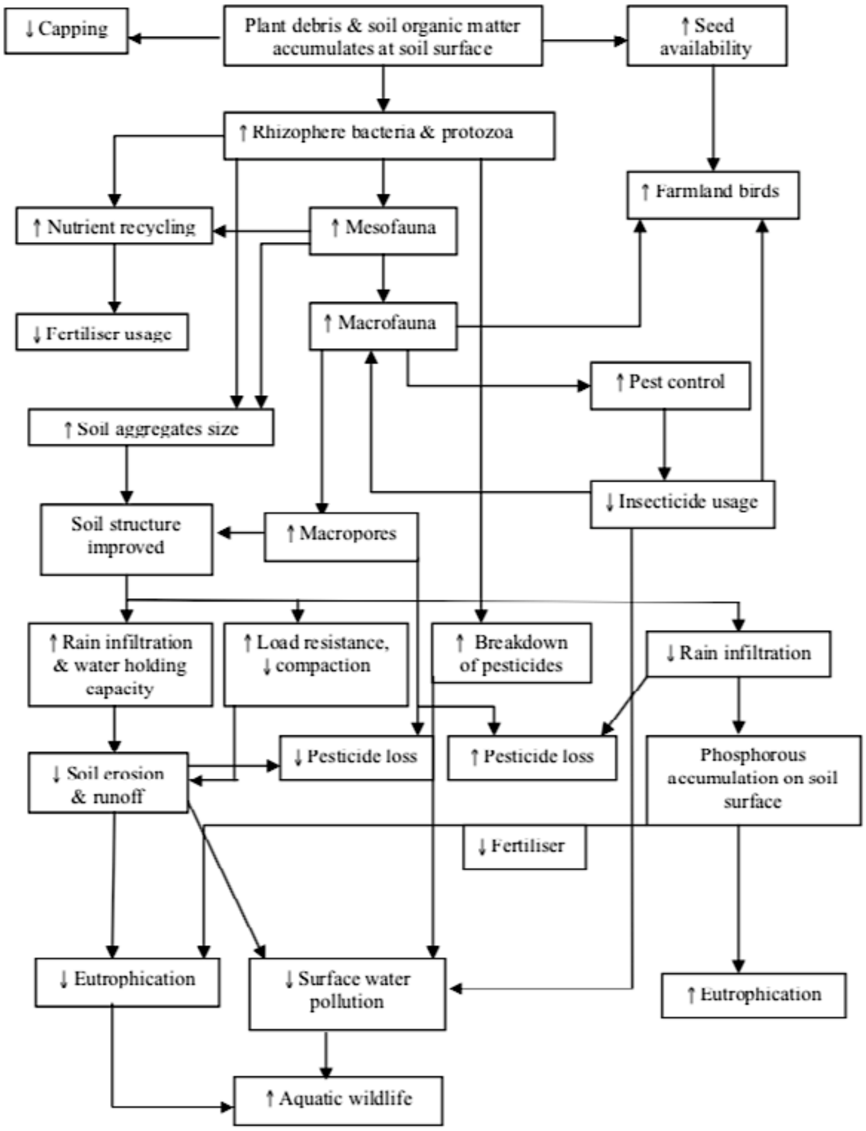

Figure 3: Interactive processes through which conservation tillage can generate environmental benefits (Holland, 2004).

2.6. The Role of Catch Crops in Agriculture

It can be distinguished between two forms of catch crops, summer and winter. Summer catch crops are sown after the harvest of main crops, their vegetation period peaks in late summer or autumn. There are either harvested before winter or are left on the field, where they are killed by frost (freeze-killed catch crops) or resist the cold (winter-hardy catch crops) and protect the soil until spring. Winter catch crops need 40-60 vegetation days before winter and 50-80 after to develop yield. They are sown in late August until mid of September, freeze partly or not at all during winter (winter-hardy) and are harvested from April to May (Lütke Entrup, 1991, Kolbe, 2004). Furthermore, summer catch crops can be cultivated as undersown or stubble crops. Undersown crops are sown with a main crop and stay on the field after the main crops is harvested. Main crops mostly used with undersown crops are cereals, winter faba bean and maize (Lütke Entrup, 1991). Catch crops suitable for mixed cultivation as undersown crops are white and red clover, Italian raygras and orchard grass (Kolbe, 2004). Stubble catch crops are sown after the harvest of the main crop, soil cultivation is adapted to the primary purpose of the stubble crop (fodder, green manure, weed control, etc.) (Lütke Entrup, 1991). Egyptian clover, fodder pea, fodder radish, phacelia and crimson clover are examples for stubble crops. Leguminous catch crops play an essential role in organic agriculture, as they provide the farm with N and C (in form of organic matter) (Kolbe, 2004).

It can be distinguished between fodder legumes and grain legumes. Depending on the type of farm, primary importance of catch crops and especially N-fixating legumes is shifting. Arable farms depend on perennial N-fixating catch crops, as they are the primary enhancers of soil fertility. When fodder legume yields are taken from the field and leave the farm system, a loss of nutrients is risked. In mixed farms, grassland and animal manure are other N sources next to legumes. Organic livestock farms need fodder catch crops (catch crops used as fodder) as main source of protein for the animal husbandry. Catch crops can be sown pure or mixed with a covering crop or other catch crops. Furthermore, they can be planted as undersown crops or after main crops. Legumes are only planted when N reservoirs are low, as their fixation capacity decreases in N rich soils. When N levels are low, legumes can fix N from the air, once their root systems are developed sufficiently (Freyer et al., 2005).

2.6.1. Advantages and Disadvantages of Catch Crop Cultivation

In agriculture, protection of the soil is accredited many times to catch crop cultivation. Depending on the type, deep or largely spread root systems can take up nutrients and water from deeper soil layers. Thus, they also protect nutrients from leaching into groundwater by transporting them back into upper horizons. Moreover, their roots enhance SOM formation and ensure a stabile soil structure. Another positive effect is the reduction of weeds and pests in soil, which allows diminished application of herbicides and pesticides. Weeds and catch crops compete for nutrients, water and light. When soil is cultivated adequately and catch crops are sown under the right conditions and at the right time, they are an efficient measure in weed control (Freyer et al., 2005, Lütke Entrup, 1991). Fodder catch crops are valuable green manure sources, as roots and other residues remain on the field (Lütke Entrup, 1991).

Catch crop mixtures of legumes and grasses or herbs support biodiversity, which can help ensuring a healthy agricultural ecosystem. Moreover, they improve yield security of the subsequent crop and, in some cases, improve yields up to 10%. As legumes are competing with grasses for growth factors, N-fixation capacity may be diminished. As grasses, on the other hand, reduce inorganic N content in soil, the activity of rhizobia is increasing which causes a net rise in N-fixation performance in many cases (Freyer et al., 2005). Mixed crops protect soil from nitrate leaching, improve soil cultivation conditions, increase SOM built-up when adequately balanced and enhance fodder quality (Freyer et al., 2005).

Problems occurring with forage crop cultivation are i.e. enhanced levels of nitrate in soil when ploughing the crops down. Nitrate then can leach into deeper layers or groundwater. These effects can be minimized by mixing legumes with non-legume catch crops, applying reduced soil tilling methods or the removing of legume biomass. Most of all, choosing the right time to terminate the forage crops reduces risks of leaching. In general, late autumn or on sandy soils, spring is recommended (Friedel, 2019). Intensive cultivation of legumes can moreover enhance pest occurrence. Therefore, careful selection of catch crops, cultivars and mixtures is recommended. When water and nutrient availability are low, they can lead to unfavourable conditions for the following crop or, when planted as undersown crops, compete with the main crop for water, nutrients and light (Freyer et al., 2005, Kolbe, 2004).

A careful selection of suitable catch crops for the given main crop and environmental conditions is vital to achieve good results (Kolbe, 2004). Winter catch crops can cause water scarcity for following cultures sown in spring by lowering storage water content (Lütke Entrup, 1991).

2.6.2. Important Catch Crops in Agriculture

2.6.2.1. Egyptian clover (Trifolium alexandrinum)

Yield: 80-100 dt DM ha^{-1} year^{-1}
N-fixation capacity: 50-150 kg^{-1} ha^{-1} year^{-1}
Egyptian clover in an annual legume and prefers light and middle heavy soil with high nutrient content. It tolerates salty soils and likes warm, moist climate. It has high yields and harvest residuals decompose fast.

2.6.2.2. Lucerne (Medicago sativa)

Yield: 50-70 dt DM ha^{-1} year^{-1}
N-fixation capacity: 80-350 kg^{-1} ha^{-1} year^{-1}
Alfalfa is the oldest fodder legume in the world. It has a very deep root system (2-4 m) and tolerates droughts. It prefers deep, warm and porous soils with pH between 6,5 and 7,5.

2.6.2.3. Orchardgrass (Dactylis glomerata)

Yield: 5-13,5 dt DM ha^{-1} year^{-1} (Mir et al., 2018)
High in yield and quality, allows clover cultivation in dry areas, usable in semi-humid and humid areas, often mixed with Lucerne.

(Freyer et al., 2005)

2.7. Maize

Maize belongs, as all cereals, to the family of grasses (Gramineen). Maize (*Zea mays L.*) is the only botanical species of the genus Zea. It comes in several varieties that differ in plant height, optimal growing period and kernel shape. Nevertheless, all forms belong to the same botanical species and have 20 chromosomes. According to the kernel shape, seven groups can be formed: dent, flint, pop, sweet, flour, waxy and pod. The plant develops out of a 0,25-0,3 g heavy kernel and reaches a height of 2-3 m after 12 weeks. After 2-3 more months, the plant produces 400-600 kernels. This fast development is enabled by the C-4 cycle, which allows enhanced photosynthetic activity (Zscheischler, 1990). The male two flowered spikelets develops a panicle shaped flower on the top of the plant (tassle) (figure 4), whereas the female spikelets are formed to an ear or cob (figure 5). This makes maize a monoecious cross-pollinator. From each ovary a 40-50 cm style develops which can take up the male pollen, pollination is performed by wind. As the pollen is released 2-4 days before the styles appear, maize plants protect themselves from self-pollination. The pollen falls on the styles, starts germinating, penetrates the egg and the kernel formation begins. The ripe kernel consists of the pericarp, the endosperm and the embryo. The endosperm consists of 90 % starch, 7% protein and smaller portions of oil and minerals, whereas the embryo is made up by 35% oil, 20% protein, 10% starch, sugar and ash. The kernels sit on the cobs and are covered by leaves, which forms the corn cob (Zscheischler, 1990).

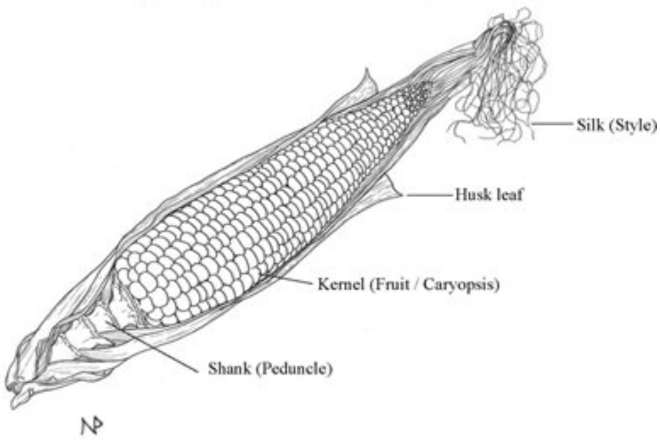

Figure 4: Zea mays ear. (Source: Polato, s.a.).

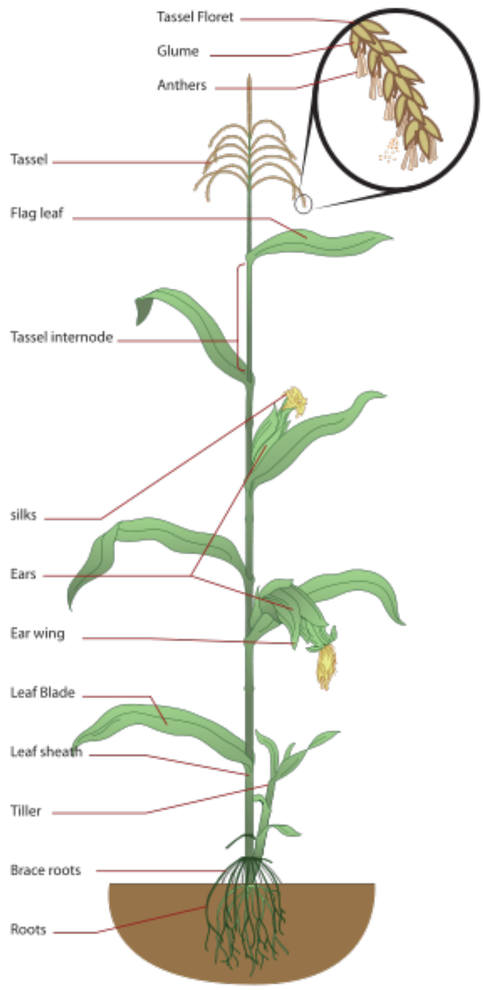

Figure 5: Maize Plant. (Source: Mariana Ruiz Villarreal, 2011).

Maize is one of the oldest cultivated plants on earth which origins in Mexico. It is estimated that from there it spread to Argentina and Canada (Zscheischler, 1990). About 5.700 years ago, Maize used to have very small cobs with a size of 2,5 cm. By selection and probably crossing, indigenous people started to cultivate maize. In the 16th century, maize found its way into Spanish and Italian house hold gardens. From there it spread to the oriental areas of the Mediterranean Sea. In the 17th century maize replaced millet in western Europe. Around this time, maize cultivation in Austria started, to be precise in the Vorarlberg Rhein valley. After the second world war, both maize and wheat produced about two tons per ha yield. The introduction of hybrids led to the development of more and more high performing species, which resulted in higher maize yields compared to wheat within a few decades. The development of special machinery and methods allowed farms to cultivate maize with the same efforts as other crops. Because of its great properties, maize can be cultivated almost everywhere in Austria. Especially in grassland areas with relatively small proportions of arable land, maize is used intensively (see figure 6). In the eastern region maize is cultivated in smaller scales (Ökosoziales Forum Österreich, 2015). Since the 1970s, land cultivated with grain maize and yields increased steadily (see figure 7). In 2018, 107,1 dt/ha DM (1.835.195 t total) conventional and 70,8 dt/ha DM (123.467 t total) organic maize was harvested in Austria (Agrarmarkt Austria, 2018).

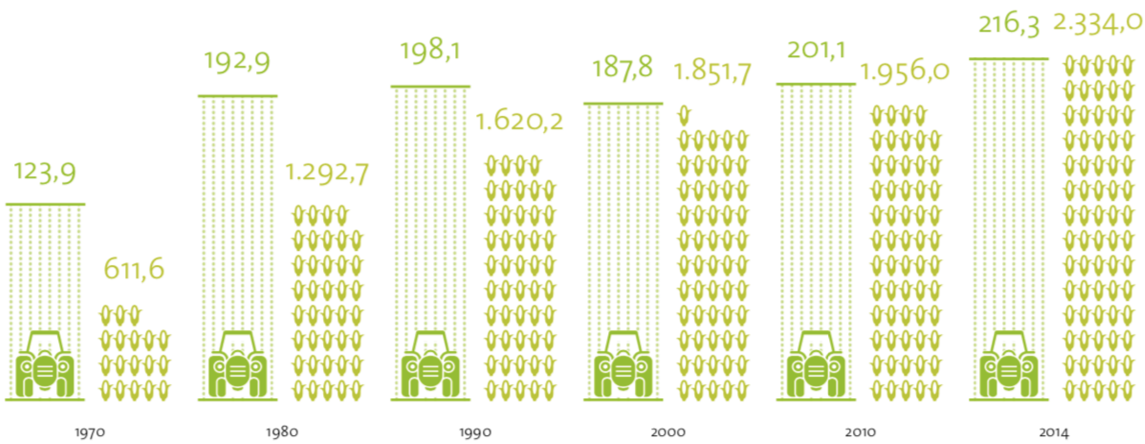

Figure 6: Development of land cultivated with grain maize and yield (incl. Corn-Cob-Mix [CCM]). Land in thousand ha, yield in thousand t. (Source: Statistik Austria, s.a., as cited in Ökosoziales Forum Österreich, 2015).

In Austria, maize plays a central role in agriculture for several reasons. Firstly, it has a great yield performance. Especially compared to other crops, maize needs less space, work force and financial inputs to achieve the same amounts of yield. Moreover, it can be used versatile. The whole plant can be fed as silage to cows or used to produce gas in biogas plants. Corn-cob-mixtures can be fed to pigs or poultry, the kernels can become products for human consumption, as feed or resource for the industry. Lastly, the breeding of new maize species is more profitable than for other cultivated plants, as maize has a special way of reproduction, breeding and specific physiological characteristics. This leads to a steady increase in yields (Ökosoziales Forum Österreich, 2015).

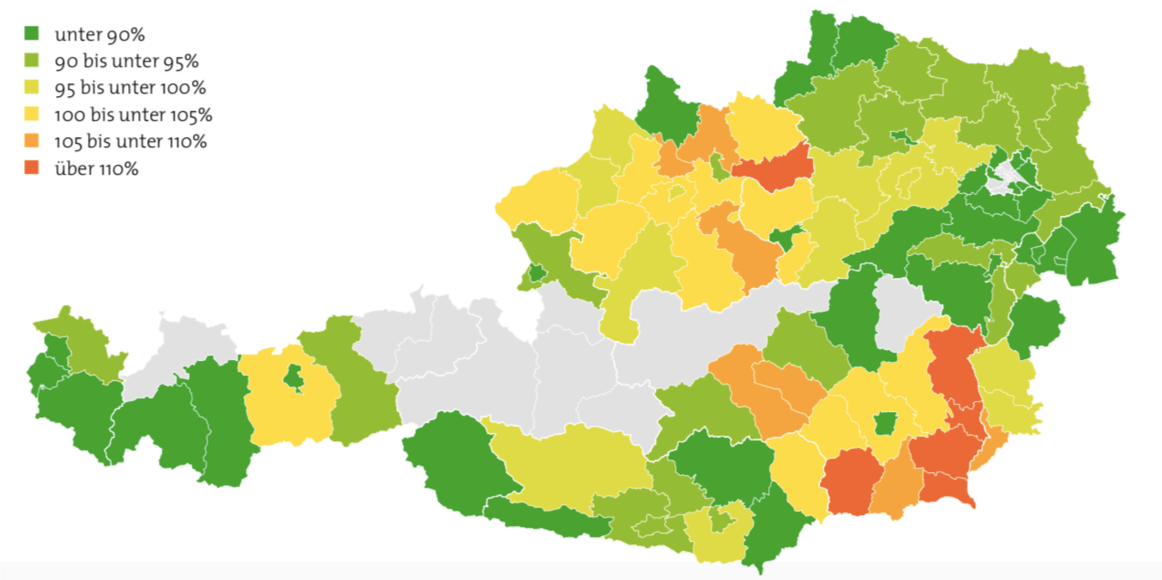

Figure 7: Earning levels for grain maize (incl. CCM) according to districts. Deviation from the average for Austria, 2009-2013 (5 years). (Source: Ökosoziales Forum Österreich, 2015).

As a subtropical plant, maize has a high requirement on warmth but low demands on soil (Zscheischler, 1990, Ökosoziales Forum Österreich, 2015). It requires a rapid warming potential of soil and no compaction, optimum bulk density allows deep root development (Ökosoziales Forum Österreich, 2015). Maize grows from April to October; the sowing date depends on soil temperature and risk of frost. Optimum temperatures are at around 30°C, even daily declines under 10°C can cause a reduction in growth. Water requirements peak during the period of growth in length and the end of grain filling phase. Water retention capacity and nutrient availability are also important factors. Sites with sandy, shallow soils and distance to ground water show greater yield security (Sinabell et al., 2015).

Shallow to middle deep tillage in spring should be performed 2-3 weeks before sowing to allow soil warming. A temperature of 8-10 °C in a soil depth of 5 cm, usually reached end of April or beginning of May, is the optimum for seed germination. Liquid manure and manure should be tilled into the soil. Catch crops should be shredded to avoid formation of crop matts. Seeds should be sown 3-4 cm deep in heavy and 4-6 cm deep in light soils. The desired number of plants per m^2 are 8-10 for grain maize (+5 to +15 % for silage maize), depending on type of maize and water availability (Drangmeister, 2011).

There are several challenges of maize cultivation in organic agriculture. Firstly, maize has high demands on nutrients and previous crops. Moreover, weed control is difficult in young stages of maize, as they have slow development of early stages, which leads to lower yields and quality. Further, maize can have unfavourable environmental impacts as increased potential of soil erosion or compaction. Lastly, maize plants are sensitive against low temperatures, water logging and drought in their younger stages. Low N and P uptake leads to light green or blue-violet colouring of the leaves (Drangmeister, 2011).

The cultivation of maize with catch crops is possible. They can also be sown as undersown crops under maize, when water availability is sufficient (Freyer et al., 2005). This brings several possible advantages, as decreased erosion, nutrient depletion or weed development, improved crop rotation and soil biota and phytosanitary effects (Drangmeister, 2011). To assure sufficient N availability, it is recommended to cultivate maize after legumes (as clover grass or leguminous catch crops). When fertilization is high, cultivation after root crops or cereals is possible. Suitable crops before maize are legumes, winter wheat and root crops (Drangmeister, 2011). Moreover, lucerne grass, peas, lupin, lentils chickling vetch and red clover grass are very suitable previous crops for maize. Winter faba bean and soy bean are also applicable (Freyer et al., 2005).

After silage maize, grain legumes, winter wheat and summer cereals can be cultivated. Root crops, summer cereals and grain legumes are suitable after corn maize (Drangmeister, 2011).

3. Scope

3.1. Aims

In this experiment, two treatments were compared. Each treatment consisted of a catch crop mix and a tillage method. In treatment A, winter-hardy catch crops were tilled by a rotary cultivator, in treatment B freeze-killed catch crops were tilled by a cultivator. Moreover, in treatment A, an undersown crop was sown in maize. The aim of this study was to assess which treatment is more suitable for a conservation-oriented soil cultivation on a specific site. Moreover, a goal was to investigate how the different treatments influence biomass development, nutrient supply and yields of the subsequent crop, maize. Another objective was to assess how the treatments are influencing soil parameters, especially nitrogen content, and affect weed pressure. By obtaining these results, recommendations for catch crop mixture applications and combinations with tillage methods could be given to farmers in order to achieve better harvests while improving soil health. As the trial is conducted according to the principles and laws of organic farming in Austria, especially organic farmers could benefit from the results.

3.2. Hypotheses

Regarding the formulated aims of the study, the following hypotheses were defined:

H1: The treatments do not have different effects on soil, therefore the surveyed soil parameters will show no differences when comparing the treatments.

H2: Weed pressure does not differ between the two treatments.

H3: Maize kernel yield, carbon and nitrogen content of maize plants, and above-ground biomass of maize do not differ between the treatments.

4. Material and Methods

4.1. Experimental Site

In summer 2016 the trial was started on farmland of Johann Kurzbauer, one of the organic farmers participating in the BIOBO project. Mr. Kurzbauer owns 11.5 ha land, which is below Austria's average, and converted to organic agriculture in 2008. Since then, the farmer is focusing on soil, reduced tillage and green manure. The farm is stockless since 1998. He takes part in a machinery cooperation, which provides a wide range of agricultural equipment. The trial area is located in Raipoltenbach, lower Austria (district Neulengbach). Raipoltenbach is situated in the south of Tulln, 230 m above sea level. The first year, the experiment (Johann Kurzbauer 1: JK1) was set on a different field which was leased. The second year, the trial field was changed to assess the effects of the treatments on maize. In August 2017, the experiment was continued on land owned by the farmer (Johann Kurzbauer 2: JK2). There, the trail area was set, then, on 21.8.2017, the catch crop treatments were sown. Due to the authors later joining to the BIOBO project, this thesis will focus on the second trial area and its results.

4.1.1. Soil Characteristics

The soil on the field belongs to the soil type orthic Luvisols (Lo) (German: Parabraunerde) (Umweltbundesamt Österreich, s.a.). As visible in table 1, dominant soil texture was silty loam (Lu) (according to KA4/KA5 pedological guidelines). In figure 8, particle fraction distribution in % over soil depth can be found. As clay content was on average above 25%, the soil can be categorised as heavy soil (BMLFUW, 2017). In table 2, values for pH, phosphate, phosphorus, potassium oxide and potassium for both treatments can be found. Mean values of pH for both treatments were 6.7, which is slightly higher than the recommended values (6 – 6.5) for heavy soils used as arable land (BMLFUW, 2017). Soil phosphorus mean values (55.75 for treatment A, 53.33 for treatment B) can be classified as category C – sufficient. Potassium (104.41 for treatment A, 102.83 for treatment B) can be categorized as low (category B) for heavy soils (BMLFUW, 2017).

