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The role of soil types in altering the response of arable agroecosystems to future rainfall patterns

Der Einfluss von Bodentypen auf die Wirkung von zukünftigen Niederschlagsmustern auf ackerbaulich genutzte Agrarökosysteme

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Zusammenfassung

Der anthropogene Klimawandel wird in Mitteleuropa weniger, aber schwerere Niederschlagsereignisse verursachen (IPCC 2007; IPCC 2013). In der vorliegenden Arbeit untersuchten wir die Auswirkungen des zukünftigen Niederschlagsmusters in Modell-Agrarökosystemen mit verschiedenen Bodentypen.

Die Versuchsanlage am Stadtrand von Wien bestand aus 18 Lysimetern mit jeweils 3 m2. Die untersuchten Bodentypen, sandiger Phaeozem (S-Böden), Feuchtschwarzerde (F-Böden) und tiefgründige Schwarzerde (T-Böden), wurden schichtenweise an den Originalstandorten entnommen und in die Lysimeter gefüllt. Jeder der drei Bodentypen war sechsmal wiederholt. Die Hälfte der Böden wurde mit dem aktuellen langjährigen Niederschlagsmuster (C) bewässert, die andere Hälfte mit dem für 2071-2100 prognostizierten Niederschlagsmuster (D) mit ca. 1/3 reduzierter Niederschlagsintensität. In den Lysimetern wurde Pisum sativum und in der darauffolgenden Vegetationsperiode Triticum aestivum angebaut.

Bodentypen und Niederschlagsmuster reduzierten Pflanzendichte, Ertrag, Ernteindex, Mykorrhizierung, Unkrautbefall und Biomasseproduktion, erhöhte aber im Weizen die Kohlenstoff-13 Isotop ($\delta^{13}C$). Das zukünftige Niederschlagsmuster führte in beiden Kulturen zur Verringerung des Blattflächenindex und dadurch zur Reduktionen von Wachstumsrate, Biomasseproduktion und Ertrag, während das Wurzelwachstum erhöht wurde. Die Verringerungen waren auf den S-Böden besonders ausgeprägt. Das zukünftige Niederschlagsmuster reduzierte die Abundanz der meisten oberirdischen Arthropoden-Taxa um mindestens 39%, erhöhte aber die Abundanz der Gastropoda um 69%. Die Bodentypen zeigten keinen signifikanten Effekt auf die Arthropodenabundanz. Die Unkrautdichte korrelierte signifikant mit der Abundanz fast aller Arthropoden-Taxa.

Die ähnliche Reaktion von Erbse und Weizen auf das zukünftige Niederschlagsmuster lässt eine breitere Auswirkung des Klimawandels erwarten. Da der Bodentyp viele Agrarökosystem-Parameter signifikant beeinflusste, empfehlen wir, bei der Abschätzung der Auswirkungen des Klimawandels auf Agrarökosysteme künftig den Bodentyp stärker zu berücksichtigen.

Abstract

The impact of climate change is felt worldwide with different magnitude due to global warming. This global warming is expected to alter precipitation patterns with fewer, but heavier rainfall events prognosticated for the future in Central Europe (IPCC 2007; IPCC 2013). We tested this future rainfall patterns on different soil types to assess agroecosystem response using a huge lysimeter facility.

The facility located at the outskirt of the city of Vienna comprised of 18 lysimeters each of 3m2. The soil types; calcaric phaeozem (S), gleyic phaeozen (F), and calcic chernozem (T) were carefully transported from the fields unaltered into the facility and arranged in 2 rows of 9 lysimeters, each in 3 repetitions. One row was supplied with the current rainfall pattern (C) while the other row was applied the future rainfall pattern (D) calculated by averaging the IPCC prognosticated rainfall patterns for the years 2071 and 2100, with 1/3 reduced rainfall intensity. The lysimeters were cultivated for two vegetative periods with *Pisum sativum* and *Triticum aestivum* successively, and agroecosystems´ parameters investigated.

Soil types and rainfall both reduced crops density, yield, harvest index, AMF Mycorrhization, weeds infestation and biomass production but increased wheat carbon -13 isotopes ($\delta^{13}C$). The future rainfall patterns led to the reduction in the LAI of both crops, which further translated to the reduction in their growth rates, biomass productions and grain yields but increased the roots development. These changes were more pronounced on S Soils than on the other soil types. The above ground arthropods decreased with the future rainfall pattern by at least 39% for most taxa but increased by 69% for the Gastropoda. Soil type showed no significant effect on arthropods abundance while weed density correlated significantly with the abundance of almost all taxa.