Table 1: Soil particle distribution (%) and resulting soil texture.

Treatment	depth (cm)	Sand	Silt	Clay	Texture
A	0-15	11.41	63.48	25.13	silt loam (Lu)
	15-30	11.04	61.00	27.95	silt loam (Lu)
	30-50	9.32	67.10	23.58	silt clay loam (Ut4)
	mean	10.59	63.86	25.55	
B	0-15	11.89	60.70	27.44	silt loam (Lu)
	15-30	11.24	62.08	26.70	silt loam (Lu)
	30-50	9.80	62.30	27.89	silt loam (Lu)
	mean	10.98	61.69	27.34	

Table 2: pH, phosphate (mg (100 g)$^{-1}$), phosphorus (mg kg^{-1}), potassium oxide (mg (100g)$^{-1}$) and potassium (mg kg^{-1}) values for three soil depths (5.9.2017).

Treatment	depth (cm)	pH	Phosphate	Phosphorus	Potassium Oxide	Potassium
A	0-15	6.59	19.8	88.3	17.8	147.8
	15-30	6.65	15.8	68.5	11.9	99.0
	30-50	6.91	2.4	10.5	8.0	66.5
B	0-15	6.62	19.2	83.5	17.0	141.3
	15-30	6.67	15.4	67.3	12.1	100.3
	30-50	6.88	2.2	9.3	8.1	67.0

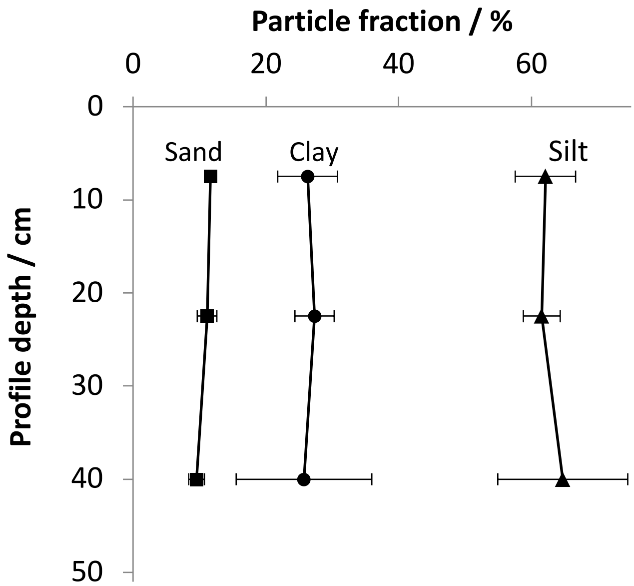

Figure 8: Particle size distribution (%). (Source: Institute BOKU Institute of Hydraulics and Rural Water Management, 2018).

4.1.2. Climatic Conditions

In 2018, the precipitation measured in this area was 626 mm/year and the average annual temperature was 11.5 °C. The cumulative precipitation and monthly average temperatures are displayed in figure 9. The same information for the years 1991-2010, 2016, 2017 and 2018 can be found in table 3 (Bundesministerium für Nachhaltigkeit und Tourismus, 2018).

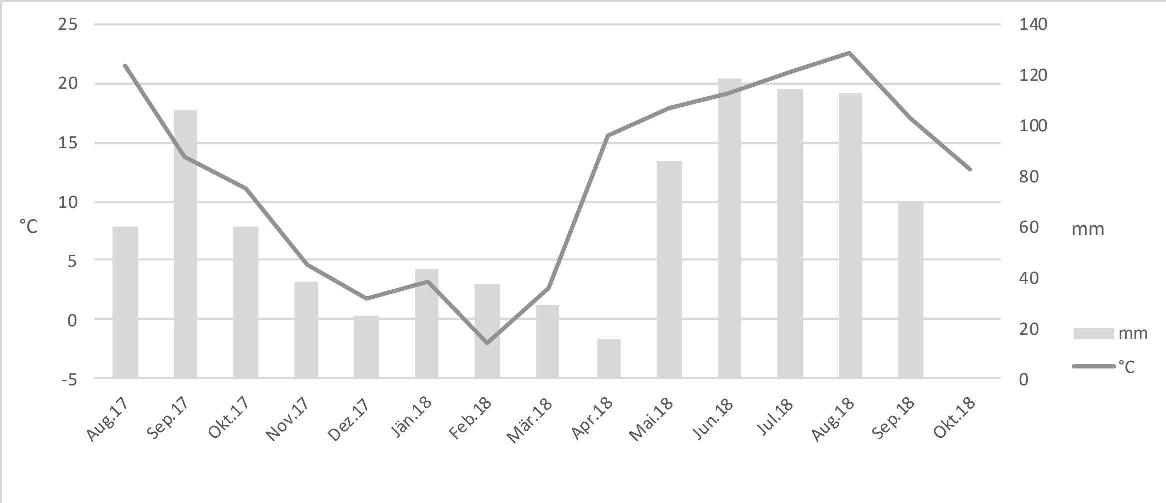

Figure 9: Precipitation and temperature from August 2017 to October 2018. (Source: adapted from (Bundesministerium für Nachhaltigkeit und Tourismus, 2018).

Table 3: Air temperature (C°) and precipitation (mm) in the years 2016, 2017, 2018 and the means of 1991-2010; Data from the weather station in Maria-Anzbach (Source: adapted from Bundesministerium für Nachhaltigkeit und Tourismus, 2018)

	Average Air Temperature				Cummulated Precipitation			
Month	1991-2010	2016	2017	2018	1991-2010	2016	2017	2018
January	0.1	0.3	-4.3	3.2	23.9	48.2	28.6	43.5
February	1.6	5	2.7	-2	21.3	50.9	31.7	37.4
March	5.4	5.3	8.3	2.6	40.4	41.5	26.4	29
April	10.1	10.3	8.9	15.5	43.1	64.2	73.1	15.9
May	15	14.3	15.7	17.8	66.1	120.9	78.2	86
June	18.1	18.8	21	19.2	86.8	104.7	41.7	118.2
July	19.8	20.7	20.6	21	89.4	118.6	140.7	114
August	19.3	19.2	21.4	22.6	75	47.1	59.8	112.2
September	14.7	17.9	13.8	16.9	71.4	63.3	106.2	70
October	9.9	8.8	11.1	12.6	37	113.4	60	0
November	5	4.3	4.7	5.7	37.6	57.9	38.6	0
December	0.4	0.7	1.7	2.4	36.9	20.6	24.8	0
Jan-Dec	**9.9**	**10.5**	**10.5**	**11.5**	**628.9**	**851.3**	**709.8**	**626.2**

4.2. Experimental Design and Set-Up

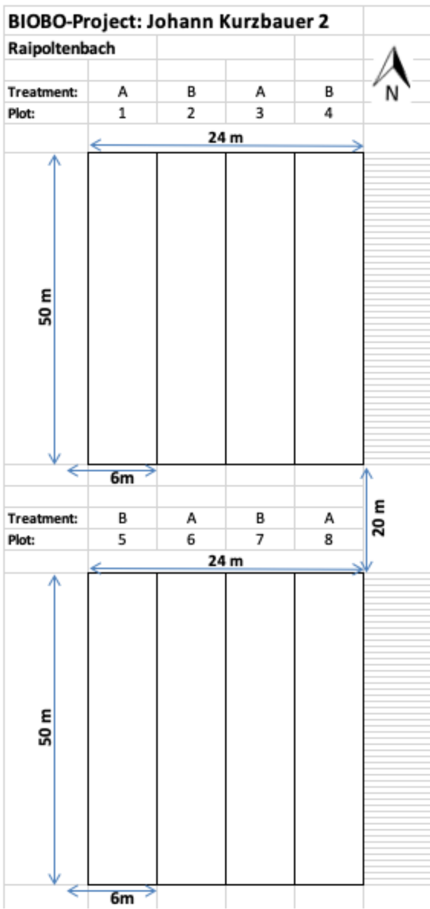

Figure 10: Measure of trial set-up. 8 plots with treatment A and B. (Source: Benedikt Blankenhorn, 2017).

The field was 120 m long, 24 m wide (2880 m^2 or 0,28 ha) and separated into eight plots (each 6 m x 50 m). There was a 20 m space in between the upper and lower row. Two treatments (A and B, description see chapter ***4.3. "Trial treatments"***) were repeated four times (see figure 10 and 11). The trial was set-up as a standard block design with four blocks. Each treatment was therefore repeated four times. Each block consisted of two plots, cultivated with both treatments. For statistical analysis, fixed factor was the treatment, random factor the block.

The crop cycle was designed as the following (Only the steps in bold were part of the experiment):

Clover-grass – Winter wheat – **Catch crops – Maize (Undersown crops) - Soybean**

Figure 11: Satellite picture of the trial area (JK2). Adapted by Benedikt Blankenhorn. (Source: Google Earth, s.a.).

4.3. Trial Treatments

Two different catch crop mixtures were applied on the field. One consisted of winter-hardy catch crops, the other one of catch crops which are freeze-killed. Moreover, soil cultivation after catch crop harvest differed between the treatments. The winter-hardy catch crop mix was tilled by a rotary cultivator, whereas the freeze-killed mix was tilled by a cultivator. Lastly, an undersown crop mix under maize was established in treatment A, as the farmer wanted to intensify the effects of green covering. The system of winter-hardy catch crops, tillage by the rotary cultivator and undersown crop is named “Treatment A”. The system of freeze-killed catch crops and tillage by the cultivator is named “Treatment B”.

The winter-hardy catch crop mix consisted of winter vetch (*Vicia villiosa*), Italian raygras (*Lolium multiflorum*) and crimson clover (*Trifolium incarnatum*). The freeze-killed catch crop mix was composed of fodder pea (*Pisum sativum L. arvense*), common vetch (*Vicia sativa*), chickling vetch (*Lathyrus sativus*), buckwheat (*Fagopyrum esculentum*), phacelia (*Phacelia tanacetifolia*) and fodder radish (*Raphanus sativus var. oleiformis*). In the following, each catch crop mix will be described in more detail, average yields (dt DM ha^{-1}) and nitrogen fixation capacity (kg ha^{-1}) are listed in table 4. The precise composition, seed rate and cultivation method can be found in table 5.

Winter-hardy Catch Crops

“Landsberger Gemenge” consists of the following catch crops (Freyer et al., 2005):

<u>Winter vetch (*Vicia villiosa*)</u>

Yield: 25-30 dt DM ha^{-1} $year^{-1}$

N-fixation capacity (on average): 100 kg^{-1} ha^{-1} $year^{-1}$

Soil and climate demands are lower compared to the common vetch. When water supply is given, it can also grow on sandy soils. The winter vetch prefers warm, moist autumns and dry springs. Optimum pH is around 6,5-7,0.

<u>Crimson clover (*Trifolium incarnatum*)</u>

Yield: 70-100 dt DM ha^{-1} $year^{-1}$

N-fixation capacity: 50-150 kg^{-1} ha^{-1} $year^{-1}$

Prefers light to medium and calcareous soils and mild winters. Crimson clover grows fast and is winter-hardy. It is not suitable as a nurse crop, as it shows rapid development in young stages.

Italian raygras (*Lolium multiflorum*)

Yield: 30-40 dt DM ha^{-1} year^{-1} (Bio Austria, 2018)

Fast growing perennial fodder grass, sensitive against rough climate, suppresses catch crops in mixture as it shows rapid development in young stages.

(Freyer et al., 2005)

Freeze-killed Catch Crops

Fodder pea (*Pisum sativum L. arvense*)

Yield (grain and straw): 60-90 dt DM ha^{-1} year^{-1} (Aufhammer, 1998, Keller et al., 1999 cited as in Freyer et al., 2005)

N-fixation capacity on average: 100 kg^{-1} ha^{-1} year^{-1}

Most cultivated grain legume in organic agriculture. Fodder peas improve soil structure in subsequent crops and show strong vegetative growth which suppresses weeds.

Common vetch (*Vicia sativa*)

Yield: 10-25 dt DM ha^{-1} year^{-1} (Aufhammer, 1998, Keller et al., 1999 cited as in Freyer et al., 2005)

N-fixation capacity on average: 100 kg^{-1} ha^{-1} year^{-1}

The common vetch is tolerant to low pH but prefers soil pH around 6. It is drought resistant but needs sufficient water supplies when forming flowers and grains to achieve adequate yields.

Chickling vetch (*Lathyrus sativus*)

Yield (grain): 10-40 dt DM ha^{-1} year^{-1}Aufhammer, 1998, Keller et al., 1999 cited as in Freyer et al., 2005)

N-fixation capacity on average: 80 kg-^{1} ha^{-1} year^{-1}

The chickling vetch has low demands on climate, is drought tolerant, frost-resistant and grows on lime rich soils (Kolbe, 2004).

Buckwheat (*Fagopyrum esculentum*)

Yield: 5-15 dt DM ha^{-1} year^{-1} (Limbacher et al., 2015)

Buckwheat is very drought resistant and sensitive to cold temperatures. It has a rapid youth development and therefor suppresses weeds effectively (Limbacher et al., 2015).

<u>Phacelia (*Phacelia tanacetifolia*)</u>

Yield: 25-30 dt DM ha^{-1} year^{-1}

Phacelia is very drought tolerant and can produce high amounts of biomass in a short time. It can be cultivated on all soils and has low demands on climate (Kolbe, 2004).

<u>Fodder radish (*Raphanus sativus var. oleiformis*)</u>

Yield: 40-50 dt DM ha^{-1} year^{-1}

Often used catch crop which has powerful weed controlling effects. It has a strong root system and is tolerant to low nutrient availability (Kolbe, 2004).

(Freyer et al., 2005)

Table 4: Yield (dt DM ha^{-1} year^{-1}) and N-fixation capacity (kg ha^{-1} year^{-1}) of catch crops of treatment A and B (Source: Freyer 2005, Bio Austria 2018, Aufhammer, 1998, Keller et al., 1999 cited as in Freyer et al. 2005, Limbacher et al. 2015 and Kolbe 2004).

Catch Crop	Treatment	Yield	N-fixation capacity
Winter vetch	A	25-30	100
Crimson clover	A	70-100	50-150
Italian raygrass	A	30-40	-
Fodder pea	B	60-90	100
Common vetch	B	10-25	100
Chickling vetch	B	10-40	80
Buckwheat	B	5-15	-
Phacelia	B	25-30	-
Fodder radish	B	40-50	-

Table 5: Description of treatments: Catch crop mixes, composition, seed rate (kg ha^{-1}), ratio (%) and soil cultivation.				
Treatment	**Cultivation**			
	Catch Crops (CC)	Seed rate	% of mix	Soil Cultivation
A	**Winter-hardy CC:** Winter vetch Ital. Raygras Crimson Clover	 102.50 11.25 11.25 **Total: 125.00**	 82 9 9	Rotary Cultivator (3-4cm)
B	**Freeze-killed CC:** Fodder Pea Common vetch Chickling vetch Buckwheat Phacelia Fodder radish	 142.00 58.00 50.00 12.00 8.50 8.50 **Total: 279.00**	 50.90 20.79 17.92 4.30 3.05 3.05	Cultivator (3-4cm)

In May 2018 maize, variety “Connexion RZ 340” was sown with the precision air planter “Monosem”. The seed rate was 7.4 C/m^2, the distance within the row 18 cm and the row distance 75 cm on all eight plots.

On 18.7.2018 and 19.7.2018, undersown crops were established by hand in maize in treatment A (plots 1, 3, 6 and 8). The mixture consisted of 1.5 kg TerraLife Bio Active Green, 0.6 kg M2 and 0.35 kg phacelia (a sum of 2.45 kg) and seed rate was 41.5 kg ha^{-1} (see table 6). TerraLife Bio Active Green has a high ratio of legumes (73.4 %), is fast growing, covers soil well and roots deeply. M2 consists of 10 % legumes, grows slowly but dense and has high root penetration, which is decreasing weed pressure (Deutsche Saatveredelung AG, s.a.).

Table 6: Description of undersown crop mix: Mixes, composition, seed rate (kg ha^{-1}) and ratio (%).				
Mix	Common name	Latin name	% of mix	seed rate
TerraLife Bio Active Green	Egyptian clover Squarrose clover Linseed Phacelia Persian clover Serradella	*Trifolium alexandrinum* *Trifolium squarrosum L.* *Linum usitatissimum L* *Phacelia tanacetifolia* *Trifolium resupinatum* *Ornithopus sativus*	20 20 15 15 15 15	1.5
M2	Ryegrass White clover	*Lolium perenne* *Trifolium repens*	90 10	0.6
Pure	Phacelia	*Phacelia tanacetifolia*	100	0.35
				2.45

4.4. Cultivation Methods

Both treatments were cultivated the same. On the 21.8.2017 winter-hardy and freeze-killed catch crops were sown and currycombed two days later, on the 23.8.2017. Treatment A was tilled by a rotary cultivator with a depth of 3-4 cm on the 19.4.2018, treatment B was tilled by a cultivator on the 27.4.2018 in a depth of 3-4 cm. As maize does not require a very fine seedbed, it is sufficient if the cultivation is finished between April and May (Peszt, 2007). The advantages and disadvantages of the cultivation with rotary cultivator and cultivator can be found in table 7.

Table 7: Advantages and disadvantages of rotary cultivator and cultivator (adapted from Peszt, 2017).

Rotary Cultivator	Cultivator
Advantages:	**Advantages:**
- no distrubtion of layers, hence preservation of soil biota - shallow cultivation across the full working width possible - incorporation of long straw possible - promotes decomposition of organic material - crushes soil blocks in heavy soils	- no distribution of layers, hence preservation of soil biota - cultivation across the full working width possible (wing share or sweep share)
Disadvantages:	**Disadvantages:**
- risk of rotary cultivator pan and disruption of structure - risk of insufficient shredding of tough plants, hence problems during sowing	- risk of clogging if high amounts of long straw material - risk of cultivator pan if shares are set very flat

On the 30.4.2018 both treatments were tilled by a rotary cultivator und harrowed. On the 5.5.2018 all plots were currycombed and two days later, maize was sown. The used variety was "Conexxion RZ 340", which can be used as grain and silage maize. It belongs to the group of dent/flint and has a high protein content. The TKW (thousand kernel weight) is between 350-360 g (Saaten, 2019).

On the 12.5.2018 both treatments were currycombed and on the 1.6. and 8.6.2018 the hoeing equipment was used to diminish thistle weed pressure. Weed management by hand had to be done on the 12.7. on plot 1 and 3, on the 13.7. on plot 6 and on the 14.7. on plot 8 (all formally cultivated with treatment A). On the 18.7. undersown crops were sown by hand in plots 1 and 3. The same was done for plots 6 and 8 one day later, on the 19.7.2018. Maize was harvested on the 8.10.2018 and straw mulched with a scuffle hoe on the 12.10.2018 (complete time table see table 8).

Table 8: Time table of experiment.

Date	Measure	Who?	Comments
18.08.17	Measure trial	BB	
21.08.17	Winter-hardy and freeze-killed catch crops sown	JK	
23.08.17	Treatment A+B currycombed	JK	
05.09.17	Soil samples (AGES)	BB	
08.09.17	Bulk density, Particle Size Distribution	BB	
07.11.17	Harvest and visual assessment of both catch crop mixes	BB	
15.02.18	Project meeting	JK, GG, BB	
09.03.18	GPS measurement of trial	BB	
14.03.18	GPS measurement of trial	BB	
27.03.18	Root samples, 0-15 cm, 15-30 cm, Parc 1-4, GPS measurement finished	BB	
29.03.18	Root samples, 0-15 cm, 15-30 cm, Plot 5-8, JK2 GPS marks for yield and soil samples set	BB	
06.04.18	Planned: soil samples (Nin, Min) (0-30, 30-50, 50-90 cm) -> taken on 19.4.18 (broken generator)	BB	
19.04.18	Soil samples (Nin, Min, 0-90 cm) and harvest catch crops treatment A	BB	
19.04.18	Tilling by rotary cultivator of treatment A	JK	3 to 4 cm
20.04.18	WPA hole digging and soil sampling, soil moisture measurement in 10 cm to 80 cm depth	BB	
27.04.18	Catch crop harvest of treatment B	BB	
27.04.18	Tilling by cultivator of treatment B	JK	3 to 4 cm
30.04.18	Tilling by rotary cultivator of treatment A+B	JK	5 to 8 cm
30.04.18	Harrowing treatment A+B	JK	
05.05.18	Treatment A+B currycombed	JK	
07.05.18	Sowing maize „Conexxion RZ 340", treatment A+B	JK	3 to 4 cm
12.05.18	Currycombing (blind) of treatment A+B	JK	
01.06.18	Usage hoeing equipment treatment A+B	JK	
08.06.18	Usage hoeing equipment treatment A+B	JK	
03.07.18	Soil samples (Nin, Min, aggregate stability) (0-15, 15-30, 30-50, 50-90 cm)	BB	
12.07.18	Weed hoeing by hand plot 1+3, treatment A	JK	
13.07.18	Weed hoeing by hand treatment plot 6, treatment A	JK	
14.07.18	Weed hoeing by hand treatment plot 8, treatment A	JK	
18.07.18	Sowing undersown crops in plots 1 and 3, treatment A	JK	sown by hand
19.07.18	Sowing undersown crops in plots 6 and 8, treatment A	JK	
21.08.18	WPA hole digging and soil samples, setting marks for maize harvest	BB	
08.10.18	Maize harvest (Samples)	BB	
09.10.18	Maize harvest (by farmer): yield 25% moisture; 4.540 kg FW; DM net: 3.900 kg	JK	
12.10.18	Maize straw mulched with scuffle hoe	JK	
24.10.18	Soil samples (AGES)	BB	
31.10.18	Bulk density	BB	

BB Benedikt Blankenhorn, Field technician; JK Johann Kurzbauer, Farmer; GG Gabriele Gollner, Project Supervisor

4.5. Soil Sampling

The great number of measurements was done to assess different soil parameters and therefore receive sufficient information on the initial state of the soil and its possible changes during the experiment. Soil sampling for chemical analyses was done by the Division of Organic Farming. The analyses were done in the laboratories of the own division, of the Institute of Hydraulics and Rural Water Management (IHLW) and the Austrian Agency for Health and Food Safety (AGES). Physical soil assessment was conducted by WPA Beratende Ingenieure GmbH. In the following, the sampling and analysing procedures done will be explained.

4.5.1. Physical Soil Assessment by WPA Beratende Ingenieure GmbH

WPA Beratende Ingenieure GmbH (WPA) conducted their soil measurements twice, first on the 20.4.2018 and secondly on the 21.8.2018. For each date, two testpits with a size of 1x1x1 m were dug, each in a plot cultivated with a different treatment. On the 20.4.18, pits in plots 3 and 4 were dug to assess root penetration intensity and soil structure. Moreover, water infiltration and penetration resistance (humidity was measured parallel to penetration resistance) were assessed for plots 3 and 4. The weather was sunny with 26°C. On the 21.8.2018, the same was done for plots 5 and 6, except for the penetration resistance measurements, as the soil was too dry. It was planned to conduct the tests on plots 3 and 4, but weed pressure was too high. Again, the weather was sunny with 30°C. In the following, the conduction of the named measurements will be described in detail.

4.5.1.1. Water Infiltration

Water infiltration was determined with a double ring infiltrometer (see figure 12). The two rings are put partially into the soil and filled with water, the time is stopped, and the speed of infiltration is measured. The lateral spread of water is limited by the double ring construction (Eijkelkamp Soil & Water, 2018).

Figure 12: Example of a double ring infiltrometer. (Source: DI Trugina & Partner, Ziviltechniker für Kulturtechnik und Wasserwirtschaft ZT-GmbH, s.a.).

“Infiltration is the process of water penetrating the ground surface. The intensity of this process is called the infiltration rate. The infiltration rate is expressed in terms of the volume of water per ground surface and per unit of time [L/T [remark by author: length per time], for instance mm/min]. The infiltration capacity of the soil indicates the maximum infiltration rate at a certain moment. […] The rate of flow also depends on the hydraulic conductivity of the soil. The hydraulic conductivity [L/T] varies with moisture content of the soil: the dryer the soil, the lower the level of hydraulic conductivity; soil pores filled with air do not conduct water. Saturated soil has the highest level of hydraulic conductivity (saturated hydraulic conductivity). This hydraulic conductivity is mainly determined by the geometry and the distribution of pores” (Eijkelkamp Soil & Water, 2018, p. 3). In table 9, a soil classification table based on saturated hydraulic conductivity K_f can be found.

Table 9: Soil classification table based on values of saturated hydraulic conductivity K_f ($m\ s^{-1}$) (according to the formerly valid Czech standard). (Source: Adapted from Czech University of Life Sciences Prague, 2013).

Soil (according the relative permeability)	**Approximate range of saturated hydraulic conductivity**	**Examples of soil types**
Highly impermeable	$< 10^{-10}$	clays with low and medium plasticity, clays with high and extremely high plasticity
Impermeable	from 10^{-8} to 10^{-10}	gravel loams, gravel clays and sandy clays, loams with low and medium plasticity
Lowly (poorly) permeable	from 10^{-6} to 10^{-8}	sandy loams, loamy sands and clayey sands, loamy gravels and clayey gravels
Permeable	from 10^{-4} to 10^{-6}	sands and gravels, containing fine-grained fraction (5 – 15 %)
Highly permeable	$> 10^{-4}$	sands and gravels without or with very low fine grained fraction (<5%)

On the 20.4.18, the experiment lasted 40 minutes on plot 4 and 45 minutes on plot 3. After that a constant infiltration rate was achieved. The measurement on the 21.8.2018 lasted 115 minutes on plot 5 (due to the dry conditions and crack in the soil) and 40 minutes on plot 6.

4.5.1.2. Penetration Resistance

Penetration resistance gives information about the bearing capacity of the soil. Moreover, it makes it possible to assess how easy roots can spread through it. This data is especially important for agriculture or civil engineering. Penetration resistance is a mechanical size which is dependent on parameters that change throughout the soil profile, for example moisture, density or connection strength between mineral particles. This data can be collected by using an electronic penetrometer connected to a datalogger, called a penetrologger. It is a flexible tool which can be used for measurements on the field (Eijkelkamp Soil and Water, 2019), which was also used for this experiment.

Bearing capacity gives information about the resistivity of the soil to agricultural cultivation or cattle. Sufficient bearing capacity allows fundamental agricultural practises. “To assess the bearing capacity, a critical limit can be set for several applications. In the case the resistance to penetration is above this critical limit, the bearing capacity is sufficient, below that limit it the capacity is insufficient” (Eijkelkamp, 2013, p. 3f). Regarding rootability, a maximum of 1 MPa can be used as a guideline. This is the force that roots can have on soil. Nevertheless, roots can grow around stones or compacted aggregates, which cannot be achieved by the penetrologger. Due to that, maximum levels for root penetration exceed 1 MPa. Interrupted root growth can lead to reduced nutrient and water absorption of the plant and therefore reduced production. Moreover, resistance of penetration is related to soil moisture and SOM content. “The higher the moisture content of the soil, the lower the resistance to penetration and hence the bearing capacity” (Eijkelkamp, 2013, p. 4). SOM has positive effects on the bearing capacity (Eijkelkamp, 2013).

4.5.1.3. Root Penetration Intensity

To assess soil fertility, determination of root area is crucial. Root penetration intensity is defined by the size and shape of the root system, its spreading on an area and especially the water absorbing root surface and is measured as the number of fine roots per 1 dm^2. Root penetration is classified in “weak”, “middle” and “strong”. As root growth is linked to germination, annual plants as maize show less intense root penetration intensity compared to perennial plants as lucerne grass or silphie (*Silphium perfoliatum*) (see figure 13) (Schroetter, 2015, Friedel, 2019).

Information on root penetration intensity over depth was assessed by looking at the profile wall of the dug testpit. Data for eight horizons (each 10 cm depth, 0-90 cm profile) was collected.

Figure 13: Root shape of silphie (perennial, left) and maize (annual, right), grown on a sand culture. (Source: Schroetter, 2006 as cited in Schroetter, 2015).

4.5.1.4. Soil Structure

Soil structure can be described by **grade**, **class** and **type** of aggregates. The **grade** describes the degree of aggregation, meaning the cohesion within aggregates and the adhesion between them. The four major grades are 0: structureless, 1: weak structure, 2: moderate structure and 3: strong structure. The **class** describes the average size of the aggregates. There are five classes: very fine/thin, fine/thin, medium, coarse/thick and very coarse/thick. The **type** describes the shape of the aggregates (FAO, s.a. (c)). There are four major categories (figure 14):

- Granular and crumb structures: individual sand particles, clay and silt particles are grouped into small and nearly spherical grains. Water can circulate easily through the soils. These structures are often found it the A horizon.
- Blocky and subangular blocky structures: particles are adhered together in square or angular blocks with sharper edges. The larger blocks do not allow easy flow of water and resist penetration. Often found in the B horizon with clay accumulations.

- Prismatic and columnar structures: particles formed into pillars and vertical columns separated by small, vertical cracks. Drainage and water circulation are poor. Often found in the B horizon with clay accumulations.
- Platy structure: particles are aggregated into thin plates or sheets. They are piled on another horizontally and often overlap. This disturbs water circulation. These structures are found in A horizons in forest soils or in claypan soils.

(FAO, s.a. (c))

Figure 14: The four types of soil structures. (Source: FAO, s.a. (c)).

WPA determined the soil structure by looking at the soil profile and classified it with an identification key (ÖNORM L 1050) which separates the structure from platy to crumbly (Schwarz et al., 1999). Data for eight horizons (each 10 cm depth, 0-90 cm profile) was collected.

4.5.2. Soil Analysis by Austrian Agency for Health and Food Safety

The Austrian Agency for Health and Food Safety (AGES) received samples from the trail area, the analyses were done in their laboratories. The samples (20 per plot) were taken on the 5.9.2017 (before catch crop cultivation) and on the 24.10.2018 (after maize harvest) in depths of 0-15 cm, 15-30 cm and 30-50 cm. For the 5.9.2017, AGES determined pH, plant available phosphorus [mg kg^{-1}] and potassium [mg kg^{-1}] (with calcium-acetate-lactate (CAL)-method), total organic carbon [% and g kg^{-1}] and total nitrogen content [% and g kg^{-1}]. Phosphate and potassium oxide content [mg $(100\ g)^{-1}$] and the carbon-to-nitrogen ration (C/N ratio) were calculated with the collected data. On the 24.10.2018, only total organic carbon [% and g kg^{-1}], total nitrogen content [% and g kg^{-1}], soil organic matter [% and g kg^{-1}] and C/N ratio of the soil was analysed. The results of these samples should give information on the effects of catch crops on soil parameters. By comparing their means, changes of values can be observed.

4.5.2.1. Total Nitrogen Content

Total nitrogen content is “the sum of total Kjeldahl nitrogen (ammonia, organic and reduced nitrogen) and nitrate-nitrite“ (Environmental Protection Agency, 2013, p.1). By assessing organic nitrogen compounds, free-ammonia and nitrate-nitrite separately and then adding the results, total nitrogen can be calculated (Environmental Protection Agency, 2013). AGES assessed total nitrogen content by dry combustion. Example values can be found in table 10.

Table 10: Site typical range of TOC, Nt and C/N ratio of Bavarian arable soils. (Adapted from: Institut für Ökologischen Landbau, Bodenkultur und Ressourcenschutz, s.a.).

Soil Type	Hight (m)	Corg (%)	Nt (%)	C/N
light	< 350	0,7 - 1,4	0,06 - 0,12	10,4 - 12,6
	350-550	0,8 - 1,6	0,07 - 0,14	
middle	<350	1,0 - 1,5	0,09 - 0,15	9,6 - 11,3
	350-550	1,1 - 2,1	0,11 - 0,19	
	>550	1,5 - 2,6	0,15 - 0,24	
heavy	<350	1,2 - 2,1	0,12 - 0,22	9,2 - 10,8
	350-550	1,3 - 2,6	0,13 - 0,25	
	>550	2,3 - 3,8	0,23 - 0,40	

4.5.2.2. Carbon to Nitrogen Ratio

The carbon to nitrogen ratio or C/N ratio gives information about the proportion of nitrogen and carbon in soil. If the C/N ratio is small, decomposing organic matter releases nitrogen into the soil. Soil microorganisms have an ideal diet with a ratio of 24:1. If the ratio is high, microorganisms in the soil will utilize the nitrogen, as requirements rise. Soil nitrogen will then be immobilized and won't be available for plants. Catch crops can improve nitrogen management in a crop cycle. Leguminous catch crops or brassicas have a low C/N ratio and can follow cash crops like maize or wheat, which have a high ratio (see table 11) (USDA Natural Resources Conservation Service, 2011). Optimum C/N ratio in arable soils is about 10:1 (BMLFUW, 2017).

Table 11: Carbon to nitrogen ratios of crop residues and other organic materials (Souce: USDA Natural Resources Conservation Service, 2011).

Material	C:N Ratio
rye straw	82:1
wheat straw	80:1
oat straw	70:1
corn stover	57:1
rye cover crop (anthesis)	37:1
pea straw	29:1
rye cover crop (vegetative)	26:1
mature alfalfa hay	25:1
Ideal Microbial Diet	**24:1**
rotted barnyard manure	20:1
legume hay	17:1
beef manure	17:1
young alfalfa hay	13:1
hairy vetch cover crop	11:1
soil microbes (average)	8:1

4.5.2.1. Plant Available Phosphorus and Potassium

Plant available phosphorus (Pcal) and potassium (Kcal) was extracted with the Calcium-Acetate-Lactate(CAL)-method. The phosphorus concentration in the samples was measured in a microtiter reader at 660 nm. For Kcal analysis the same extracts were used as for Pcal. The analysis was done with inductively coupled plasma optical emission spectrometry (ICP-OES) (Humer, 2015).

4.5.2.2. Phosphate

To measure phosphate concentration in soil, a complexation reaction is applied, which produces a coloured complex of phosphorus and molybdate. In the presence of acid and excess ascorbate ions, the phosphate of the sample is heated with ammonium molybdate. A coloured complex is formed, colouration is depended on phosphate concentration on the sample. By comparing the received blue colour to a known standard in a photometer, phosphate concentrations can be calculated (University of Canterbury, s.a.).

4.5.2.3. Potassium Oxide

Potassium oxide in soil (K_2O) was calculated from Kcal extracted by the Calcium-Acetate-Lactate(CAL)-method.

4.5.2.4. Total Organic Carbon

Total organic carbon (TOC) is quantified by destroying the organic matter in soil. This process can be performed with heat at very high temperatures. Depending on the temperature, either only organic carbon or total carbon (C_t) are oxidized into CO_2. The CO_2 can be measured directly by infrared spectroscopy. If all forms of carbon are oxidized, total organic carbon can be calculated by subtracting inorganic carbon in form of carbonate ($C_{carbonate}$) from total carbon (TOC= C_t - $C_{carbonate}$) (Schumacher, 2002, Friedel, 2019, Institut für Ökologischen Landbau Bodenkultur und Ressourcenschutz, s.a.).

4.5.2.5. Soil Organic Matter

Soil organic matter was assessed by determination of organic carbon dry combustion (ÖNORM L 1080). This method first aims on measuring the content of organic carbon in the sample. Based on the average organic carbon content of 58%, soil organic matter is calculated by multiplying the analysed organic carbon content with a factor of 1,72. (BMLFUW, 2017).

4.5.2.6. pH

Soil pH is determined with the $CaCl_2$-method (ÖNORM EN 15933). The soil sample is mixed with 0.01 M (mole) $CaCl_2*2\ H_2O$ solution at a 1 : 1 ratio, which is left over night to reach an equilibrium. The pH is then measured with a glass electrode (Humer, 2015, Benton Jones, 2001).

4.5.3. Soil Analysis by the University of Natural Resources and Life Sciences, Vienna (BOKU)

Several soil samples were analysed by the University of Natural Resources and Life Sciences, Vienna (BOKU). Analyses were done in the laboratory of the Division of Organic Farming, the Institute of Hydraulics and Rural Water Management (IHLW) and in the laboratories of the experimental farm in Groß-Enzersdorf. Soil samples for bulk density, inorganic nitrogen (N_{in}), potential nitrogen mineralization (Min) and particle size distribution determination were taken and analysed.

4.5.3.1. Bulk Density

„Soil bulk density is the mass of dry soil per unit of bulk volume, including the air space" (Soil Web Modules, s.a., s.p.). It is affected by agricultural management practises and can vary depending on the soil texture. Great amounts of organic matter decrease bulk density, whereas agricultural practises that compact soil will increase it. In mineral soils, bulk density usually ranges from 1,0 to 1,8 g/cm^3 (Soil Web Modules, s.a.).

To assess bulk density in this trial, the core method was used. It is applied, when coarse fragments make up less than 25% of the volume. When coarse particle percentage is high or a lot of tree roots penetrate sampled soil, the core method is hard to apply. The equipment contains a double-cylinder, which has an inner cylinder. It is driven into the soil with a hammer. The inner cylinder contains the undisturbed soil sample, which can then be removed. The end is trimmed and a core is received, from which the volume can be calculated. After drying in an oven at 105°C for 18-24 hours, the weight can be measured (Soil Web Modules, s.a.).

For this trial, samples for bulk density were taken twice, one on the 8.9.2017 and on the 31.10.2018. Cylinders (5 cm height) were placed in depths of 0-15 cm, 15-30 cm and 30-50 cm. Samples were taken from all eight plots, sealed and brought to the BOKU lab, where they were dried for two days at 105 °C and weighed.

4.5.3.2. Inorganic Nitrogen (ÖNORM L 1091)

To assess available, inorganic nitrogen in soil, the N_{in} method can be used. The two main forms of available nitrogen in soil are NO_3^- (nitrate nitrogen) and NH_4^+ (ammonium nitrogen) (Humer, 2015).

For soil N_{in} determination, soil samples to 90 cm depth were taken by an auger on the 19.4.2018 (initially it was planned to take them on the 6.4.2018, but at the field the generator did not start so the sampling was postponed) and the 3.7.2018.

On the 19.4.2018, the auger samples were split into three horizons: 0-30 cm, 30-50 cm and 50-90 cm. On the 3.7.18, the profile was split into four horizons: 0-15 cm, 15-30 cm, 30-50 cm and 50-90 cm, as four depths were needed to assess aggregation stability simultaneously with N_{in}. For N_{in}, samples of depths 0-15 cm and 15-30 cm were pooled and sent to the laboratory. From each plot, nine samples were taken and pooled, separated into buckets according to the layers, and then filled into bags (four bags for the four horizons). This was done for all 8 plots. The bags were stored and transported in cooling units to prevent decomposition and stored at minus 20°C to minus 18°C until analysis.

For the analysis, the stored soil samples were defrosted for 30 min. For the analysis, samples were sieved through a 5 mm sieve (see figure 15) and roots and stones were removed. Then, the samples were weight, mixed and the soil extracts prepared.

Preparation of Extract:

<u>Weighing samples</u>

- Prepare two 500 mL bottles and label them (for double determination)
- Place the bottle on scale, tare and fill with 50 g soil (+/- 1g)
- Sort out bigger roots or other material before filling.
- Repeat with second bottle.
- For dry mass determination: Weigh an empty petri dish, note weight. Fill with 20 g of soil and note total weight of petri dish and soil.
- Put left over soil back into bag in case of further material needed.
- Clean sieve and storing pan and repeat with next sample.

<u>Mixing</u>

- Prepare at least 5l of $CaCl_2 + 2H_2O$ solution (Calciumchloride). 9,2 g $CaCl_2$ per 5l H2O.
- Put 200 mL into each bottle containing the weight soil sample.
- Put samples into rotator and shake with 20 rpm for 30 min.

Extraction

- Let samples rest for a few minutes until soil settles on bottom of bottle.
- Filtrate sample through a pleated filter into a 50 mL plastic bottle (see figure 16).
- Store extract at -20°C.

Figure 15: Sieved soil samples.

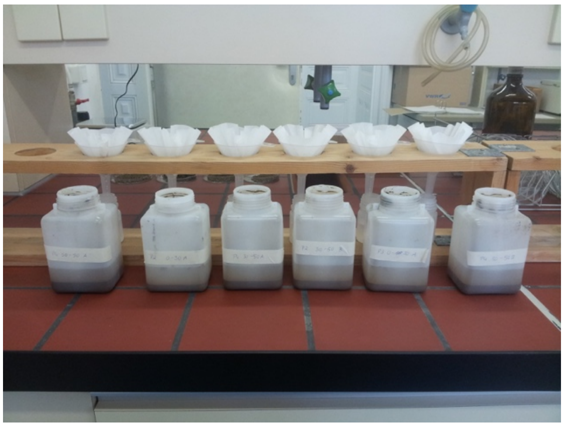

Figure 16: Filtration Process.

Determination of Ammonium (NH_4^+):

Used chemicals: Sodium nitroprusside dehydrate; Sodium salicylate; Dichloroisocyanuric acid; Sodium hydroxide pellets; Ammonium chloride

First, the mixed reagent was prepared. Equal volume parts of deionised water, 0.3 mole L^{-1} NaOH, sodium salicylate and sodium nitroprusside dehydrate were mixed. Dichloroisocyanuric acid was produced by dissolving 0.05 g of the acid into 50 mL deionised water. Next, the calibration line was prepared.

Stock solution: 1000 ppm N; 382 mg NH_4Cl were filled up to 100 mL with deionised water.

Standard solution: 50 ppm N; 5 mL stock solution (1000 ppm N) were filled up to 100 mL with deionised water (1:20 dilution).

To receive the calibration line, 125 µL, 250 µL, 500 µL, 750 µL and 1000 µL of standard solution were pipetted into a 25 mL flask and then filled up with extraction solution.

Microtiter Plate Reader Measurement:

Firstly, the calibration line was pipetted twice, then the soil samples, blanks and standard soil (twice as well). In each well, 100 µL standard/soil sample extract, 50 µL mixed reagent and 40 µL dichloroisocyanuric acid solution were pipetted. Afterwards, the plate is put into the reader, shook and incubated at 25 °C for 30 min. Afterwards, the measurement is done at 660 nm.

To calculate inorganic nitrogen with the received data, bulk density needs to be incorporated. As bulk density samples were taken from the depths 0-15 cm, 15-30 cm and 30-50 cm and inorganic nitrogen samples from 0-30 cm, 30-50 cm and 50-90 cm, data had to be adapted. Taking the data from both bulk density assessments (8.9.2017 and on the 31.10.2018), mean values were calculated for all plots and depths. To receive values usable for N_{in} (0-30 cm) calculation, mean values of horizons 0-15 cm and 15-30 cm were formed. For N_{in} 30-50 cm, the data was already fitting. Lastly, to obtain data for N_{in} 50-90 cm, the same values as for depth 30-50 was used. With these new values, N_{in} calculations could be finished.

Determination of Nitrate (NO_3^-):

Used chemicals: Hydrochloric acid 32%; Vanadium(III)chloride; N-(1-Naphthyl) ethylenediamine dihydrochloride; Sulfanilic acid; Potassium nitrate.

Firstly, the mixed reagent is produced. Then, the stock solution is prepared: 1000 ppm N; 722 mg KNO_3 were dissolved and filled up to 100 mL with deionised water.

For the standard solution, 50 ppm N; 5 mL stock solution (1000 ppm N) were filled up to 100 mL with deionised water.

Fir the calibration line, 250 µL, 500 µL, 1000 µL, 1500 µL, 2000 µL, 2500 µL and 3000 µL of the standard solution were pipetted into a 25 µL flask and filled up with extract.

Microtiter Plate Reader Measurement:

Firstly, the calibration line was pipetted twice, then the soil samples, blanks and standard soil (twice as well). In each well, 100 µL standard/sample extract, 100 µL mixed reagent and 100 µL Vanadium(III)chloride solution were pipetted. The plate was put into the reader, incubated at 37°C for 30 minutes and then measured at 540 nm.

4.5.3.3. Potential Nitrogen Mineralization

The transition of organic forms of nitrogen to inorganic forms in soil is called nitrogen mineralization and is catalysed by many microorganisms. By incubating the soil samples under anaerobic conditions, nitrification is inhibited and only ammonification can take place. Then, NH_4^+ can be measured.

Samples were taken the same time and the same way as for inorganic nitrogen. A greater sample size was taken and split for both potential nitrogen mineralization and inorganic nitrogen. The procedure can be read in chapter ***4.4.3.2. Inorganic Nitrogen***. The stored samples were defrosted and sieved through a 2 mm sieve.

Preparation of Extract and incubation:

5 g of soil sample was filled into a test tube and filled with 15 mL deionized water. This was done for three test tubes per soil sample (see figure 17 and 18). Two of the filled test tubes were sealed and incubated for 7 days at 40 °C in the incubator. The third tube (blank) is additionally filed with 15 mL extract (2 M KCl; 298,2 g/2 L KCl; mixed with 2 L deionized water), sealed and shook for 30 min on the horizontal shaker. Afterwards, the sample is filtered into plastic bottles. The same was done for the non-blanks after incubation.

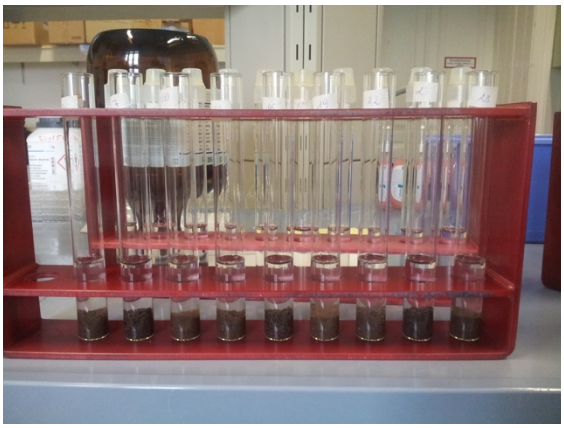

Figure 18: Samples filled with deionized water.

Figure 17: Weighing of soil and preparation for incubation.

Determination of Ammonium (NH_4^+):

For the <u>mixed reagent</u> and dichloroisocyanuric acid solution is produced. The <u>stock solution</u> is prepared the following: 1000 ppm N; 382 mg NH_4Cl is filled into a 100 mL flask and filled up with deionized water.

For the standard solution, 100 ppm N, 10 mL stock solution were filled up to 100 mL with deionised water.

For the calibration line, 0,125 mL, 0,250 mL, 0,5 mL, 0,75 mL, 1,25 mL, 2,5 mL and 3,75 mL of the standard solution were pipetted into 25 mL flasks and filled up with extract.

Mix in 25 mL Erlenmeyer flasks and Microtiter Plate Reader Measurement:

- 0,5 mL standard or extract solution
- 4,4 mL deionized water
- 2,5 mL mixed reagent
- 1,0 mL dichloroisocyanuric acid solution

The mix is then left for reaction for 30 minutes at room temperature (figure 19 and 20). Afterwards, 300 are pipetted into the microtiter plate and analysed at 660 nm.

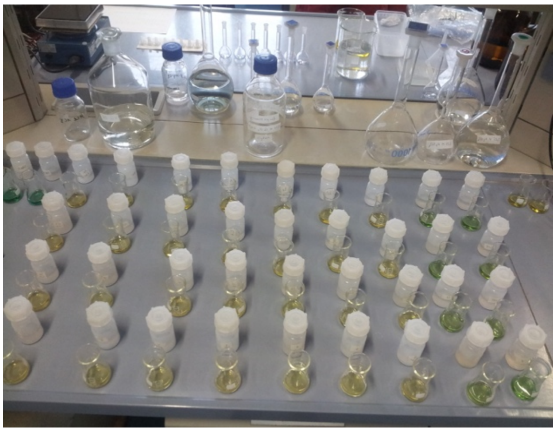

Figure 19: Samples during incubation.

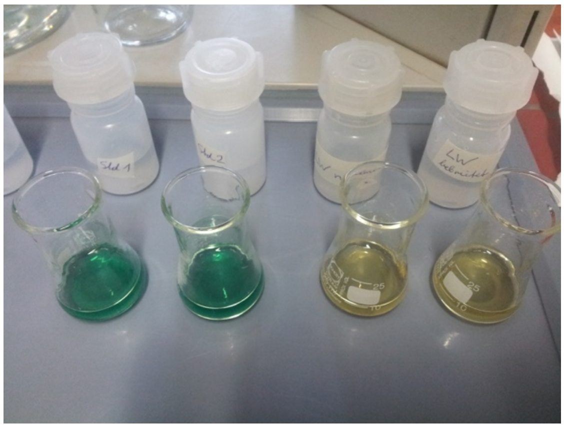

Figure 20: Standards and blanks after incubation.

4.5.3.4. Particle Size Distribution

Particle size distribution was determined once for every plot. 20 samples per plot in depths of 0-15 cm, 15-30 cm and 30-50 cm were taken and analysed by the BOKU Institute of Hydraulics and Rural Water Management (IHLW).

4.5.3.5. Aggregate Stability

Aggregate stability is defined as, “the ability of soil aggregates to resist disruption when outside forces (usually associated with water) are applied“ (The U.S. Department of Agriculture (USDA) and National Soil Survey Center, 1996). To assess aggregate stability, a method with three tests called fast wetting, slow wetting and shaking after pre-wetting is conducted. As a result, an index of water stable aggregates (WSA, [%]) is received (Rohoskova and Valla, 2004). The analysis was done by the BOKU Institute of Soil Research (IBF).

4.5.3.6. Soil Moisture

Soil moisture, as defined by the volumetric water content (VWC [%]), is defined as the quotient of the volume of removed water and sampled soil (Stahr et al., 2008). To measure VWC, an EC-5 sensor (product of Metergroup) was used. The data was collected by a data logger (Em50-1) and transferred to a laptop via USB cable.

4.6. Plant Biomass Sampling

Next to soil samples, plant biomass sampling of catch crops, maize and maize grain yield was done. Samples were analysed in the laboratories of the own division. Precise explanation of implementation can be found in the upcoming chapters.

4.6.1. Catch Crops

For the winter-hardy and freeze-killed catch crop mixtures (see figure 21 and 22), above-ground biomass, soil coverage and root biomass as well as C/N ratio of roots was sampled and analysed.

Figure 22: Treatment A (winter-hardy catch crops) on the 29.3.2018.

Figure 21: Treatment B (freeze-killed catch crops) on the 29.3.2018.

4.6.1.1. Above-ground Biomass

Catch crop above-ground biomass was sampled on the 7.11.2017, the 19.4.2018 and the 27.4.2018. On the 7.11.2018, treatment A and B were harvested. For each plot, 1 m^2 was harvested six times and filled into separate bags. Fresh weight (FW) (kg/ha), water content (%) and dry weight (DW) (kg/ha) was measured. Moreover, on the 7.11.2017, total soil coverage (%) with each catch crop treatment as well as the proportion of each catch crop (%) from the total coverage and weed coverage (%) was assessed for all plots twice. On the 19.4.2018, only treatment A was sampled (6 x 1 m^2). Again, fresh weight (FW) (kg/ha), water content (%) and dry weight (DW) (kg/ha) was measured. The samples were dried at 60 °C to determine dry weight.

On the 27.4.2018 only treatment B was harvested (4 x 1 m^2 per plot) to assess the percentage of weeds of total above-ground biomass (see figure 23). This was done, to achieve higher accuracy of the results of catch crop root biomass. Due to the high weed pressure, percentage of weed roots might distort the results of catch crop root biomass. By determining the percentage of weeds and catch crops of above-ground biomass, a factor can be calculated which is applicable for determining the actual catch crop root biomass. Samples were first air dried and then dried for 48 h at 105 °C (see figure 24).

Figure 23: Harvest of treatment B to assess catch crop: weed ratio on the 27.4.2018.

Figure 24: Air drying of samples on the 27.4.2018.

4.6.1.2. Root Biomass

Soil samples for catch crop root biomass were taken on the 27.3.2018 and on the 29.3.2018. An impact drill was used to dig up a 30 cm deep soil sample with 10 cm diameter. For each plot, six samples were taken. The received profile samples were split into an upper part (0-15 cm) and a lower part (15-30 cm) (see figure 25) and put into plastic bags (two bags per plot, for depth 0-15 cm and 15-30 cm). The samples were stored at cool temperatures until root washing was conducted.

Figure 25: Soil profile for catch crop root determination (27.3.2019).

For the root washing procedure (from 10.4.-13.4.2018), all soil samples were weight and put into plastic tubs. The soil then was crushed, and 8 litres of water were added as well as a hand full of road salt. With a wooden stick and a shovel, the soil was further crushed into smaller pieces and stirred to allow a proper dispersion. The mixtures were left for 24 h. Unfortunately, the soil did not disperse because of the high clay content, so another 2 litres water and 2 more hands of salt were added to each sample and left to disperse for another 24 h. This allowed sufficient dispersion, but still each sample needed about 20 minutes kneading by hand to guarantee good sieving results. The mixture was then sieved through a 5 mm (labelled G; coarse), a 2 mm (labelled M, middle) and a 1 mm sieve (labelled F; small) (see figure 26 and 27).

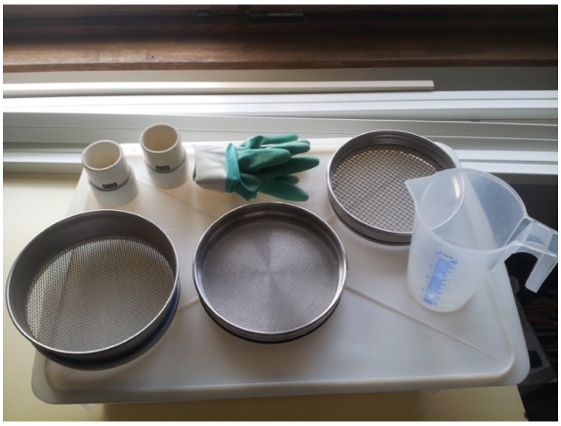

Figure 27: Equipment used for root sieving.

Figure 26: Sieving process.

After sieving, roots need to be separated from the sieved matter (see figure 28 and 29). (13, 18, 19, 20 and 23.4.2018). For the separation of coarse matter, a times was set on 15 minutes. This was the time frame roots were separated with forceps and put into petri dished. The same was done for middle sized matter for 10 minutes and for small sized matter for 5 minutes (less time taken due to smaller amounts of sieved matter). The collected roots then were weighed.

Figure 29: Separation of roots from sieved matter.

Figure 28: Sieved matter for 5 mm, 2 mm and 1 mm.

On the 23.4.2018 roots samples were dried at 60 °C for 41 h. As described in chapter ***4.6.1.1. Above-ground Biomass***, a factor for treatment B was calculated, as weed pressure during sampling was very high in this treatment. The goal was to assess the ratio of catch crops and weeds in above-ground biomass to calculate how much of the sampled root biomass was originated by catch crops and weeds. The results for catch crop root biomass were then used for comparison with treatment A.

4.6.1.3. C/N Ratio of Root Biomass and Treatment A

C/N ratio of above ground catch crop biomass was assessed for treatment A on the 19.4.2018, when treatment A was harvested.

On the 21.6.2018, catch crop root samples (see figure 30) were milled and portioned into smaller samples to fit into the C/N analyser.

The milling of the samples was done with a Retsch Mixer Mill 400, an oscillating mill which allowed fine milling of the roots without losing to much sample mass during the milling process (see figure 31 and 32). Each sample was milled for 20 sec. with a frequency of 30/sec. After each milling, the cups and grinding equipment was cleaned with water and properly dried. Afterwards, the ground roots were transferred into labelled paper bags and dried in the oven at 105°C for 4 hours. On the 22.6.2018 the dried root samples needed precise weighing before the C/N analysis could be conducted. Therefore, two smaller samples were taken from the total mass of each milled root paper bag, weight with a Mettler Toledo analytical balance (see figure 33), capsuled and formed into little tablets which were used for the C/N analysis.

Figure 30: Example of a root sample used for C/N determination.


Figure 31: Equipment used for the milling process.

Figure 33: Retsch Mixer Mill 400.

Figure 32: Mettler Toledo analytical balance.

4.6.2. Maize Harvest and Plant Residues

In the following, the harvest of the plants, the assessment of fresh weight and dry weight of plant residues (above-ground plant without maize cobs) and the determination of C/N ratio of the plant residues are described.

4.6.2.1. Harvest of Maize Plants

On the 8.10.2018 the maize was harvested for both treatments. For each plot, six samples were taken. A sample consisted of a running meter (133,33 cm) of maize plants, which were cut at the bottom. Number of maize plants, corncobs per plant, weight of cobs and weight of plant without cobs was assessed. The cobs were collected and taken to the laboratory for yield fresh weight determination. Additionally, one plant (with cobs) per plot (no plant from the running meters) was selected and put together with the other plants of the plot (in total six plants per plot). These additional plant samples were used to assess C/N ratio, fresh weight and dry matter of maize kernels and shoot biomass. The cobs (of harvest) and additional plants were taken to the own laboratories to make further investigations. There, the cobs were separated from the additional maize plants. The kernels were separated from the core and the plants (plant residues plus core of maize cobs) were shredded. These samples were then split into two for fresh weight and dry matter determination as well as C/N ratio assessment of kernels and plant residues.

4.6.2.2. Fresh and Dry Weight of Plant Residues

Moreover, on the 8.10.2018, the shredded residue samples were dried at 105 °C for 24 h. Dry matter (kg/ha) was calculated with the results from the 105 °C dried samples.

4.6.2.3. C/N ratio of Plant Residues

For analysing C/N ratio of maize residues the shredded samples were dried at 60 °C for 24 h. C/N analysis was done in the BOKU laboratories in Tulln.

4.6.3. Maize Kernels

Data for maize kernels was assessed parallel to plant residue sample collection and data analysis. Detailed explanation for maize kernel yield determination, fresh and dry weight assessments and C/N ratio analysis can be found in the following.

4.6.3.1. Maize Kernel Yield

On the 7.12.2018 the assessment of total maize yield was conducted. The corn cobs (maize cobs per running meter (133 cm), 6 samples per plot), which have been air dried for eight weeks, were put into a machine which separated the kernels from the core. Then, kernels and cores were weighed separately. For the kernels, an average loss of 10 kernels per cob was estimated (2,97 g), added to the weight and average yield (kg ha^{-1}) for both treatments was calculated.

4.6.3.2. Correlation Analysis between Dry Matter of Maize Kernels and Plant Residues and Inorganic Nitrogen

Moreover, correlation analysis between dry matter of maize kernels and maize residues and inorganic nitrogen was calculated with Spearman rank-order correlation coefficient (r). For inorganic nitrogen values, data from the 19.4.2018 was taken and mean values for all depths calculated.

4.6.3.3. Fresh and Dry Weight of Kernels

One half of the kernels of the six selected plants per plot, which were already separated from their core, were dried at 105 °C for 24 h. Dry matter (kg ha^{-1}) was calculated with the results from the 105 °C dried samples.

4.6.3.4. C/N Ratio of Kernels

For analysing C/N ratio of the kernels, one half of the shredded samples were dried at 60 °C for 24 h. C/N analysis was done in the BOKU laboratories in Tulln.

4.7. Visual Assessment

On the 24.5.2018 the first visual assessment of maize was conducted. Data about maize height, development stage of maize and plants per m^2 as well as weed pressure was collected. Data on diseases or sowing errors was collected as well labelled as "addition assessments". Furthermore, for each assessment a map was drawn to capture weed pressure and sowing errors. For each field visit, data on maize plant height, development stages, plants per m^2 and weed pressure (%) was collected in a Microsoft Excel© document. Moreover, pictures of healthy and diseased plants, plant coverage, sowing errors etc. were taken. In total, eleven visual assessments were done (see figure 34).

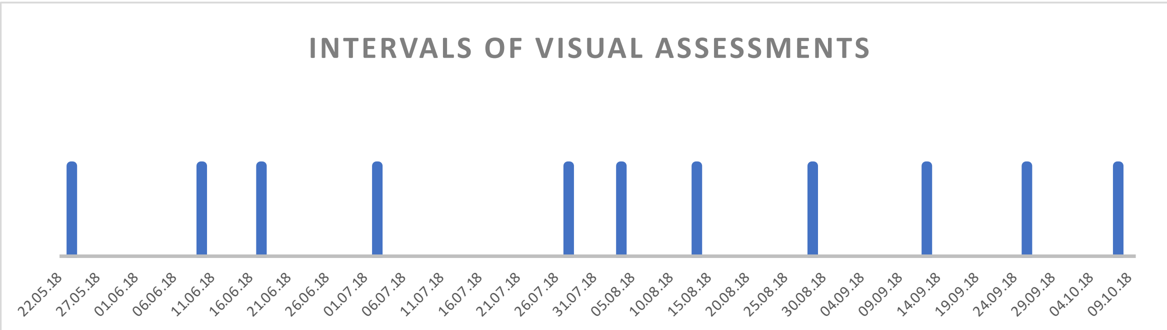

Figure 34: Intervals of conducted visual assessments (24.5., 10.6., 18.6., 3.7., 28.7., 4.8., 14.8., 29.8., 13.9., 26.9., 8.10.).

4.7.1. Growth

For maize height, ten plants per plot were measured. Plants were chosen randomly and were spread all over the plot.

4.7.2. Development Stages

Development stage was measured six times, again plants were chosen randomly. To assess development stages, the BBCH Monography 2nd edition (Meier, 2001) for Maize was used. In figure 35 several pictures of maize plant development stages can be found.

Figure 35: Maize plant development stage 17 on the 10.6.2018 (left); development stage 65 on the 28.7.2018 (middle) and stage 99 on the 8.10.2018 (right).

4.7.3. Plants per m^2

For plants per m^2, six measurements per plot were conducted. Sampled sites were chosen randomly.

4.7.4. Weed Pressure

Weed pressure (mainly thistles) was determined by estimating a value for area infested with weeds per plot (%). Moreover, a map was drawn to capture the areas with most intense weed pressure. Figure 36 shows several pictures of weed pressure during the months of visual assessment. On the last assessment date, thistle plants per m^2 were assessed.

Figure 36: Weed pressure on the 18.6.2018. (left), the 28.7.2018 (middle) and the 6.9.2018 (right).

4.7.5. Additional Assessments

Moreover, diseases, sowing errors and other unexpected developments were captured. As weed pressure, sowing errors were also drawn in the map. Development of undersown catch crop was monitored as well.

5. Statistical Analysis

For statistical analysis, the computer program IBM SPSS Statistics 24 was used. The General Linear Model Univariate with an alpha of 0.05 was performed. It provided analysis of variance (ANOVA) for a dependent variable by the two factors “treatment” and “replication”. One of the prerequisites for applying the ANOVA is the homogeneity of error variances of the residues. If the residues of the ANOVA did not meet homogeneity of variances, data was logarithmically transformed (logarithmically, 1/x, x^2 or square root) in order to obtain more homogenous variances (Humer, 2015). Spearman rank-order correlation coefficients and its significance levels were calculated with the Bivariate Correlations procedure. For other calculations, or figure and table designs, Microsoft Excel 16.22 was used.

6. Results

6.1. Soil

6.1.1. Results of WPA Beratende Ingenieure Samples

6.1.1.1. Water Infiltration

For treatment A, the water infiltration measurements on the **20.4.2018** lasted 45 minutes until a constant infiltration rate was reached. The calculated k_f-value was $6.6*10^{-6}$ m s^{-1}. For treatment B, the same value was reached after 40 minutes (see table 12).

On the **21.8.2018**, the measurements lasted 40 minutes for treatment A and 115 minutes for treatment B. Calculated kf-values were $1.3*10^{-5}$ m s^{-1} and $9.3*10^{-5}$ m s^{-1} respectively (see table 13). The measurements for treatment B lasted that long because of very dry conditions and cracks in the soil. As no constant infiltration rate could be achieved, kf-value of treatment B should not be seen as an absolute, but relative value compared to kf-value of treatment A. As soil conditions on the date of the second measurement were unsuitable, a comparison between the results of the two dates is difficult.

Table 12: Water Infiltration (m s^{-1}) on the 20.4.2018.

Treatment	Duration (min)	k_f-value
A	45	0.0000067
B	40	0.0000067

Table 13: Water Infiltration (m s^{-1}) on the 21.8.2018.

Treatment	Duration (min)	kf-value
A	40	0.000013
B	115	0.000093

6.1.1.2. Penetration Resistance

Penetration resistance was measured for the first time on the **20.4.2018**. On treatment A high resistance was determined. From depths of 10 cm to about 50 cm penetration resistance was of more than 1.5 MPa, which can be explained by the dry condition of the soil (see figure 37). These conditions result in significant limitation of root growth. From depth below 50 cm penetration resistance normalised. For treatment B, similar results were achieved. Penetration resistance was 2 MPa in the first 40 cm and declined to 1.5 MPa in depth below 50 cm (see figure 38).

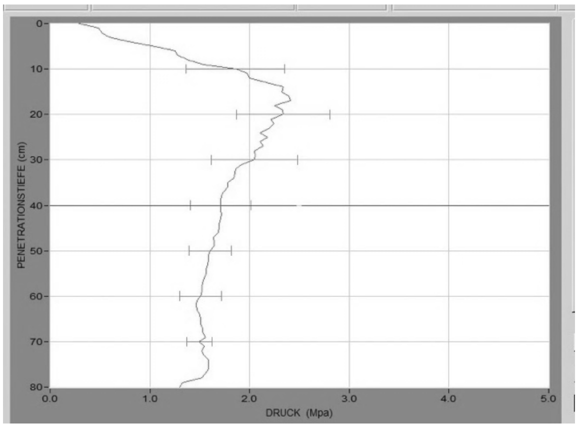

Figure 38: Penetrometer data of Treatment A on the 20.4.18 (depth and MPa). (Source: WPA Beratende Ingenieure).

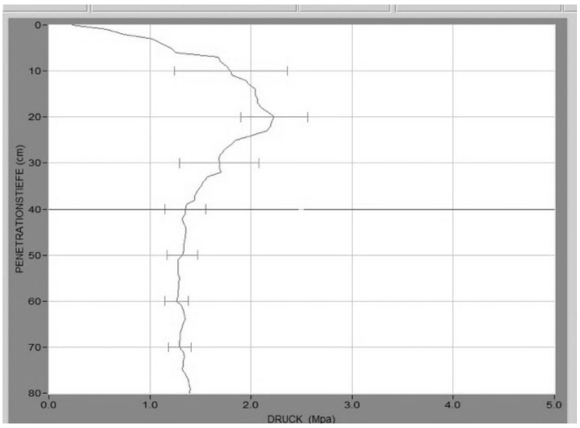

Figure 37: Penetrometer data of Treatment B on the 20.4.2018 (depth and MPa). (Source: WPA Beratende Ingenieure).

On the **21.8.2018** penetration resistance tests could neither be done for treatment A or B, as the soil was too dry. Therefore, a comparison between the results of the two dates in not possible.

6.1.1.3. Root Penetration Intensity

Root penetration intensity was determined from the soil profile of the testpit. First measurements were done on the **20.4.2018**. In treatment A, the first 10 cm showed middle to strong root penetration intensity. In depths of 20-30 cm, intensity was middle to weak. Below 50 cm almost no roots could be found. In treatment B, root penetration intensity was middle to weak in the first 10 cm, weak between 10-30 cm and close to zero below 40 cm (see table 14). When comparing the values of the both treatments, winter-hardy catch crops achieved slightly better soil root penetration.

On the **21.8.2018**, root penetration intensity was strong in the upper 10 cm, middle from 10-20 cm, weak from 20-30 cm and very weak from 40-90 cm in treatment A. In treatment B, intensity was strong as well in the first 10 cm, middle from 10-50 cm, weak from 50-60 cm and very weak from 60-80 cm (see table 15). When looking at the differences between the two treatments, it can be found that treatment B shows slightly better root penetration intensity in the soil layers of 20-60 cm. Root penetration intensity was higher in both treatments on the 21.8.2018 compared to the 20.4.2018. This might be explained by the greater penetration of maize roots compared to catch crops.

6.1.1.4. Soil Structure and Humidity

Soil structure was also assessed from the soil profile of the testpit and classified with an identification key. On the **20.4.2018**, soil structure could be described as friable in the first 20 cm for treatment A. From 30-90 cm structure was crumbly. In treatment B results were similar. Soil moisture was low in layers 0-30 and moderate in deeper layers in treatment A. In treatment B, soil humidity was very low in the first 10 cm, then low until 50 cm depth, and moderate until 90 cm depth (see table 14).

On the **21.8.2018**, soil structure in treatment A was friable in the first 10 cm, friable to crumbly from 10-70 cm and crumbly from 70 cm with high silt content. Treatment B showed the same results. Soil humidity was dry in layer 10 – 20 cm and low in deeper layers for both treatments (see table 15).

Table 14: Root Penetration, Soil Structure and Humidity of Treatment A and B on the 20.4.2018.

	Treatment A			Treatment B		
Profile Depth	Root Penetration	Structure	Humidity	Root Penetration	Structure	Humidity
0-10	medium-strong	friable	low humidity	medium-weak	friable	very low humidity
10-20	medium	friable	low humidity	weak	friable	low humidity
20-30	weak	friable-crumbly	low humidity	weak	friable-crumbly	low humidity
30-40	very weak	crumbly	moderate humidity	very weak	friable-crumbly	low humidity
40-50	weak-none	crumbly	moderate humidity	none	crumbly	low humidity
50-60	none	crumbly	moderate humidity	none	crumbly	moderate humidity
60-70	none	crumbly	moderate humidity	none	crumbly	moderate humidity
70-80	none	crumbly	moderate humidity	none	crumbly	moderate humidity
80-90	none	crumbly	moderate humidity	none	crumbly	moderate humidity

Table 15: Root Penetration, Soil Structure and Humidity of Treatment A and B on the 21.8.2018.

	Treatment A			Treatment B		
Profile Depth	Root Penetration	Structure	Humidity	Root Penetration	Structure	Humidity
0-10	strong	crumbly	dry	strong	crumbly	dry
10-20	medium	friable-crumbly	dry	medium	friable-crumbly	dry
20-30	weak	friable-crumbly	low humidity	medium	friable-crumbly	low humidity
30-40	weak	friable-crumbly	low humidity	medium	friable-crumbly	low humidity
40-50	very weak	friable-crumbly	low humidity	medium	friable-crumbly	low humidity
50-60	very weak	friable-crumbly	low humidity	weak	friable-crumbly	low humidity
60-70	very weak	friable-crumbly	low humidity	very weak	friable-crumbly	low humidity
70-80	very weak	friable	low humidity	very weak	friable	low humidity
80-90	very weak	friable	low humidity	-	-	-

6.1.2. Results of AGES Samples

In the following, the evaluation of soil sample results, analysed by AGES, can be found. Tested samples were taken on the **5.9.2017**, when catch crops were growing (one month after sowing) and on the **24.10.18**, after maize was harvested. All samples were statistically tested with GLM Univariate. For each tested parameter, results are shown in a table with the mean values and standard deviations for all depths for each treatment can be found. Below the mean values, the statistical results of the ANOVA are indicated. There, significant (*) or non-significant (n.s.) differences between the treatments or the blocks are stated. This design of tables, containing statistical results, was used for all other tested parameters that will follow.

6.1.2.1. Total Nitrogen Content

The mean values for total nitrogen content (g kg-1) of the soil samples are similar for both sampling dates (see table 16). In treatment A, values of the second sampling were slightly lower compared to the first sampling date, especially in depth 15-30 cm and 30-50 cm, can be seen. Treatment B showed the same trends. Moreover, statistical results were the same for both dates. There were no significant differences in total nitrogen content between the two treatments on both sampling dates. Nevertheless, significant results between the blocks of each treatment were obtained for all three depths on both dates. Possible reasons for the Nt lower values on the second sampling date are catch crop cultivation, green manure of treatment B and root biomass (which stayed on the field for decomposition) of both treatments.

Table 16: Total nitrogen content of soil (g kg^{-1}) (5.9.17 and 24.10.18).

		05.09.17		24.10.18	
Treatment	depth (cm)	Nt	St.d.	Nt	St.d.
A	0-15	2.53	0.62	2.52	0.72
	15-30	2.12	0.63	2.00	0.69
	30-50	1.31	0.23	1.24	0.24
B	0-15	2.45	0.67	2.47	0.69
	15-30	2.07	0.58	2.00	0.67
	30-50	1.30	0.18	1.22	0.17
Treatment	0-15	n.s.		n.s.	
	15-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
Block	0-15	*		*	
	15-30	*		*	
	30-50	*		*	

Significance level p<*0.05*, significant (*), not significant (n.s.)

6.1.2.2. Total Organic Carbon

Total organic carbon (g kg^{-1}) was higher in the top soil after catch crop cultivation in both treatments (see table 17). Initial values were slightly higher in treatment A compared to treatment B, which is confirmed by the significant results of the statistical analysis. In all other soil depths of both treatments, TOC values were slightly higher on the first sampling date compared to the second. Results for TOC t ha^{-1} can be found in chapter ***6.1.2.5. Results of Other Assessed Parameters***.

Table 17: Total organic carbon (g kg^{-1}) of soil (5.9.17 and 24.10.18).

		05.09.17		24.10.18	
Treatment	depth (cm)	TOC	St.d.	TOC	St.d.
A	0-15	22.65	6.07	24.10	7.34
	15-30	18.55	5.81	18.05	6.31
	30-50	12.88	3.50	12.70	3.39
B	0-15	21.78	6.18	22.93	6.63
	15-30	18.40	5.40	18.25	6.41
	30-50	12.90	3.13	12.65	3.15
Treatment	0-15	*		n.s.	
	15-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
Block	0-15	*		*	
	15-30	*		*	
	30-50	*		*	

Significance level $p<0.05$, significant (*), not significant (n.s.)

6.1.2.3. Carbon-to-Nitrogen Ratio

C/N ratio was calculated by using the obtained results for total organic carbon and total nitrogen. When comparing the mean values of the two dates, values of the second sampling were higher compared to the first in all depths for both treatments. This can be explained, as total nitrogen contents were lower on the second assessment compared to the first whereas total organic carbon contents stayed relatively constant. On the **24.10.2018**, treatment A achieves a higher C/N ratio in the first horizon compared to treatment B, but lower ones in the second and third. These results cannot be connected with the C/N ratios of above-ground catch crop biomass of treatment A and B, as C/N ratio was only assessed for treatment A. Overall, C/N ratio was higher on the second sampling date in both treatments compared to the first. The statistical analysis concluded that there were no significant differences between the treatments in all depths (see table 18). For blocks, results were not significant as well, except for the depth of 30-50 cm. This is valid for the samples of both dates.

Table 18: C/N ratio of soil (5.9.17 and 24.10.18).

		05.09.17		24.10.18	
Treatment	depth (cm)	C/N	St.d.	C/N	St.d.
A	0-15	8.93	0.21	9.52	0.37
	15-30	8.71	0.99	8.99	0.28
	30-50	9.68	0.99	10.17	0.90
B	0-15	8.86	0.13	9.26	0.15
	15-30	8.88	1.10	9.08	0.22
	30-50	9.86	1.10	10.28	1.23
Treatment	0-15	n.s.		n.s.	
	15-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
Block	0-15	n.s.		n.s.	
	15-30	n.s.		n.s.	
	30-50	*		*	

Significance level $p<0.05$, significant (*), not significant (n.s.)

6.1.2.4. Results of Other Assessed Parameters

SOM in t ha^{-1} did not show significant differences between the treatments on the first assessment date. The same can be said about TOC results (table 19).

Table 19: Soil organic matter (SOM) and total organic carbon (TOC) (5.9.2017) in t ha^{-1}.

Treatment	depth (cm)	SOM	St.d.	TOC	St.d.
A	0-15	74.22	15.68	43.10	9.00
	15-30	67.08	18.56	38.87	10.81
	30-50	62.36	15.79	36.07	9.06
B	0-15	71.39	18.32	41.44	10.78
	15-30	64.91	19.44	37.61	10.96
	30-50	61.20	16.08	35.89	9.61
Treatment	0-15	n.s.		n.s.	
	15-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
Block	0-15	*		*	
	15-30	*		*	
	30-50	*		*	

Significance level p<*0.05*, significant (*), not significant (n.s.)

6.1.3. Results of BOKU Samples

6.1.3.1. Bulk Density

Bulk density (g cm^{-3}) was sampled twice, on the 8.9.2017 (during catch crop cultivation) and on the 31.10.2018 (after maize harvest and straw was mulched with a scuffle hoe). Bulk density was lowest in the 0-15 cm soil layer for both treatments on the first sampling date compared to the deeper layers (table 20). This is also true for the second assessment. Moreover, bulk density values were higher on the second assessment date compared to the first in both treatments, which was probably caused by the machinery used for harvest and soil cultivation. A significant difference between treatments was found on the 31.10.2018 in depth 15-30 cm.

Table 20: Bulk density of soil (g cm^{-3}) (8.9.17 and 31.10.18).

		08.09.17		31.10.18	
Treatment	depth (cm)	bulk density	St.d.	bulk density	St.d.
A	0-15	1.29	0.09	1.38	0.07
	15-30	1.41	0.08	1.45	0.11
	30-50	1.41	0.07	1.47	0.12
B	0-15	1.28	0.09	1.37	0.11
	15-30	1.36	0.03	1.50	0.11
	30-50	1.38	0.04	1.52	0.08
Treatment	0-15	n.s.		n.s.	
	15-30	n.s.		*	
	30-50	n.s.		n.s.	
Block	0-15	n.s.		n.s.	
	15-30	n.s.		*	
	30-50	n.s.		n.s.	

Significance level p<*0.05*, significant (*), not significant (n.s.)

6.1.3.2. Inorganic Nitrogen, Ammonium and Nitrate

In table 21, results of inorganic nitrogen (kg ha^{-1}) in soil for both sampling dates can be found. On the first sampling date (**19.4.2018**) treatment A was growing, whereas treatment B was freeze-killed. The second date (**3.7.2018**) was during maize cultivation (development stage 18) and before undersown crop propagation in treatment A. On the first sampling date, N_{in} values were highest in the topsoil. Treatment B showed overall higher values in all depths. When comparing the mean values for soil layer 30-50 cm, N_{in} in treatment B was almost double as high as in treatment A. Nevertheless, there were no significant differences in N_{in} between the treatments, except for the soil layer 50-90 cm. Comparing the mean values of both sampling dates, N_{in} content of soil was higher in the second assessment in all layers of both treatments. Statistical analysis for the second sampling date showed no significant results.

Moreover, the mean values over all depths per plot were calculated and statistically analysed. For the first sampling date, no significant differences were calculated, although thee mean value of treatment B was almost double as high as the value of treatment A (28 kg ha^{-1} and 15 kg ha^{-1}, respectively). On the second sampling date, again no significant differences were found (table 22).

Table 21: Inorganic nitrogen (in kg ha^{-1}) on the 19.4.18 and 3.7.18.

		19.04.18		03.07.18	
Treatment	depth (cm)	N_{in}	St.d.	N_{in}	St.d.
A	0-30	32	10	82	4
	30-50	8	2	29	7
	50-90	7	3	24	11
B	0-30	50	28	90	25
	30-50	14	7	28	7
	50-90	18	6	27	9
Treatment	0-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
	50-90	*		n.s.	
Block	0-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
	50-90	n.s.		n.s.	

Significance level $p<0.05$, significant (*), not significant (n.s.)

Table 22: Inorganic nitrogen mean values over all depths (in kg ha^{-1}) on the 19.4.18 and 3.7.18.

		19.04.18		03.07.18	
Treatment	depth (cm)	N_{in}	St.d.	N_{in}	St.d.
A	0-90	15	4	45	6
B	0-90	28	13	48	13
Treatment	0-90	n.s.		n.s.	
Block	0-90	n.s.		n.s.	

Significance level $p<0.05$, significant (*), not significant (n.s.)

When looking at results of ammonium (mg kg^{-1}) (see table 23), values for treatment A and B were similar on the first measuring date (**19.4.2018**). On the second sampling date (**3.7.2018**), treatment A showed lower ammonium content in the first horizon compared to the first measurements. The deeper soil layers, especially in 50-90 cm depth, contents were higher compared to the first sampling date. In treatment B the top soil also showed lower ammonium values. Again, in deeper layers ammonia content was higher than the values of the first assessment date. Statistical analysis for the first sampling date showed no significant differences between the treatments. The same can be said about the results of the second assessment.

Table 23: Ammonium (in mg kg^{-1}) on the 19.4.18 and 3.7.18.

		19.04.18		03.07.18	
Treatment	depth (cm)	Ammonium	St.d.	Ammonium	St.d.
A	0-30	0.30	0.17	0.25	0.10
	30-50	0.11	0.14	0.16	0.13
	50-90	0.14	0.15	0.25	0.10
B	0-30	0.32	0.25	0.18	0.05
	30-50	0.13	0.21	0.29	0.10
	50-90	0.09	0.16	0.18	0.05
Treatment	0-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
	50-90	n.s.		n.s.	
Block	0-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
	50-90	*		n.s.	

Significance level $p<0.05$, significant (*), not significant (n.s.)

Results for nitrate and N_{in} showed similar tendencies, which can be explained, as nitrate made up the majority of inorganic nitrogen. Mean values of nitrate contents in all soil layers of treatment B were higher than in A in the first assessment. Nevertheless, only in the layer of 50-90 cm a significant difference could be found. Comparing these results to the second sampling results, nitrate values were higher on the second assessment in all layers and both treatments. Moreover, data between the treatments was more similar (see table 24). No significant differences could be found.

Table 24: Nitrate (in mg kg^{-1}) on the 19.4.18 and 3.7.18.

		19.04.18		03.07.18	
Treatment	depth (cm)	Nitrate	St.d.	Nitrate	St.d.
A	0-30	7.39	2.75	19.49	1.87
	30-50	2.52	0.95	9.82	2.65
	50-90	1.08	0.59	3.98	1.74
B	0-30	12.08	7.57	21.72	6.80
	30-50	4.83	2.62	9.24	2.21
	50-90	3.05	1.13	4.41	1.55
Treatment	0-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
	50-90	*		n.s.	
Block	0-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
	50-90	n.s.		n.s.	

Significance level $p<0.05$, significant (*), not significant (n.s.)

The results of ammonium and nitrate showed that nitrate made up most of the content of inorganic nitrogen (table 25).

Table 25: Ratio of ammonium and nitrate of inorganic nitrogen (%) on the 19.4.18 and 3.7.18.

		19.04.18		03.07.18	
Treatment	depth (cm)	Ammonium	Nitrate	Ammonium	Nitrate
A	0-30	4	96	1	99
	30-50	4	96	2	98
	50-90	12	88	6	95
B	0-30	3	97	1	99
	30-50	3	97	3	97
	50-90	3	97	4	96

6.1.3.3. Potential Nitrogen Mineralization

Potential nitrogen mineralization measured in the first samples was highest in the first horizons and declined heavily in depth in both treatments. The results of the second samples show lower values in the top soil of both treatments and slightly lower values in the layer of 30-50 cm compared to the first. In the 50-90 cm layer, values of potential nitrogen mineralization were slightly higher than in the first date, which can be said for both treatments (see table 26). The statistical analysis resulted in no significant differences between the treatments on both sampling dates.

Table 26: Potential nitrogen mineralization (Min) in mg N kg^{-1} soil 7 d^{-1} (19.4.18 and 3.7.18).

		19.04.18		03.07.18	
Treatment	depth (cm)	Min	St.d.	Min	St.d.
A	0-30	40.36	14.00	35.24	9.63
	30-50	3.99	3.20	3.03	1.01
	50-90	1.28	0.33	1.39	0.83
B	0-30	39.76	15.24	31.11	9.03
	30-50	4.19	1.60	2.48	0.12
	50-90	1.28	0.49	1.52	1.35
Treatment	0-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
	50-90	n.s.		n.s.	
Block	0-30	*		n.s.	
	30-50	n.s.		n.s.	
	50-90	n.s.		*	

Significance level $p<0.05$, significant (*), not significant (n.s.)

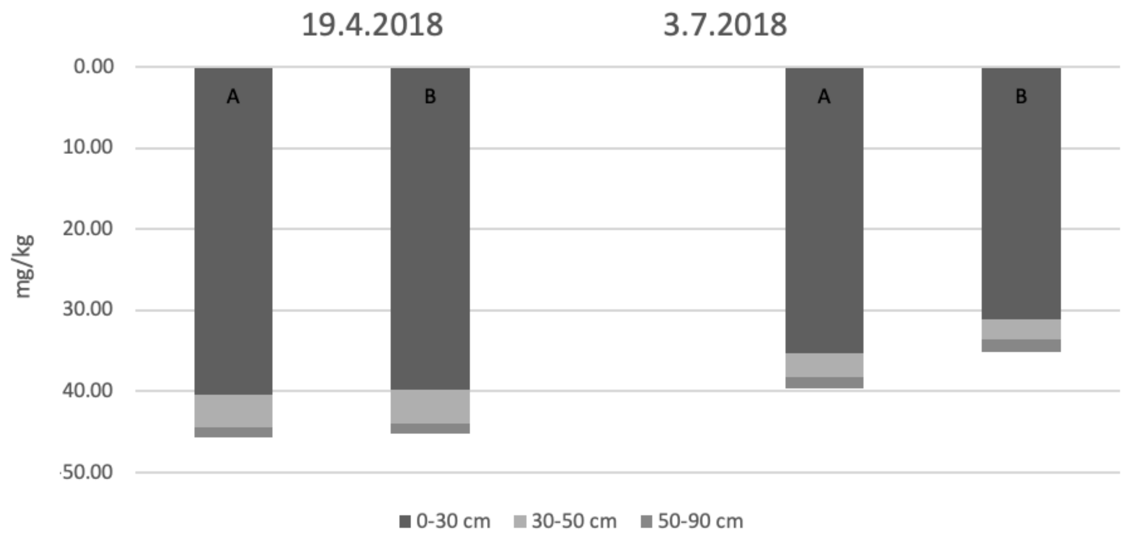

Figure 39: Accumulated potential nitrogen mineralization (mg N kg^{-1} soil 7 d^{-1}) of three soil layers (cm) of both treatments on the 19.4.18 and 3.7.18.

6.1.3.4. Aggregate Stability

Soil aggregate stability was assessed on the **3.7.2018** for two depths. There were no significant differences found between the treatments (see table 27).

Table 27: Soil aggregate stability (%) on the 3.7.2018.

Treatment	depth (cm)	SAS	St.d.
A	0-15	64.01	17.35
	15-30	61.25	18.68
B	0-15	61.79	14.89
	15-30	59.34	19.38
Treatment	0-15	n.s.	
	15-30	n.s.	
Block	0-15	*	
	15-30	*	

Significance level $p<0.05$, significant (*), not significant (n.s.)

6.1.3.5. Soil Moisture

Soil moisture was measured on the **20.4.2018** and on the **27.8.2018** (table 28). When looking at the data from the first sampling, VWC was lower in all depths of treatment B compared to A. A possible explanation for the elevated values in treatment A is the higher catch crop biomass compared to treatment B (figure 40), which might have protected the soil water from evaporation. The results of the second sampling show higher values in the first 50 cm of treatment A, followed by a decline. Treatment B showed inconsistencies.

Table 28: Volumetric water content (%) of soil on the 20.4.2018 and on the 27.8.2018 in several depths.

		20.04.18	27.08.18
Treatment	depth (cm)	VWC (%)	VWC (%)
A	10	15.70	19.10
	20	21.50	21.70
	30	23.20	27.30
	40	26.20	28.30
	50	25.80	29.10
	60	25.20	22.80
	70	26.00	18.20
	80	26.70	-
B	10	10.30	16.60
	20	17.00	16.00
	30	16.70	19.80
	40	22.60	26.10
	50	25.00	26.10
	60	24.30	25.00
	70	24.70	20.20
	80	26.00	-

Figure 40: Plot 2 with freeze-killed catch crops in the middle and plot 1 and 3 with winter-hardy catch crops on the sides (6.4.2018).

6.2. Crop Biomass

6.2.1. Catch Crop Above-ground Biomass

Catch crop emergence and soil coverage for both treatments was assessed on the **7.11.2017**. In treatment A, all three sown catch crops emerged. Weed pressure was almost negligible for all plots (< 1 %) except for plot 3, where weed pressure was still very low (5 %). In treatment B, fodder pea, chickling vetch and phacelia emerged, whereas common vetch, buckwheat and fodder radish soil coverage was zero. Probable explanations are reduced seed quality or unsuitable conditions during sowing. Weed pressure was also negligible for treatment B (< 1 %).

In figure 41, the soil coverage (%) of each catch crop of the winter-hardy mix for all four blocks in November 2017 can be found. It is visible that Italian raygras covered soil the most in all blocks. In figure 42, the same is shown for treatment B. Compared to treatment A, no clear trend in soil coverage could be found. In block one and two, chickling vetch covered the most soil, whereas in block three and four phacelia coverage was highest. Fodder pea covered similar percent of soil in all blocks.

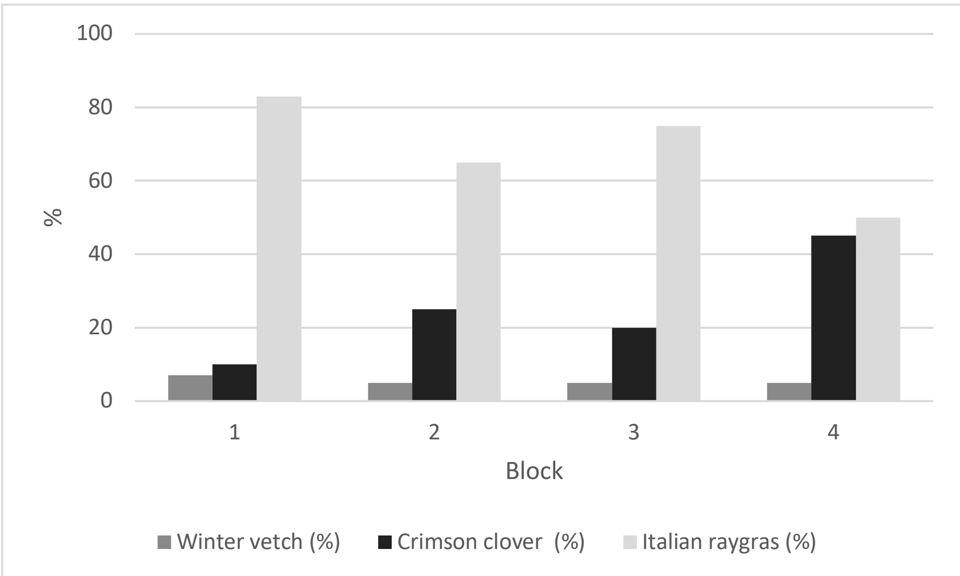

Figure 41: Soil coverage by winter-hardy catch crops (%) in November.

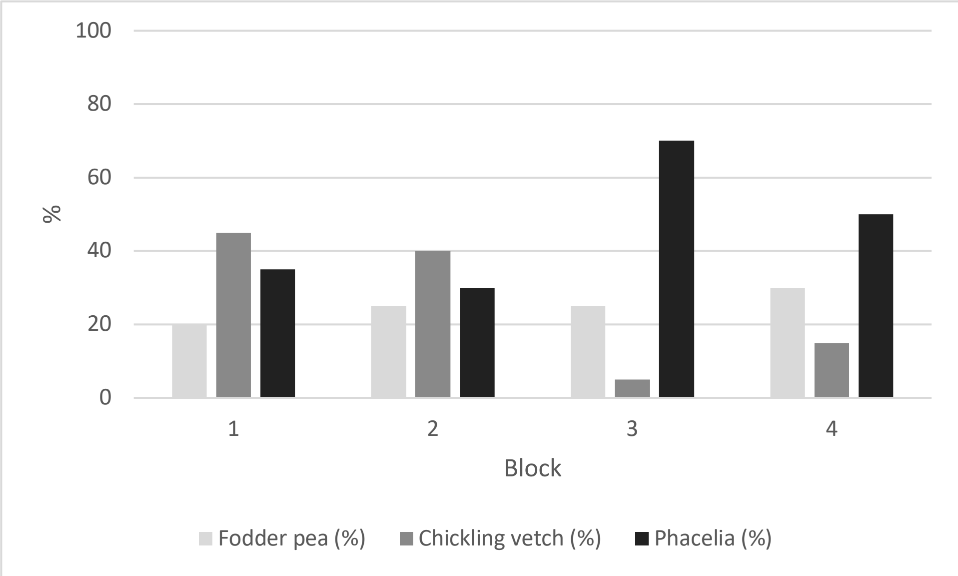

Figure 42: Soil coverage by emerged freeze-killed catch crops (%) in November.

On the **7.11.2017** both catch crop mixes were sampled for analysing yields. Treatment B accumulated more above-ground biomass than treatment A. The mean values for fresh weight (dt ha^{-1}) and dry matter (dt ha^{-1}) of the two treatments can be found in table 29. The statistical analysis showed that for both, fresh matter and dry weight, there were significant differences between the treatments.

Table 29: Fresh weight and dry matter of catch crop treatments in dt ha^{-1} (7.11.2017).

Treatment	FW Catch Crops	DM Catch Crops
A	112.78	17.30
B	278.19	29.20
St.d. A	32.39	3.50
St.d. B	111.20	8.12
Treatment	*	*
Block	n.s.	n.s.

Fresh weight (FW), dry matter (DM); significance level p<*0.05*, significant (*), not significant (n.s.)

On the **19.4.2018**, treatment A (winter-hardy catch crops) was harvested once more, as the catch crops remerged in spring. Compared to the harvest on the **7.11.2017**, fresh matter and dry weight increased (see table 30). On the **27.4.2018**, due to intensive weed pressure, treatment B was harvested to assess the ratio between catch crops and weeds, which was used for further calculations (for explanation see chapter ***4.6.1.1. Above-ground Biomass***). Dry matter, with a mean value of 1.05 (dt ha^{-1}), was very low (see table 31).

Table 30: Fresh weight (FW) and dry matter (DM) means of treatment A in dt ha^{-1} (19.4.2018).

Plot	FW Catch Crops	DM Catch Crops
1	130.28	22.49
3	165.12	25.74
6	91.95	17.71
8	179.12	27.73
mean	141.62	23.42

Table 31: Dry matter (DM) means of treatment B in dt ha^{-1} (27.4.2018).

Plot	DM Catch Crops
2	0.22
4	2.12
5	0.06
7	1.80
mean	1.05

6.2.2. Catch Crop Root Biomass

Samples for catch crop root biomass determination were taken on the **27.3.2018** (plots 1-4) and on the **29.3.2018** (plots 5-8). As already described in chapter ***4.6.1.1. Above-ground Biomass***, by including the data from the catch crop harvest of treatment B on the 27.4.2018, factors for each of the four plots for treatment B were calculated. These factors were used to calculate more accurate results for the catch crop root biomass of treatment B. In the table 32, the statistical analysis of root biomass dry matter for both treatments can be found. Root dry matter without the factor incorporation and with factor incorporation (for treatment B) was analyzed. The results show that total root biomass of treatment A (**239.38 kg ha^{-1}**) was higher than both calculations for treatment B (**179.41 kg ha^{-1}** without factor and **16.40 kg ha^{-1}** with factor). When applying the factor on treatment B, a significant difference between treatment A and B was found for both depths. Nevertheless, the assessment of catch crop root biomass in spring not very accurate, as treatment B is a freeze-killed mix. Because of the later joining of the author, root assessment could only be done in spring. Including the problem of high weed pressure, a comparison between treatments is difficult. Root assessment should therefore have been made in autumn 2017.

Table 32: Catch crop root biomass dry matter in kg ha^{-1}, without and with factor inclusion (March 2018).

Treatment	depth (cm)	Root DM	St.d.	Root DM with factor	St.d.
A	0-15	83.3	17.1	83.3	17.1
	15-30	156.1	131.6	156.1	131.6
B	0-15	88.6	57.1	7.5	11.3
	15-30	90.8	82.2	8.9	14.5
Treatment	0-15	n.s.		*	
	15-30	n.s.		*	
Block	0-15	n.s.		n.s.	
	15-30	n.s.		n.s.	

Dry matter (DM); significance level $p<0.05$, significant (*), not significant (n.s.)

In figure 43, the results of the catch crop dry matter harvest (**19.4.2018** and **27.4.2018**) and root dry matter biomass are linked and visualized. As already described, treatment A built-up more biomass dry matter (kg ha^{-1}) than treatment B, above and below ground.

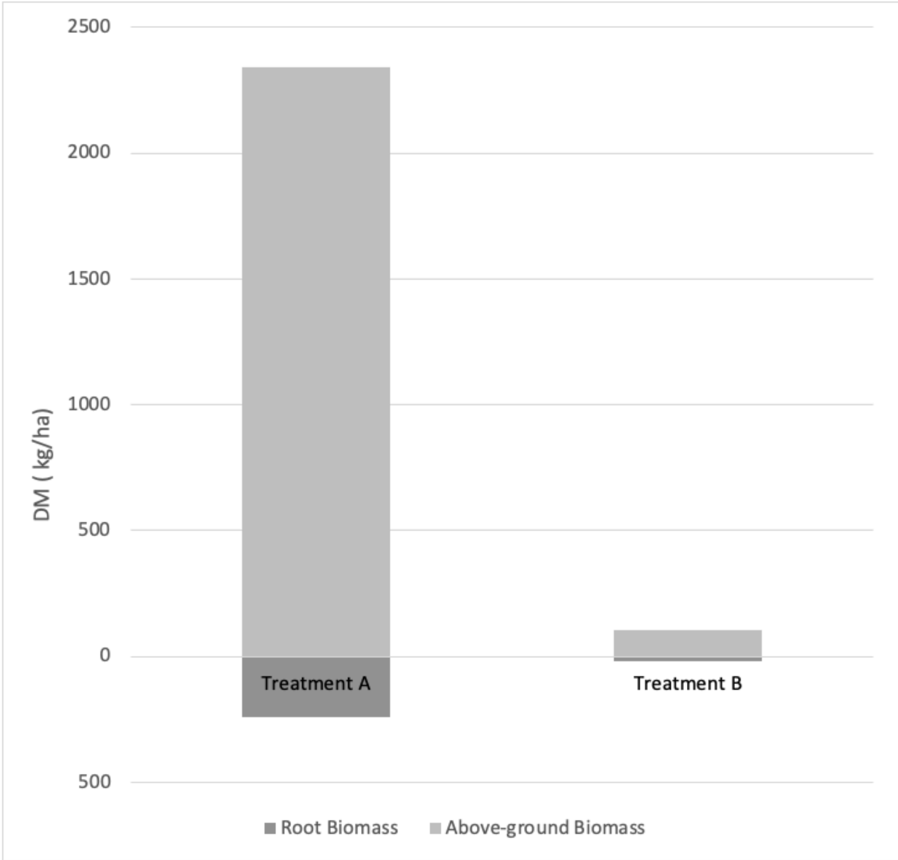

Figure 43: Above and below ground catch crop biomass dry matter in kg/ha (spring 2018).

6.2.3. C/N Ratio of Catch Crop Root Biomass and Catch Crop Mix A

Nitrogen (%), carbon (%) and C/N ratio of catch crop root biomass was assessed (samples taken on the **27.3.2018** and **29.3.2018**) (table 33). For N and C/N ratio, no significant differences were found between the treatments. C contents of soil layer 0-15 cm was significantly different between treatment A and B. Again, these results are influenced by the high weed pressure in treatment B. The significant difference in carbon might thus be a result of impact by weeds.

Table 33: Nitrogen (%), carbon (%) and C/N ratio of catch crop root biomass (March 2018).

Treatment	depth (cm)	N (%)	St.d.	C (%)	St.d.	C/N	St.d.
A	0-15	1.06	0.05	35.70	3.87	33.67	3.83
	15-30	1.05	0.26	30.19	6.36	30.49	10.44
B	0-15	0.94	0.27	31.30	5.16	36.34	13.32
	15-30	1.14	0.33	28.79	7.21	25.87	4.62
Treatment	0-15	n.s.		*		n.s.	
	15-30	n.s.		n.s.		n.s.	
Block	0-15	n.s.		*		n.s.	
	15-30	*		n.s.		n.s.	

Significance level p<*0.05*, significant (*), not significant (n.s.)

In table 34, nitrogen (%), carbon (%) and C/N ratio of catch crop mix A above-ground biomass (harvested on the **19.4.2018**) can be found. The mean value for C/N was 13.19. For treatment B, no samples for C/N ratio assessment were taken, as biomass was minimal.

Table 34: Nitrogen content (%), carbon content (%) and C/N ratio of catch crop mix A above-ground biomass (19.4.2018).

	Plot	Catch Crop	N (%)	C (%)	C/N
Catch Crop Above-ground Biomass	1	A	2.94	39.83	13.53
	3	A	3.08	39.88	12.96
	6	A	2.89	39.56	13.70
	8	A	3.10	38.92	12.57
		mean	3.00	39.55	13.19

6.2.4. Dry Matter of Maize Kernels and Plant Residues

Maize was sampled to assess biomass with 86% dry matter of maize kernels and plant residues (in kg ha^{-1} and %) on the **8.10.2018** (see table 35). Plant residues consisted of stems, leaves and core of the maize cobs. There were no significant differences found between the treatments for any of the assessed parameters. Nevertheless, mean DM kernel yield for treatment A was higher than treatment B.

6.2.5. Correlation Analysis between Dry Matter of Maize Kernels and Plant Residues and Inorganic Nitrogen

The correlation analysis between dry matter of maize kernels and inorganic nitrogen samples from the 19.4.2018 resulted in a non-significant correlation according to statistical analysis with Spearman’s correlation (figure 44). Correlation coefficient was 0.143.

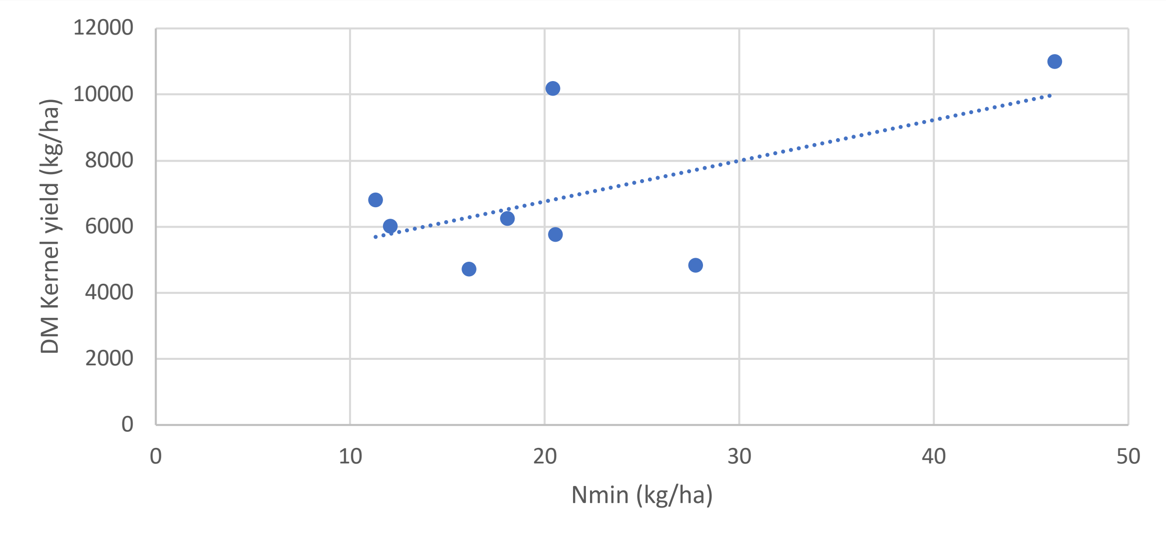

Figure 44: Correlation between maize kernel DM (kg ha-1) (8.10.2018) and Nin (kg ha-1) (19.4.2018) (r= 0.143).

The correlation analysis between dry matter of maize residues and inorganic nitrogen samples from the 19.4.2018 resulted as well in a non-significant correlation according to statistical analysis with Spearman's correlation (figure 45). Correlation coefficient was 0.667.

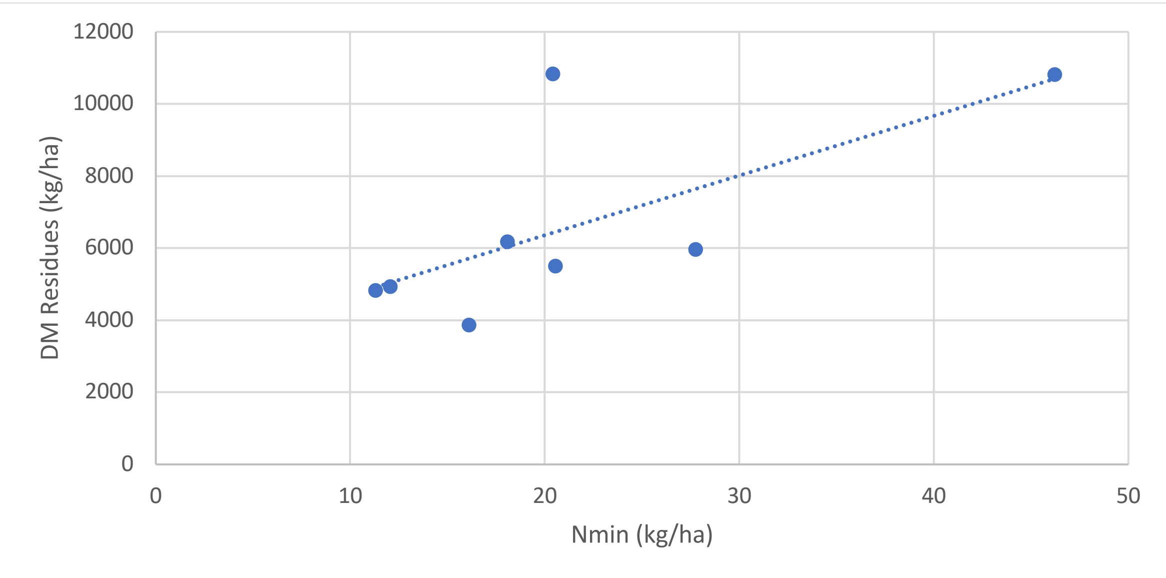

Figure 45: Correlation between maize residue DM (kg ha-1) (8.10.2018) and Nin (kg ha-1) (19.4.2018) (r= 0.667).

6.2.6. Fresh Weight of Maize Cobs and maize Shoot Biomass

Fresh weight of maize cobs and shoot biomass (in dt ha^{-1} and %) was assessed as well on the **8.10.2018** (see table 36). Shoot biomass consisted of stems and leaves, maize cobs of the maize core, kernels and husk leaves. Shoot biomass was higher in treatment B (A: 114.54 dt ha^{-1}, B: 122.54 dt ha^{-1}), cob biomass was higher in treatment A (A: 124.74 dt ha^{-1}, B: 121.55 dt ha^{-1}). Again, no significant differences were found between the treatments for all parameters (including total fresh weight and percentage values).

6.2.7. Maize Kernel Yield

Kernel yield (kg ha^{-1}) was assessed on the **8.10.2018** (see table 36). Maize cobs were air dried for eight weeks and then kernels were separated from the cobs and weighed. Statistical analysis resulted in no significant differences between the treatments.

The farmer harvested the maize with machinery one day later, on the **9.10.2018**. Fresh weight was 4540 kg for the whole field including the 20 m gap between plots 1-4 and 5-8 (2880 m^2). Nett dry matter was 3900 kg (25% moisture).

Table 35: Biomass 86% dry matter of kernels, maize residues and total (in kg ha^{-1} and %).

Treatment	Kernels (kg ha^{-1})	St.d. (kg ha^{-1})	Residues (kg ha^{-1})	St.d. (kg ha^{-1})	Total (kg ha^{-1})	St.d. (kg ha^{-1})	Kernels (%)	St.d. (%)	Residues (%)	St.d. (%)
A	7324.1	1940.7	6692.0	2827.0	14016.0	4710.6	53.09	4.56	46.91	4.56
B	6583.5	2988.6	6535.5	2991.4	13119.0	5921.1	50.35	4.21	49.65	4.21
Treatment	n.s.		n.s.		n.s.		n.s.		n.s.	
Block	*		n.s.		*		n.s.		n.s.	

Residues (stem, leaves and core of cobs), total (kernels and residues); dry matter (DM); significance level $p<0.05$, significant (*), not significant (n.s.)

Table 36: Fresh weight of shoot biomass, maize cob, total (in dt ha^{-1} and %) and kernel yield (kg ha^{-1}).

Treatment	Shoot (dt ha^{-1})	St.d. (dt ha^{-1})	Maize Cob (dt ha^{-1})	St.d. (dt ha^{-1})	Total (dt ha^{-1})	St.d. (dt ha^{-1})	Shoot (%)	St.d. (%)	Maize Cob (%)	St.d. (%)	Kernel yield (kg ha^{-1})	St.d. (kg ha^{-1})
A	114.54	49.46	124.74	34.30	239.28	82.67	47.08	4.33	52.92	4.33	8547.3	2429.8
B	122.54	50.15	121.55	48.77	244.10	98.68	50.17	1.66	49.84	1.66	8093.8	3656.6
Treatment	n.s.		n.s.		n.s.		n.s.		n.s.		n.s.	
Block	*		*		*		n.s.		n.s.		*	

Shoot (stems and leaves), maize cob (core, kernels and cob leaves), total (shoot and cob), kernel yield air dried 8 weeks; fresh weight (FW); significance level $p<0.05$, significant (*), not significant (n.s.)

6.2.8. C/N Ratio of Maize Kernels and Plant Residues

Data for nitrogen and carbon content (%) as well as C/N ratio determination of maize kernels and maize plant residues was assessed from samples taken on the **8.10.2018** during maize harvest. Maize residues consisted of stem, leaves and core of cobs. For maize kernels, mean values of N, C and C/N were almost identical (see table 37). Statistical analysis conducted did not show significant differences between the treatments. For maize plant residues, mean values were similar, and again, no significant differences were found (see table 38).

Table 37: Nitrogen content (g kg^{-1}), carbon content (g kg^{-1}) and C/N ratio of maize kernels (8.10.2018).

Treatment	N	C	C/N
A	13.72	421.27	30.74
B	13.71	420.07	30.95
St.d. A	0.42	2.56	1.06
St.d. B	1.57	2.14	3.57
Treatment	n.s.	n.s.	n.s.
Block	n.s.	n.s.	n.s.

Significance level $p<0.05$, significant (*), not significant (n.s.)

Table 38: Nitrogen content (g kg^{-1}), carbon content (g kg^{-1}) and C/N ratio of maize residues (8.10.2018).

Treatment	N	C	C/N
A	6.51	413.02	64.72
B	7.13	407.44	59.83
St.d. A	1.07	5.19	10.07
St.d. B	1.68	3.03	15.44
Treatment	n.s.	n.s.	n.s.
Block	n.s.	n.s.	n.s.

Significance level $p<0.05$, significant (*), not significant (n.s.)

6.3. Visual Assessments

6.3.1. Growth

Visual assessments started on the 24.5.2018, two weeks after maize was sown, and ended on the 8.10.2018, when maize was harvested. When looking at the values of maize plant height (cm) over time, it is visible that maize reached its maximum on the 14.8.2018 and kept stable from then (see figure 46 and mean values in table 39). Statistical significance between the treatments was only found for the first two assessments, on the **24.5.2018** and on the **10.6.2018**, where treatment A showed increased height compared to treatment B.

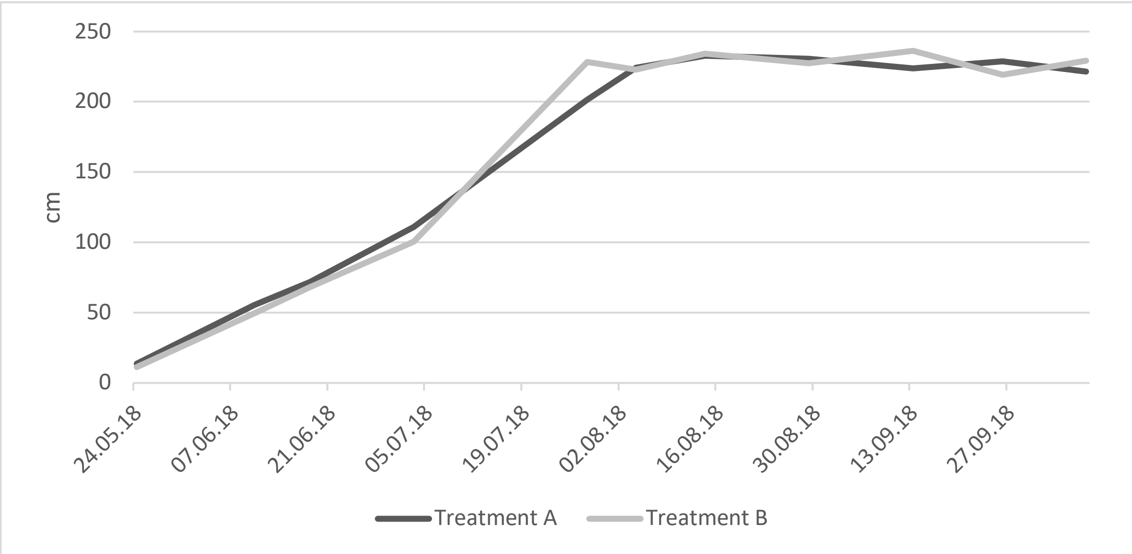

Figure 46: Development of height (cm) for both treatments (dates in figure are not the dates of visual assessment but serve as guideline).

6.3.2. Development Stages

Development of maize plants was similar for both treatments on all assessment dates. Only on the **4.8.2018** a significant difference of development stage between treatments was found. On that assessment, treatment B showed a more advanced development (see table 40).

6.3.3. Plants per m^2

The assessment of maize plants per m^2 resulted in a significant difference between the treatments on the **4.8.2018**. Treatment A showed a mean value of 6 plants per m^2, treatment B a mean value of 5.21 plants per m^2. On all other dates, results were similar, and no significant differences were found (table 41).

The results of the visual assessment on the 4.8.2018 showed significant differences of development stages and plants per m^2 between the treatments. There are several factors that could have influenced these results. Firstly, undersown crops were sown on the 18. And 19.7.2018, which could have been in competition for nutrients and water with maize. As it was assessed that cover crop emergence was extremely low due to the dry conditions, it is unlikely that they affected maize development. Secondly, weeds were harvested in treatment A before undersown crops were propagated. By reducing the soil cover, more water could have been evaporating from the soil and lead to overall dryer conditions in treatment A. Lastly, visual assessments were sampled randomly and have a high error rate, which could lead to false results.

6.3.4. Weed Pressure

On the **1.6.2018** and the **8.6.2018** the hoeing equipment was used on all plots to reduce weed pressure. This explains the drop in weed pressure (%) after the first and second assessment (see figure 47). A significant difference between treatments was found on the 3.7.2018, where treatment A showed higher weed pressure. Moreover, on the **12.**, **13.**, and **14.7.2018** weed hoeing by hand was done in treatment A, as undersown crops were sown on the **18**. and **19.7.2018**. This drop is visible as well in figure 47 and table 42, which contains the mean values of weed pressure for both treatments. Interestingly, weed pressure showed steadily higher values from **mid-August** in treatment A after weed supressing measures in **mid-July**. On the last assessment, weed pressures of both treatments were almost identical. This can be explained, as undersown crops did not emerge due to the very dry conditions. Therefore, weeds were able to reinfest treatment A. Although maize development stage was around 74 for both treatments on the **14.8.2018**, competition of maize against weeds in treatment A was not successful. The results of thistles per m^2 on the 8.10.2018 (equally high infestation in both treatments) supports this conclusion (see table 43). It has to be noted that weed pressure was assessed by estimating soil coverage per parcel by eye. This method is sensitive to errors and highly subjective.

Main weeds determined during the trial were *Cirsium arvense*, *Stellaria media, Lamium purpureum, Chenopodium album*, *Setaria glauca*, *Solanum nigrum*, *Galium aparine*, and *Echinochloa crus-galli*, although *Cirsium arvense* infestation dominated and competed most with maize.

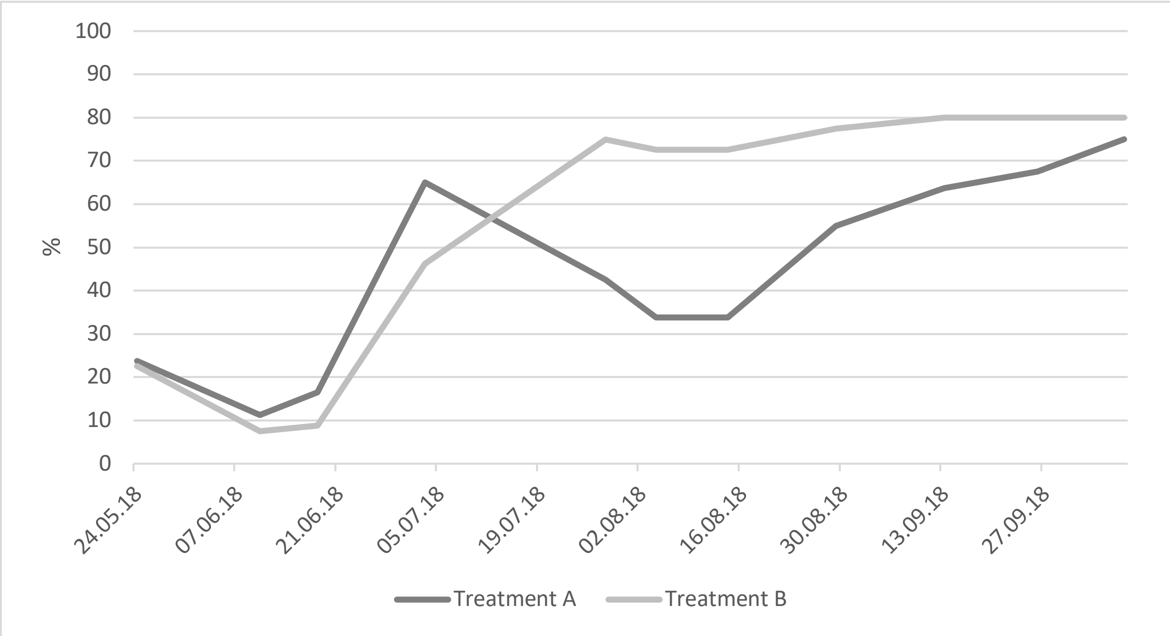

Figure 47: Weed pressure (%) over time for both treatments (dates in figure are not the dates of visual assessment but serve as guideline).

Table 39: Maize plant height (cm) measured on visual assessment dates

Treatment	24.05.18	10.06.18	18.06.18	03.07.18	28.07.18	04.08.18	14.08.18	29.08.18	13.09.18	26.09.18	08.10.18
A	14	55	72	111	202	224	233	231	224	229	222
B	11	49	68	101	229	223	234	227	236	219	229
St.d. A	1	10	14	17	15	31	25	26	30	23	14
St.d. B	2	10	11	25	24	20	12	25	15	18	9
Treatment	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Block	n.s.	*	*	*	n.s.	*	n.s.	n.s.	n.s.	n.s.	-

Significance level p<0.05, significant (*), not significant (n.s.)

Table 40: Development Stages measured on visual assessment dates.

Treatment	24.05.18	10.06.18	18.06.18	03.07.18	28.07.18	04.08.18	14.08.18	29.08.18	13.09.18	26.09.18	08.10.18
A	13.3	15.5	16.1	18.7	66.9	70.5	74.4	83.1	88.4	92.3	99.0
B	13.0	15.4	16.0	18.3	66.8	71.2	74.2	84.0	88.0	92.4	99.0
St.d. A	0.4	0.4	0.6	0.8	0.8	1.0	0.9	1.1	1.0	0.6	0.0
St.d. B	0.3	1.1	0.9	1.4	0.6	1.1	1.2	0.7	0.5	0.3	0.0
Treatment	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.	n.s.	-
Block	n.s.	n.s.	n.s.	n.s.	n.s.	*	*	n.s.	n.s.	n.s.	-

Significance level p<0.05, significant (*), not significant (n.s.)

Table 41: Plants per m^2 measured on visual assessment dates.

Treatment	24.05.18	10.06.18	18.06.18	03.07.18	28.07.18	04.08.18	14.08.18	29.08.18	13.09.18	26.09.18	08.10.18
A	5.2	5.7	5.6	5.2	5.2	6.0	6.6	6.4	5.8	6.3	6.6
B	4.5	5.4	5.0	5.4	5.3	5.2	6.3	5.8	5.4	6.2	6.1
St.d. A	1.0	0.7	1.2	0.6	0.8	0.7	1.3	1.7	0.8	1.1	0.9
St.d. B	1.1	1.6	1.2	0.8	0.7	0.4	0.6	0.6	0.7	1.5	1.5
Treatment	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.
Block	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Significance level p<0.05, significant (*), not significant (n.s.)

Table 42: Weed pressure (%) measured on visual assessment dates.

Treatment	24.05.18	10.06.18	18.06.18	03.07.18	28.07.18	04.08.18	14.08.18	29.08.18	13.09.18	26.09.18	08.10.18
A	24	11	17	65	43	34	34	55	64	68	75
B	23	8	9	46	75	73	73	78	80	80	80
St.d. A	12	11	22	31	44	38	38	37	33	40	32
St.d. B	16	6	9	32	44	46	46	38	40	40	40
Treatment	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Block	*	n.s.	n.s.	*	n.s.	n.s.	n.s.	*	*	*	*

Significance level p<0.05, significant (*), not significant (n.s.)

Table 43: Thistles per m^2 on the 8.10.2018.

Treatment	Thistles per m2	St.d.
A	28	18
B	31	21
Treatment	n.s.	
Block	*	

Significance level p<*0.05*, significant (*), not significant (n.s.)

6.3.5. Additional Assessments

During the months of visual assessment of maize, several diseases and pests were detected on the field. Firstly, European corn borer (*Ostrinia nubilalis*) was present in some plots but caused only minor damage, as infestation rate was low (see figure 48). Moreover, corn smut (*Ustilago maydis*) was found on three maize plants (see figure 48). Some plants also showed signs of disturbed fertilization, the cause could not be determined (see figure 48).

Figure 48: European corn borer on the 29.8.2018 (left), corn smut on the 14.8.2018 (middle), disturbed fertilization process on the 4.8.2018 (right).

The most damage was done by the corn root worm (*Diabrotica virgifera virgifera)* (see figure 49). It could be found on all plots in various densities and caused damage on the corn cobs. As a result, *Fusarium spp*. had improved conditions to infest the cobs (see figure 49). Other diseases and pest, only found infrequently on the experimental site, were *Setosphaeria turcica* and aphids.

Figure 49: Corn root worm beetle (left) its damage on maize on the 14.8.2018 (middle) and resulting *Fusarium spp*. infection on the 8.10.2018 (right).

Already during the second visual assessment on the 10.6.2018 it was very visible that sowing errors occurred on all plots in various intensity (see figure 50). Towards the end, especially plots 2, 3, 4, 7 and 8 showed large areas where, instead of maize plants, weeds covered the soil densely. Main weed competing with maize in these sowing error areas was the creeping thistle (*Cirsium arvense*) (see figure 50). Plot 6 showed least sowing errors.

Figure 50: Sowing errors on plot 3 (treatment A) on the 10.6.18 (left) and the 3.7.18 (middle); infestation of free area by thistle on the 14.8.2018 (right).

Due to the dry weather conditions in July, undersown catch crops in treatment A (sown on the **18**. and **19.7.2018**) did hardly emerge (see figure 51). Moreover, competition with weeds of was high. Phacelia growth was assessed on plot 1 on the 13.9.2018, but density was low until maize harvest. All other undersown crops did not emerge. Therefore, effects of undersown crops can be neglected.

Figure 51: Treatment A on the 4.8.18 (left) and on the 14.8.18, with weed infestation (middle); Plot 1 on the 8.10.18 with phacelia plant (right).

7. Discussion

Assessment of catch crops in autumn 2017 revealed that in the freeze-killed mix, only phacelia, chickling vetch and fodder pea emerged. Buckwheat, fodder radish and common vetch did not grow. Possible reasons are low quality of the seeds or unsuitable conditions during sowing. In treatment A, all winter-hardy catch crops emerged. Catch crop above-ground fresh weight was higher in treatment B than A (278.19 dt ha^{-1} and 112.78 dt ha^{-1}, respectively). The same trend was found for dry matter of above-ground biomass (B: 29.20 dt ha^{-1} and 17.30 dt ha^{-1}). Moreover, differences between the treatments for fresh weight and dry matter were significant. Büchi et al. (2018) received similar results for above-ground dry matter of freeze-killed catch crop mixes (around 27 dt ha^{-1}) under minimum tillage. Komainda et al. (2016) found dry matter values of 97.9 kg ha^{-1} in November for Italian raygras, which was sown in mid-September after silage maize. Schließer et al. (2010) found dry matter values of 13.85 kg ha^{-1} and 26.23 kg ha^{-1} for Landsberger gemenge and a freeze-killed catch crop mix (phacelia, buckwheat, Persian clover and chickling vetch), respectively. A study by Rosa (2015) received mean fresh weight values of about 13 t ha^{-1} for Italian raygras and 18 t ha^{-1} for hairy vetch (seeding rate of 35 kg ha^{-1} and 70 kg ha^{-1}, respectively). Taking the soil cover into account, Italian raygras showed highest soil coverage in all blocks. In treatment B, chickling vetch and phacelia coverage showed inconsistencies, thus no clear trend was found. A two-year study by Bodner (2007) found that in the first year, after cultivation in August, phacelia showed the highest maximum soil cover whereas winter vetch showed delays in development of ground cover until mid-October. In April 2018, dry matter of treatment A was 23.42 dt ha^{-1}, whereas the freeze-killed mix developed only 1.05 dt ha^{-1}. Gruber and Thamm (2006) found very similar mean values for above-ground dry matter of Landsberger gemenge (about 21.6 dt ha^{-1}).

For root biomass, treatment A developed 239 kg ha^{-1}. Root biomass of treatment B was 179 kg ha^{-1} without factor and 16 kg ha^{-1} with factor inclusion. In both cases, a significant difference between the treatments was found. The ratio between root and above-ground biomass of treatment A is very low (239 kg ha^{-1} and 2342 kg ha^{-1} respectively, result in a root to shoot ratio of 0.1). Bodner (2007) for example found root to shoot ratios of 0.4 for phacelia and winter vetch. The same study found that rye produced high root biomass and achieved a root to shoot ratio of 0.79, although above-ground biomass development resulted in a low soil cover of around 50 %. Askegaard and Eriksen (2007) found root DM values of 1328 kg ha^{-1} for white clover and 1073 kg ha^{-1} for ryegrass in soil depths of 0-25 cm in November. This leads to the conclusion, that errors during root biomass determination occurred. The assessment of catch crop root biomass in spring is not very accurate, as treatment B is a freeze-killed mix. A calculation of above-ground and root biomass ratio was therefore foregone. Thus, it is recommended to do root sampling of catch crops in autumn, especially when freeze-killed species are contained.

The assessment of C/N ratio (March 2018) of root biomass between the catch crop treatments resulted in no significant differences. The C/N ratio of above-ground biomass of treatment A was 13.19. For treatment B, no samples for C/N ratio assessment were taken, as biomass was minimal. C/N values for above-ground biomass of Landsberger gemenge in a study by Schließer et al. (2010) were around 8, a freeze-killed catch crop mix (consisting of phacelia, buckwheat, Persian clover and chickling vetch) reached a value of about 11.5. Kramberger et al. (2014) found C/N values of 45.5 for above-ground biomass of Italian raygras residues before cultivation of maize. Rüegg et al. (1998) found nitrogen contents of 62 kg ha^{-1} for winter-hardy rye above-ground biomass in spring before silage maize sowing.

Overall it has to be noted, that a comparison of the results of catch crop mix B with literature was difficult, as almost no data for leguminous and non-leguminous freeze-killed catch crop mixes is available. Landsberger gemenge, as a winter-hardy mix with leguminous and non-leguminous catch crops, is quite well represented in other studies. Moreover, data for pure legume or non-legume mixes is more accessible than for mixtures between them.

H1: The treatments do not have different effects on soil, therefore the surveyed soil parameters will show no differences when comparing the treatments.

Soil moisture was assessed twice, on the 20.4.2018 (shortly before catch crop was incorporated into soil) and on the 27.8.2018 (maize development stage at 83). The data from the first sampling shows that VWC was lower in depths 10-40 cm in treatment B compared to A (for example 10.3 % and 15.7 % in 10 cm depth, respectively). A study by Joyce et al. (2002) found VWC values of 28 % after winter-hardy common vetch in depths of 45 cm in an organically cultivated field (results of the first of two years). Precipitation in April was very low (15.9 mm) and temperatures already elevated (average of 15.5 °C). Soil coverage of winter-hardy catch crops was dense and greater than for the freeze-killed mix, which also showed spots of bare soil. A study by Bodner (2007) concluded that under water-supply driven conditions, there are only slight differences of evapotranspiration between bare fallows and soils covered with catch crops. On the other hand, evapotranspiration is higher in catch crop systems compared to fallows when conditions are dry. Allen (1990) also found that in sparse canopies, evaporation losses are greater than in fallows when precipitation is very low. Bodner (2007) moreover drew the conclusion that coverage of soil by catch crops can reduce soil water evaporation and improve water availability for crops. Therefore, it is difficult to make a final statement on the reason of enhanced soil moisture in treatment A on the first assessment date. The results of the second assessment showed lower soil moisture in the upper layers compared to the deeper layers in treatment A (19.1 % in 10 cm depth and 29.1 % in 50 cm depth) and B (16.6 % in 10 cm depth and 26.1 in 40 and 50 cm depth). Overall, values of the second assessment were higher than of the first for both treatments.

Water infiltration on the first measuring date (20.4.2018, shortly before catch crop incorporation into soil) was, with a k_f-value of $6.6*10^{-6}$ m s^{-1}, similar in both treatments. According to the water infiltration classification by AG Boden (1994, p. 306), water infiltration was high for both treatments. Folorunso et al. (1992) found that after common vetch cultivation, steady infiltration rate was 35.8 mm/h (equals $9{,}94*10^{-5}$ m s^{-1}) in spring. A comparison of the results of water infiltration on the second measuring date (21.8.2018) is difficult (A: $1.3*10^{-5}$ m s^{-1}; B: $9.3*10^{-5}$ m s^{-1}), as soil conditions in treatment B were very dry, and a constant infiltration rate could not be achieved. Water infiltration of treatment A and B on the second assessment date can be classified as very high and extremely high, respectively (AG Boden, 1994). The dry soil conditions were a result of the unusual warm temperatures and low precipitation since April. All monthly temperatures were above long-term averages (Schally, 2019). When taking the soil humidity measurements into account, both treatments showed dry conditions in layers 0-20 cm and low moisture content in deeper layers. Therefore, k_f-values of treatment B should not be seen as absolute, but relative compared to treatment A. Nevertheless, values of the second sampling date were higher by a decimal power compared to the first sampling date.

Penetration resistance on the 20.4.2018 was very similar for both treatments (for both over 2 MPa were measured at around 20 cm depth and values normalised around 1.5 MPa in 40-50 cm depth). Therefore, no differences could be found between the treatments. Folorunso et al. (1992) found that under similar soil conditions as in our experiment (22.4 % clay and 50.6 % silt), penetration resistance measurements in spring (after winter-hardy vetch cultivation) resulted in a mean value of 4.25 N (MPa= N/ cone surface in mm^2). On the second measuring date (21.8.2018), penetration resistance tests could neither be done for treatment A or B, as the soil was too dry. Therefore, a comparison between the results of the two dates in not possible.

Root penetration intensity on the 20.4.2018 showed that treatment A achieved slightly higher results than treatment B. This can be explained by the winter-hardy catch crops (A) that built up additional biomass after winter, whereas freeze-killed catch crops showed almost no fresh biomass in spring. Moreover, a great part of the freeze-killed catch crop root biomass before winter was decomposed by the time the samples were taken. On the 21.8.2018, treatment B showed slightly better root penetration in depths of 20-60 cm compared to treatment A. Soil structure on the 20.4.2018 and 21.8.2018 was very similar in both treatments, meaning that the treatments did neither have different effects on root penetration intensity on the individual sampling dates, nor over time.

Total organic carbon (g kg^{-1}) results on the 5.9.2017 revealed a significant difference in soil layer 0-15 cm between the treatments. Treatment A (22.65 g kg^{-1}) had slightly higher TOC contents than treatment B (21.78 g kg^{-1}). This significant difference was probably caused by an error during sampling or analysis or an inhomogeneity in blocks. On the 24.10.2018, no significant differences were found. Gadermaier et al. (2011) found TOC values of 2.51 % (25.1 g kg^{-1}) in 0-10 cm and 2.11 % (21.1 g kg^{-1}) in 10-20 cm after silage maize cultivation under reduced tillage with slurry fertilization (winter pea catch crop before maize). Overall, TOC values were higher in the topsoil and lower in deeper depths in both treatments when comparing the results with the first assessment date. Possible explanations are the mulching of catch crops into the topsoil and decomposition of maize residues with high carbon content after harvest (on the 8.10.2018). TOC values of both dates were in the average range of arable soil with clay contents around 25 % (Stahr et al., 2008, Verheijen et al., 2006). TOC in t ha^{-1} was assessed on the 5.9.2017 only and did not show a significant difference between treatments.

Soil organic matter in t ha^{-1} was assessed on the 5.9.2017 and showed a significant difference between treatments. As SOM built-up is a slow process (Johnston et al., 2009), this significant difference was probably caused by an error in sampling. Overall, SOM content in both treatments was above the minimum recommended levels of 3 % for heavy soils (AGES, 2015).

Total nitrogen content did not show significant differences between the treatments on both sampling dates. When comparing the mean values of the two assessment dates (5.9.2017 during catch crop cultivation and 24.10.2018 after maize harvest), a trend was found. Nt was lower in the layers of 15-30 and 30-50 cm in both treatments on the second sampling date. This change can be seen as a possible decrease caused by maize depleting inorganic nitrogen in soil (decrease of Nt in A: 0.12 g kg^{-1} and 0.07 g kg^{-1}; B: 0.07 g kg^{-1} and 0.08 g kg^{-1}, for soil layers 15-30 and 30-50 cm, respectively). These changes equal a decrease of 261 kg N ha^{-1} and 206 kg N ha^{-1} in treatment A and 158 kg N ha^{-1} and 242 kg N ha^{-1} in treatment B between the assessment dates. Nt content in the first soil layer stayed relatively stable, which might be a product of increased inorganic nitrogen in soil after catch crop termination and N_{in} depletion by maize, which could have kept Nt in balance. N contents of total maize biomass (kernels and residues) were 20.2 g kg^{-1} for treatment A and 20.8 g kg^{-1} for treatment B. N values of dry matter of total maize biomass per ha were about 241 kg ha^{-1} for treatment A and 235 kg ha^{-1} for treatment B. Kramberger et al. (2009) found N contents in total maize biomass of 147 kg ha^{-1} after Italian raygras and 241 kg ha^{-1} after crimson clover cultivation before maize (maize was additional fertilized with 120 kg N ha^{-1}). Nevertheless, the found lower values in deeper soil layers on the second assessment date compared to the first might also be caused by errors during sampling or analysis and therefore might represent no actual decreases.

Carbon-to-nitrogen ratio did not show significant differences between the treatments on both assessment dates (5.9.2017 during and 24.10.2018). Typical C/N ratios in arable land in Austria vary from 7.9 – 13.1 (average 9), optimum values are around 10 (BMLFUW, 2017). Therefore, the findings (values between 8.71 and 10.28) correspond with common results. McVay et al (1989) found soil C/N ratios of 7.8 (mean for depth of 50 cm) under winter-hardy hairy vetch and crimson clover cultivation over three years. When comparing the mean values of both assessment dates, it can be observed that C/N ratio showed trends towards higher values on the second sampling dates in all depths for both treatments compared to the first. This can be explained, as measured total nitrogen contents decreased over time whereas total organic carbon contents stayed relatively constant. Moreover, maize residues which remained on the field after harvest (8.10.2018) have a wide C/N ratio of around 57:1 and are high in carbon (USDA Natural Resources Conservation Service, 2011), and probably enriched soil with C.

Inorganic nitrogen was sampled twice, first on the 19.4.2018, shortly before catch crops were incorporated into soil, and on the 3.7.2018, during maize cultivation (development stage 18) and before undersown crop propagation in treatment A. Results of the first sampling date showed trends towards higher N_{in} values for treatment B than A in the topsoil (50 kg ha^{-1} and 32 kg ha^{-1}, respectively). Statistical analysis of the samples of the first assessment date resulted in a significant difference of N_{in} between the treatments in soil layer 50-90 cm, where the mean value of treatment B was higher than of treatment A (18 kg ha^{-1} and 7 kg ha^{-1}, respectively). Kramberger et al. (2014) found soil N_{in} values after cultivation of Italian raygras and before maize sowing of 38.8 kg ha^{-1} (soil depth 0-60 cm). Grosse (2017) found N_{in} values of about 60 kg ha^{-1} in March after freeze-killed common vetch cultivation (soil depth 0-60 cm) on trial field “DFH1”. Overall, mean values in treatment B were higher in all soil layers compared to treatment A. This can be explained, as the winter-hardy catch crop mix (Landsberger Gemenge) survived cold temperatures and could store N in its biomass, which therefore was not mineralized into inorganic forms when temperatures rose. Menke and Rauber (2015) and Kramberger et al. (2014) also came to the result that Italian raygras was able to successfully reduce N_{in} contents in soil. A study by Rüegg et al. (1998), which investigated the effects of different cropping systems on silage maize, also found that winter-hardy rye achieved lower N_{in} values in spring compared to a freeze-killed mix consisting of phacelia and white mustard. Moreover, winter-hardy catch crops resumed growth in spring and took up N_{in} from soil.

When including the results of development of height of maize, where a significant difference between the treatments was found on the first two assessment dates (24.5.2018 and 10.6.2018), it can be seen that treatment A showed elevated height compared to treatment B. It can thus be concluded that the initial differences in N_{in} in soil did not influence maize growth in juvenile stages. The advantage of growth in height of treatment A in juvenile stages is unclear. A possible explanation are the beneficial soil moisture conditions in treatment A, which were discussed before.

Results of the second assessment date (3.7.2018) of N_{in} showed that there were no significant differences between the treatments. N_{in} levels in treatment A in the 0-30 cm soil layer were at 82 kg ha^{-1}, in treatment B at around 90 kg ha^{-1}. These layers showed the highest N_{in} contents. Maize development stage on the 3.7.2018 was at 18, where maize needs higher levels of N_{in} as it starts to strengthen the stem and increase leave size (Zscheischler, 1990). Until this stage, only 2% of the total N demands are taken up by maize (INRA, s.a. cited from BÄR, 1987 cited from Zscheischler, 1990). Optimum Nt supply for kernel maize is about 210 kg N ha^{-1} to assure ideal development and yields (Bayerische Landesanstalt für Landwirtschaft, 2015). Kramberger et al. (2014) found that catch crop mixes with high ratios of Italian raygras or pure cultivation showed high C/N ratios of residues, which consequently might have led to a slow N mineralization and therefore low Nin values in soil during maize growth (additionally to the up-take of N_{in} by raygras before maize). This was probably the cause of reduced maize yields. Schließer et al. (2010) came to the same conclusion, when calculating the correlation between C/N ratios of different catch crops and dry matter yields of silage maize, where a negative correlation was found. As explainer later, potential nitrogen mineralization values on the 3.7.2018 were 39 and 35 mg NH_4-N kg^{-1} soil 7 d^{-1} in treatment A and B, respectively. When considering N_{in} and Min values of July, it can be concluded that both treatments were probably not able to supply maize with optimum N_{in} values. This could also explain the low maize kernel yields.

The results of mean N_{in} values of depths 0-90 cm did not show significant differences between the treatments on both sampling dates. Nevertheless, N_{in} in treatment B was almost double as high as in treatment A on the first assessment (28 kg ha^{-1} and 15 kg ha^{-1}, respectively). Similar trends for N_{in} in this soil depth were found by Rüegg et al. (1998), where values were approximately 85 kg ha^{-1} in the freeze-killed mix compared to 45 kg ha^{-1} for winter-hardy rye.

Ammonium values on the first assessment date (19.4.2018) were similar for both treatments and did not show significant differences. On the second assessment (3.7.2018), mean values showed trends towards higher ammonium contents in the topsoil and lower contents in the deeper layers in both treatments compared to the first assessment date. Again, no significant differences could be found.

Nitrate mean values of the first assessment (19.4.2018) revealed that the mean values of all depths were higher in treatment B than A. A significant difference was found in soil layer 50-90 cm. This corresponds with the results of N_{in}, where also a significant difference between treatments was found at this depth. Taking into account that ammonium levels were the same in both treatments, it can be concluded that the difference in N_{in} between treatment A and B was a result of elevated nitrate values in treatment B. On the second sampling date (3.7.2018), there were no significant differences. Nitrate values were highest in the topsoil.

Mean potential nitrogen mineralization for all depths on 19.4.2018 was similar for both treatments and no significant differences were calculated. Values were highest in the topsoil (40 mg NH_4-N kg^{-1} soil 7 d^{-1} in both treatments) and decreased to 1.28 mg NH_4-N kg^{-1} soil 7 d^{-1} in the 50-90 cm layer in both treatments. Rinnofner (2008) found values of 35.7 µg NH_4-N g^{-1} DM 7 d^{-1} after a freeze-killed catch crop mix at the beginning of the vegetation period of the main crop. The sum of potential N mineralization (0-90 cm) on the 19.4.2018 was 45 mg NH_4-N kg^{-1} soil 7 d^{-1} in both treatments.

The values of the second assessment (3.7.2018) showed similar results. On 3.7.2018 summed Min (0-90 cm) was 39 mg mg NH_4-N kg^{-1} soil 7 d^{-1} in treatment A and 35 mg NH_4-N kg^{-1} soil 7 d^{-1} in treatment B. There were no significant differences between the treatments of the second assessment date. Soil samples of both treatments can be classified as soils with middle N mineralization potential (BMLFUW, 2017). The higher Min trends in treatment A can probably be explained, as the winter-hardy catch crops produced more biomass than the freeze-killed, which then could be mineralized. Moreover, as already explained for changes in inorganic nitrogen, C/N ratios can influence the potential nitrogen mineralization. In treatment A, the C/N ratio of above-ground biomass was 13 and 32 for roots. As mentioned before, samples for analysis of C/N ratios of treatment B were not taken.

Bulk density during catch crop cultivation in autumn (8.9.2017) was low (1,28 - 1,41 g cm^{-3}) for both treatments. Results of the first assessment date showed that bulk density was lowest in the topsoil in both treatments, which are typical results for arable land where the Ap horizon is loosened by soil cultivation (Liebhard, 1994) and catch crop root penetration. There were no significant differences between treatments on that date. On the 31.10.2018, after harvest of maize and straw was mulched with a scuffle hoe, bulk density showed higher values in all depths of both treatments compared to the 8.9.2018. Treatment A showed mean values of 1.30, 1.45 and 1.47 g cm^{-3} for depths 0-15 cm, 15-30 cm and 30-50 cm, respectively, which were lower than the values of treatment B. Treatment B resulted in bulk densities of 1.37, 1.50 and 1.52 g cm^{-3}. As on the first assessment date, bulk density was lowest in the topsoil of both treatments and increased in depth. This can also be said for the second sampling date. In the layer of 15-30 cm, a significant difference was found between the treatments, as treatment B (1.5 g cm^{-3}) showed a higher value than treatment A (1.45 g cm^{-3}). As both treatments were cultivated with machinery the same number of times and the depth of cultivation by rotary cultivator and cultivator was equal, this significant difference is probably the result of inhomogeneity in blocks or a sampling error. Additionally, soil cultivation was done first for treatment A and then for treatment B, which erodes the possibility of higher compaction in treatment B caused by differences in soil cover by catch crops.

Bulk density results of the second assessment of treatment A can be classified as soil with low to middle bulk density, whereas soil of treatment B show middle bulk density (Chmieleski, s.a.). This could be explained by, firstly, the different catch crop mixes. The winter-hardy mix in treatment A promoted root penetration in spring and an overall loosening of the soil compared to the freeze-killed mix in treatment B. A 6-year study by Benoit et al. (1962) also found that winter rye cover (which was incorporated into the soil in spring) led to improved bulk density compared to no cultivation during winter. Moreover, the different soil cultivation could have affected bulk density, although it has to be considered that the depth of cultivation was equal in both treatments.

The trend towards an increase of bulk density between the assessment dates correlates with the findings of a study by Liebhard (1994), where several soil cultivation methods on silty loam were tested. Rotary cultivator (cultivation depth of 10 cm) and cultivator (cultivation depth of 24 cm) both lead to increased bulk density. On the other hand, it was shown that rotary cultivator resulted in higher bulk density compared to the cultivator. In the named study, values for soil cultivated with the rotary cultivator were 1.55 g cm^{-3} and 1.60 g cm^{-3} for sampling depths of 5-10 cm and 25-30 cm. Results for the cultivator were 1.50 g cm^{-3} and 1.60 g cm^{-3}. These results show contrary trends compared to our study.

Soil aggregate stability was assessed on the 3.7.2018 and values for both treatments were around 60 %, which can be classified as medium to good physical quality (Sundermeier and Shedekar, 2018). Statistical analysis found no significant differences. McVay et al. (1998) found values of 55 % and 58 % after cultivation of winter-hardy crimson clover and hairy vetch before maize on gravely clay loam.

To conclude, TOC, SOM, bulk density, N_{in} and nitrate showed significant differences between the two treatments, whereas Nt, C/N, ammonium, Min and aggregate stability did not. For root penetration intensity and soil moisture differences between treatments were found, but a statistical analysis on significance was not possible. Data for water infiltration and penetration resistance could not be fully evaluated due to issues during data collection. Therefore, H2 “The treatments do not have different effects on soil, therefore the surveyed soil parameters will show no differences when comparing the treatments” can be partly rejected.

H2: Weed pressure does not differ between the treatments.

Weed pressure in both treatments was similar on the first assessment date and after weed hoeing of both treatments on the 1.6.2018 and the 8.6.2018. On the 18.6.2018 weed pressure in treatment A showed higher mean values but no significant difference. The assessment on the 3.7.2018 resulted in a significant difference between the treatments (A: 65 %, B: 46.25 %). Rosa (2015) found that the mean values of weed pressure in sweet corn over three years were highest after Italian raygras cultivation (25.3 %) compared to other winter-hardy catch crops as hairy vetch (8.3%) and white clover (14.0 %). Dominant weed species in Rosa's study were for example *Viola arvensis L.* and *Amaranthus retroflexus L.*, whereas thistles did not occur on fields with catch crop cultivation. After hand hoeing and undersown crop cultivation in treatment A in mid-July, weed pressure decreased rapidly in treatment A (A: 33.75 %, B: 72.5 % on the 4.8.2018). Nevertheless, this weed suppressing effect did not last over the whole maize cultivation period, as weed pressure rose steadily in treatment A from mid-August. Results of the last assessment (8.10.2018) showed, that weed pressure was almost equal (A: 75 % and B: 80 %). Thistle plants per m^2 on that day did not show a significant difference between treatments as well. This can be explained, as undersown crops did not emerge due to the very dry conditions after sowing. Therefore, weeds were able to reinfest treatment A. Although maize development stage was around 74 for both treatments on the 14.8.2018, competition of maize against weeds in treatment A was not successful. Regarding thistle plants per m^2 is has to be noted that all plots, except for plot 5 (mostly *Stellaria media* infestation), showed intensive thistle infestation which was evenly distributed and exceeded the typical plate formations.

As undersown crops did not emerge, their effects in weed pressure can be neglected. A study by Breland (2009) concluded that, compared to pure spring barley and spring wheat, three tested undersown crops (Italian raygrass, subterranean clover and white clover) reduced weed pressure significantly.

It can be concluded, taken into account that undersown catch crops did not vegetate, that weed pressure did not differ between the treatments. H3 "Weed pressure does not differ between the treatments" can therefore be confirmed. It is left unclear if the results would have been different in case the undersown crops would have emerged.

H3: Maize kernel yield, carbon and nitrogen content of maize plants, and above-ground biomass of maize do not differ between the two treatments.

Maize plant mean heights did show significant differences on the first two assessment dates, where maize of treatment A was higher than for treatment B (24.5.18: 14 cm and 11 cm; 10.6.2018: 55 cm and 49 cm, respectively). As already explained above, elevated soil moisture contents in treatment A could be a possible explanation. For development stages of maize, a significant difference was found on the 4.8.2018, where B achieved better development (A: 70, B: 71). This significant difference could be either caused by effects of weed hoeing of treatment A on the 18. and 19.7.2018 on maize development or due to errors during measurements, as these visual assessments are highly subjective. Moreover, on the 4.8.2018 a significant difference of maize plants per m^2 between treatments was found (A: 6 plants m^{-2}, B: 5 plants m^{-2}). Possible reasons for the significant difference are the same as for maize development stages. Rüegg et al. (1998) concluded it their study that average maize plants per m^2 did not show significant differences between a freeze-killed catch crop mix and a winter-hardy rye catch crop.

Maize kernel yield of air dried samples was assessed on the 8.10.2018. Treatment A showed a trend towards increased yield compared to treatment B (8547.3 kg ha^{-1} and 8093.8 kg ha^{-1}, respectively). No significant difference between the treatments was found. A study by Kramberger et al. (2014) revealed that a mix of leguminous and non-leguminous catch crops (only if the ratio of legumes of total mix is higher compared to non-legumes) lead to same yield of subsequent crop while improving N contents in soil compared to pure leguminous treatments. The study also found that catch crop mixes with high proportion of Italian raygras (as a non-legume) or pure stands led to decreased maize yields compared to mixes with high legume contents. Total yield harvested by the farmer was 4540 kg (45.4 dt ha^{-1}), net dry matter was 3900 kg (39 dt ha^{-1}) (25% moisture). The average kernel yield for organic agriculture in 2018 was 70.8 dt ha^{-1} in Austria (Agrarmarkt Austria, 2018). The reason for overall low yields was probably because of sowing errors and the very hot and dry weather during growing period. Moreover, as described before, Nin values might have not been sufficient for good maize yield development.

When comparing the results of air dried maize kernel yields and total yield harvested by the farmer, it has to be noted that maize yield was sampled by hand, which often leads to increased values for yield, compared to harvest with machinery. Especially, as many sowing errors occurred on the field and spots for harvest were chosen on area with maize plants, data from assessed air dried yields for kernels differ a lot from the actual harvest yields.

Maize biomass with 86% dry matter for kernels and residues was sampled on the 8.10.2018. Treatment A showed a trend towards higher kernel yields compared to treatment B (7324.1 kg ha^{-1}, 6583.5 kg ha^{-1}, respectively), but no significant differences were calculated. Results of residues showed that mean values of both treatments were very similar (A: 6692.0 kg ha^{-1}, B: 6535.5 kg ha^{-1}) and again, no significant differences were found. Statistical analysis for total biomass with 86% dry matter and percent values of kernels and residues did not result in significant differences either. Caporali et al. (2004) found dry matter values of 7.59 t ha^{-1} for maize kernels after ryegrass (and 18.53 t ha^{-1} for maize residues) and values of 10.12 t ha^{-1} after hairy vetch (23.12 t ha^{-1} for residues) in the first year of a two-year trial. A study by Schließer et al. (2010) resulted in a dry matter 129.01 dt ha^{-1} for silage maize after Landsberger gemenge and 119.93 dt ha^{-1} after a freeze-killed catch crop mix. Rüegg et al. (1998) found that a freeze-killed catch crop mix, consisting of phacelia and white mustard, resulted in higher silage maize dry matter yields compared to the winter-hardy rye catch crop (both cultivated under minimum tillage). Kolbe (2007) on the other hand concluded, that a catch crop mix consisting of leguminous and non-leguminous crops lead to decreased DM yields of maize compared to fallows and only pure leguminous catch crop mixes achieved similar high maize yields as fallows.

Spearman's correlation analysis between dry matter of maize kernels and residues and inorganic nitrogen found no significant correlations (r= 0.143 and 0.667, respectively), but a positive trend. A study on catch crops before silage maize by Schließer et al. (2010) obtained results with positive trends as well, as total dry matter of maize plants was correlating with N_{in} before maize cultivation (r = 0,365).

Fresh weight of maize cobs and shoot biomass was assessed as well on the 8.10.2018. Treatment B showed trends of higher shoot biomass than treatment A (A: 114.54 dt ha^{-1}, B: 122.54 dt ha^{-1}), contrary trends were found for cob biomass (A: 124.74 dt ha^{-1}, B: 121.55 dt ha^{-1}). Nevertheless, no significant differences were found between the treatments. Regarding total fresh weight and percentage values, statistical analysis did not show significant differences between treatments.

Results of C, N and C/N ratio of maize kernels and plant residues were assessed on the 8.10.2018. The mean values for C, N and C/N ratio for maize kernels were almost identical and no significant differences were found. N content of maize kernels was at 13.7 g kg^{-1} for both treatments. Maize residues showed values of 6.5 g kg^{-1} for treatment A and 7.1 g kg^{-1} for treatment B. C/N ratio for treatment A was 30.74, for B 30.95. Results of plant residues were similar (C/N 64.72 for A and 59.83 for B) and also did not result in significant difference. Rüegg et al. (1998) found in their study that shoot nitrogen content of silage maize was higher in the winter-killed catch crop mix (11.2 mg kg^{-1}) compared to the winter-hardy rye catch crop (10.1 mg kg^{-1}). The findings of Rüegg et al. therefore show the same trends as the results of this study. Kramberger et al. (2014) observed that compared to fallows, Italian raygras reduced N contents in maize yields, as the catch crop mix was competing with maize for N.

To conclude, maize yields of kernels and residues did not show significant differences between the treatments, neither for dry matter nor for fresh weight assessments. Carbon and nitrogen content as well as C/N ratio did not result in significant differences between treatments either. Therefore, H1 “Maize kernel yield, carbon and nitrogen content of maize plants, and above-ground biomass of maize do not differ between the two treatments” cannot be rejected.

8. Conclusion

The results of this study show, that the tested treatments had different effects on several soil parameters. A difference in maize yield and maize biomass related assessments as well as weed pressure between the treatments could not be found. Regarding the parameters with significant differences between the treatments, treatment A achieved better results in all of them. It showed higher TOC and SOM levels in October, increased root penetration intensity and soil moisture in April and lowered bulk density after maize harvest compared to treatment B. Moreover, treatment A reduced N_{in} and nitrate levels in soil in spring, and therefore the risk of nitrate leaching into the environment, while achieving increased height development of young maize plants and equal yields in comparison with treatment B. It can be concluded that treatment A obtained enhanced results when it comes to soil health indicators while showing no significant differences in maize yield or weed pressure, compared to treatment B.

Nevertheless, especially regarding maize yields, sowing errors affected the results. Furthermore, the fact that the undersown crop did not emerge due to the dry soil conditions and only half of the catch crop species in treatment B grew, had influenced the trial set-up. The results for weed pressure are difficult to interpret, as hoeing of weeds was done in treatment A only, where undersown crops did not cover the soil afterwards. Regardless this development of the experiment, the results of equal weed pressure in both treatments at the end of the maize cultivation period are interesting. Moreover, sampling of catch crop root biomass should have been conducted in autumn, when catch crop yields were estimated. Also, further sampling of N_{in} should have been done in autumn to allow better traceability of N_{in} development between the treatments.

What is special about this experiment is the composition of catch crop mixes. So far, data for catch crop mixes like Landsberger gemenge, pure leguminous or non-leguminous mixes is available. Catch crop mix of treatment B offers therefore new data on catch crop mixes containing both, leguminous and non-leguminous catch crops. More investigation with mixes like these should be done to obtain more secure data on their effects on yields of subsequent crops. This data is valuable for agriculture and could be applied by farmers who want to improve or maintain their soil health and increase SOM while achieving sufficient yields.

9. References

AG BODEN 1994. *Bodenkundliche Kartieranleitung,* Hannover, Bundesanstalt für Geowissenschaften und Rohstoffe und Geologische Landesämter.

AGES. 2015. *Die Humusgehalte der heimischen Ackerböden haben sich positiv entwickelt* [Online]. Available: https://www.ages.at/themen/umwelt/boden/positive-humusentwicklung/ [Accessed 26.3.2019].

AGRARMARKT AUSTRIA. 2018. *Herbsterhebung 2018* [Online]. Available: https://www.ama.at/getattachment/4f65aff7-2f4d-4303-9cc9-a86143063926/Herbsterhebung_2018.pdf [Accessed 13.2.2019].

BAYERISCHE LANDESANSTALT FÜR LANDWIRTSCHAFT. 2015. *Wie viel Stickstoff braucht der Mais?* [Online]. Available: https://www.lfl.bayern.de/mam/cms07/iab/dateien/stickstoffduengung_mais_2015.pdf [Accessed 27.3.2019].

BENTON JONES, J. 2001. *Laboratory Guide for Conducting Soil Tests and Plant Analysis*.

BIO AUSTRIA. 2018. *Anbau von Zwischenfrüchten für die Futternutzung* [Online]. Bio Austria. Available: https://www.bio-austria.at/anbau-von-zwischenfruechten-fuer-die-futternutzung/ [Accessed].

BMLFUW 2017. RICHTLINIE FÜR DIE SACHGERECHTE DÜNGUNG IM ACKERBAU UND GRÜNLAND

ANLEITUNG ZUR INTERPRETATION VON BODENUNTERSUCHUNGS- ERGEBNISSEN IN DER LANDWIRTSCHAFT. 7 ed. Vienna.

BOT, A. & BENITES, J. 2005. *The importance of soil organic matter: Key to drought-resistant soil and sustained food and production*, FAO.

BUNDESMINISTERIUM FÜR NACHHALTIGKEIT UND TOURISMUS. 2018. *Hydrographische Daten Österreich.* [Online]. Available: https://ehyd.gv.at [Accessed 22.3.2019].

CARTER, M. R. 1996. Advances in Soil Science: Analysis of Soil Organic Matter Storage in Agroecosystems. *In:* CARTER, M. R. & STEWART, B. A. (eds.) *Structure and Organic Matter Storage in Agricultural Soils.* CRC Press.

CARTER, M. R. 2005. CONSERVATION TILLAGE. *Encyclopedia of Soils in the Environment.* Elsevier.

CHMIELESKI, J. s.a. *Lagerungsdichte und Porenvolumen* [Online]. Available: https://www.bodenkunde-projekte.hu-berlin.de/boku_online/pcboku10.agrar.hu-berlin.de/cocoon/boku/sco_6_wasserhaushalt_11152e.html?section=N100CK [Accessed 19.3.2019].

DEUTSCHE SAATVEREDELUNG AG. s.a. *DSV Ökosaatgut* [Online]. Available: https://www.dsv-saaten.de/oeko/ [Accessed 23.3.2019].

DRANGMEISTER, H. 2011. Maisanbau im ökologischen Landbau: D2 Spezieller Pflanzenbau Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz.

EIJKELKAMP 2013. Penetrologger Operating Instructions.

EIJKELKAMP SOIL & WATER 2018. Double ring infiltrometer

Operating instructions.

EIJKELKAMP SOIL AND WATER. 2019. *Penetrologger - Feldmessgerätte* [Online]. Available: https://de.eijkelkamp.com/produkte/feldmessger-te/penetrologger-set-a.html [Accessed].

EIP-AGRI. 2018. *The EIP-AGRI is part of EU's growth strategy for this decade - EIP-AGRI - European Commission* [Online]. Available: https://ec.europa.eu/eip/agriculture/node/50 [Accessed].

ENVIRONMENTAL PROTECTION AGENCY. 2013. *Total Nitrogen* [Online]. Available: https://www.epa.gov/sites/production/files/2015-09/documents/totalnitrogen.pdf [Accessed 20.2.2019].

FOWLER, D., COYLE, M., SKIBA, U., SUTTON, M. A., CAPE, J. N., REIS, S., SHEPPARD, L. J., JENKINS, A., GRIZZETTI, B., GALLOWAY, J. N., VITOUSEK, P., LEACH, A., BOUWMAN, A. F., BUTTERBACH-BAHL, K., DENTENER, F., STEVENSON, D., AMANN, M. & VOSS, M. 2013. The global nitrogen cycle in the twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 368.

FREYER, B., PIETSCH, G., HRBEK, R. & WINTER, S. 2005. *Futter- und Körnerleguminosen im Biologischen Landbau*, AV Buch.

FRIEDEL, J. K. 2019. *RE: Kommentar zu Masterarbeit.*

GALLOWAY, J. N., SCHLESINGER, W. H., LEVY, H., ANTHONY, M. & SCHNOOR, J. L. 1995. Nitrogen fixation: Anthropogenic enhancement-environmental response. *Global Biogeochemical Cycles,* 9**,** 235-252.

GOMIERO, T., PIMENTEL , D. & PAOLETTI , M. G. 2011. Environmental Impact of Different Agricultural Management Practices: Conventional vs. Organic Agriculture. *Critical Reviews in Plant Sciences* [Online], 30.

GRAß, R. 2003. *Direkt- und Spätsaat von Silomais - Ein neues Anbausystem zur Reduzierung von Umweltgefährdungen und Anbauproblemen bei Optimierung der Erträge.* Göttingen.

HOLLAND, J. M. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. *Agriculture, Ecosystems & Environment,* 103**,** 1-25.

HUMER, M. 2015. *FERTILIZING EFFECT OF COVER CROPS AND ALTERNATIVE PHOSPHORUS FERTILIZERS (APF) ON WINTER WHEAT.* Master Thesis, University of Natural Resources and Life Sciences Vienna.

INSTITUT FÜR ÖKOLOGISCHEN LANDBAU BODENKULTUR UND RESSOURCENSCHUTZ. s.a. *Humus – Humusuntersuchungen.* [Online]. Available: https://www.lfl.bayern.de/iab/boden/095122/index.php [Accessed 23.3.2019].

JOHNSTON, E. A., POULTON, P. R. & COLEMAN, K. 2009. Soil Organic Matter: Its Importance in Sustainable Agriculture and Carbon Dioxide Fluxes. Advances in Agronomy.

KOLBE, H. E. A. 2004. *Zwischenfrüchte im Ökologischen Landbau*, Sächsische Landesanstalt für Landwirtschaft.

LEHMANN, J. & KLEBER, M. 2015. The contentious nature of soil organic matter. 528**,** 60 – 68.

LIEBHARD, P. 1994. Einfluß der Primärbodenbearbeitung auf Lagerungsdichte, Porenvolumen und Porengrößenverteilung von Ackerböden im oberösterreichischen Zentralraum. Vienna.

LIMBACHER, F., SCHALLY, H. & WASNER, J. 2015. Buchweizen. NÖ. Landes-Landwirtschaftskammer.

LÜTKE ENTRUP, N. 1991. *Zwischenfrüchte im integrierten Pflanzenbau*, Auswertung- und Informationsdienst für Ernährung, Landwirtschaft und Forsten (AID).

MEIER, U. 2001. Growth stages of mono-and dicotyledonous plants, BBCH Monograph 2ed.

MIR, N., AHMAD, S. & BHAT, S. 2018. Dactylis glomerata L. (Cock's Foot/Orchard Grass): A Potential Temperate Forage Grass for Cultivation in North Western Himalaya. *Advances in Research,* 15**,** 1-10.

NATIONAL RESEARCH COUNCIL 1993. Soil and Water Quality: An Agenda for Agriculture. *In:* D.W. REEVES (ed.) *The role of soil organic matter in maintaining soil quality in continuous cropping systems.*

NETZWERK ZUKUNFTSRAUM LAND. 2018. *OG-BIOBO: Ertragsentwicklung und Humusaufbau über reduzierte Bodenbearbeitung und organische Düngungsmaßnahmen (Gründüngung und organischer Dünger)* [Online]. Available: http://www.zukunftsraumland.at/index.php?inc=project&id=1487 [Accessed].

PAUL, E. A. (ed.) 2007. *Soil Microbiology, Ecology, and Biochemistry*: Academic Press.

PESZT, W. 2007. *Umbruch von Begrünungen im Frühjahr* [Online]. Available: https://bgld.lko.at/umbruch-von-begrünungen-im-frühjahr+2500+2534322 [Accessed 24.3.2019].

POLATO, N. s.a. Zea Mays ear.

ROHOSKOVA, M. & VALLA, M. 2004. Comparison of two methods for aggregate stability measurements - A review.

SAATEN, R. 2019. *RGT Connexxion* [Online]. Available: https://ragt-saaten.at/sites/default/files/public/medias/variety/pdfs/RGT%20CONEXXION_1.pdf [Accessed 13.2.2019].

SCHALLY, H. 2019. *Maisanbau: Die Herausforderungen des Vorjahres* [Online]. Landwirtschaftskammer Burgenland Online: Landwirtschaftskammer Burgenland. Available: https://bgld.lko.at/maisanbau-die-herausforderungen-des-vorjahres+2500+2842716 [Accessed 26.3.2019].

SCHROETTER, S. 2015. *Durchwurzelbarkeit – ein Indikator für die Bodenfruchtbarkeit* [Online]. BUNDESMINISTERIUM FÜR ERNÄHRUNG UND LANDWIRTSCHAFT. Available: https://www.bmel.de/DE/Landwirtschaft/Pflanzenbau/Boden/_Texte/Boden.html?docId=6819388 [Accessed].

SCHUMACHER, B. 2002. *Methods for the Determination of Total Organic Carbon (TOC) In Soils and Sediments*.

SCHWARZ, S., HUBER, S., TULIPAN, M., DVORAK, A. & ARZT, A. 1999. *Datenschlüssel Bodenkunde*, Umweltbundesamt Österreich;

Österreichische Bodenkundliche Gesellschaft.

SINABELL, F., KAPPERT, R., KAUL, H.-P., KRATENA, K. & SOMMER, M. 2015. Maisanbau in Österreich

Ökonomische Bedeutung und pflanzenbauliche Herausforderungen. Österreichisches Institut für Wirtschaftsforschung.

SMIL, V. 1999. Nitrogen in crop production: An account of global flows. *Global Biogeochemical Cycles,* 13**,** 647-662.

SOIL WEB MODULES. s.a. *Soil Bulk Density* [Online]. Available: https://labmodules.soilweb.ca/soil-compaction-bulk-density/ [Accessed 17.2.2019].

STAHR, K., KANDELER, E., HERRMANN, L. & STRECK, T. 2008. Bodenkunde und Standortlehre.: Eugen Ulmer Stuttgart.

SUNDERMEIER, A. & SHEDEKAR, V. 2018. Soil Aggregate Stability – a soil health physical indicator. *THE C.O.R.N. NEWSLETTER.* Ohio State University

THE U.S. DEPARTMENT OF AGRICULTURE (USDA) & NATIONAL SOIL SURVEY CENTER 1996. Soil Quality Indicators: Aggregate Stability.

TONITTO, C., DAVID, M. B. & DRINKWATER, L. E. 2005. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. *Agriculture, Ecosystems and Environment,* 112**,** 58-72.

UMWELTBUNDESAMT ÖSTERREICH. s.a. *Datenportal Bodeninformationssystem BORIS* [Online]. Available: https://wasser.umweltbundesamt.at/cadenza/ [Accessed 4.3.2019].

UNIVERSITY OF CANTERBURY s.a. Determination of Phosphate Concentration in Soil.

USDA. s.a. *Role of Soil Organic Matter* [Online]. Available: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/mgnt/?cid=nrcs142p2_053859 [Accessed].

USDA NATURAL RESOURCES CONSERVATION SERVICE 2011. Carbon to Nitrogen Ratios in Cropping Systems.

VERHEIJEN, F., BELLAMY, P., KIBBLEWHITE, M. & GAUNT, J. 2006. Organic carbon ranges in arable soils of England and Wales. *Soil Use and Management***,** 3-9.

WALLNER, T. 2018. *Erfahrungen zu Untersaaten in Mais* [Online]. Landwirtschaftskammer Burgenland Online: Landwirtschaftskammer Burgenland. Available: https://bgld.lko.at/erfahrungen-zu-untersaaten-in-mais+2500+2841893 [Accessed 24.3.2019].

ZSCHEISCHLER, J. E. A. 1990. *Handbuch Mais: Umweltgerechter Anbau, wirtschaftliche Verwertung,* Frankfurt (Main), DLG-Verlags-GmbH.

ÖKOSOZIALES FORUM ÖSTERREICH 2015. Maisanbau in Österreich: Wahlen und Fakten.

10. Annex

A: Inorganic nitrogen (in mg kg^{-1}) on the 19.4.18 and 3.7.18.

		19.04.18		03.07.18	
Treatment	depth (cm)	N_{in}	St.d.	N_{in}	St.d.
A	0-30	7.69	2.61	19.73	1.96
	30-50	2.63	0.85	9.98	2.58
	50-90	1.22	0.48	4.21	1.81
B	0-30	12.40	7.42	21.89	6.83
	30-50	4.96	2.57	9.53	2.27
	50-90	3.14	1.04	4.59	1.62
Treatment	0-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
	50-90	*		n.s.	
Block	0-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
	50-90	n.s.		n.s.	

Significance level p<*0.05*, significant (*), not significant (n.s.)

B: Soil organic matter (g/kg) of soil (5.9.17 and 24.10.18).

		05.09.17		24.10.18	
Treatment	depth (cm)	SOM	St.d.	SOM	St.d.
A	0-15	39.00	10.52	41.50	12.48
	15-30	32.00	9.97	31.25	10.78
	30-50	22.25	6.08	21.75	6.13
B	0-15	37.50	10.47	39.25	11.30
	15-30	31.75	9.57	31.25	10.78
	30-50	22.00	5.23	21.50	5.26
Treatment	0-15	*		n.s.	
	15-30	n.s.		n.s.	
	30-50	n.s.		n.s.	
Block	0-15	*		*	
	15-30	*		*	
	30-50	*		*	

Significance level p<*0.05*, significant (*), not significant (n.s.)

C: Total catch crop soil coverage (%), coverage by each catch crop (%) of total and coverage by weeds (%) for both treatments (7.11.2017).

Treatment	Plot	Total soil coverage	Winter vetch	Crimson clover	Italian raygras	Weeds
A	1	100	7	10	83	<1
A	3	100	5	25	65	5
A	6	100	5	20	75	<1
A	8	100	5	45	50	<1
Height in cm:		10-20 cm				

Treatment	Plot	Total soil coverage	Fodder pea	Common vetch	Chickling vetch	Buckwheat	Phacelia	Fodder radish	Weeds
B	2	100	20	0	45	0	35	0	<1
B	4	95	25	0	40	0	30	0	<1
B	5	100	25	0	5	0	70	0	<1
B	7	95	30	0	15	0	50	0	<1
Height in cm:		40-60 cm							