The similar response of both pea and wheat cultivar to future rainfall patterns indicates a broader impact of the future rainfall patterns across crop types. Likewise, the significant effect of soil types on most agroecosystem parameters means soil types could alter plants response to future rainfall patterns. Thus, we recommend that soil types should be considered more profoundly when evaluating the impact of climate change on agroecosystems.

CONTENT

1. General Introduction

Climate change has become a heated topic nowadays not only among scientists but also among politicians, clergymen and people of all work of life. The driving force of climate change is human induced global warming from pollutants. This global warming has increased the frequency, timing and intensity of precipitations thus affecting agroecosystems (IPCC 2007, IPCC 2013). The negative impact of this global warming includes more frequent coastal floods, torrential rainfall with increase erosions, droughts, likewise temperature variability with increased health risks due to heat waves and frequent wildfires. In Europe, there is a global and seasonal warming trend with the increase in winter precipitation and reduction in summer precipitation, with regional significant but uncertain differences in the expected changes (IPCC 2007; Eitzinger 2010). Changes in phenology with earlier onset of spring events and lengthening of growing season were reported by Menzel et al. (2006). The impact of these changes on terrestrial ecosystems include widespread species losses, invasion of evergreen large leaves species (Berger et al. 2007), increased damage on crops due to hails, and crop stress resulting from the drier and hotter summer (Viner et al. 2006). Accordingly the regional climate scenarios for eastern Austria (Pannonian region) predict fewer but heavier rains during the vegetation periods without substantial changes in the annual amount of rainfall (IPCC 2007; Eitzinger 2010). Thus, this experiment was carried out to test these future precipitation patterns on different soil types.

Most past experiments show that future rainfall patterns will vividly affect plant biomass production with the reduction in plant growth, grain yield and crop density (Asseng et al. 1998; Dodig et al., 2010; Ren et al. 2010). Droughts resulting from the future rainfall patterns have been shown in many experiments to reduce significantly plant growth and yield (Auge´ et al. 2001; Whitney & Gabler 2008; Matias et al. 2011; Ziska et al. 2011). Droughts also reduce plants invasibility (Kreyling et al. 2008) and alter plants photosynthesis and transpiration thereby increasing the $\delta^{13}C$ values (Werner et al. 2012).

Soil types which receive precipitations are determined by the physical, chemical and biochemical properties of soils (Rhoton et al. 1993; Paz-Ferreiro et al. 2011). Soil types with large pores can’t hold the sinking water under atmospheric pressure so that it leads to soakage or seepage water, not available for plant’s usage. Fine pores produce high soil moisture tension which hinders plants from taking up water. Ideally, water in middle pores is readily available for plants intake. Hard soils also inhibit root extension, limiting water and nutrient supply to the leaves (Passioura 1991). Soil types with lower water and nutrient status has been shown to reduce plant growth, vegetation cover, and yield, likewise significantly affecting the soil temperature, soil respiration, as well as the solubility and concentration of dissolved carbon in surface water (Koizumi et al. 1999; Mako et al. 2008; Bestland et al. 2009; Genxu et al. 2009; Clark et al. 2011). It equally influences the availability, uptake and mobility of mineral nutrients, affecting soils interactions and the soil to plant transfer of nutrients (Echevarria et al. 2003; Matias et al. 2011). Soil types with higher water and nutrient contents have been shown to improve crops growth, and increase grain yields while soil types with higher sand content improve plants symbiotic association with AMF (Masoni et al., 2007). AMF alleviates drought, increases plants N content, improves crops nutrients and water uptake, reduces roots damages, and resist roots' infections. (Augé 2001; Bolandnazar et al. 2007; Koltai & Kapulnik 2010)

Weeds being an important biodiversity factor and also crops competitors could be affected by climate change in that various weed species could become invasive, likewise changes in its composition, density, and species richness (Augé 2001; Whitney & Gabler, 2008; Clements & Ditommaso, 2011). Weeds affect crops by competing for water, nutrients, above and below ground space, thus negatively influencing crops emergence, reducing growth, grain yield and biomass production (Kreyling et al., 2008; Bestland et al., 2009). Weeds can quickly expand its range on different soil types with future rainfall patterns due its phenotypic plasticity and high evolutionary potential (Whitney & Gabler, 2008; Clements & Ditommaso 2011).

On the various soil types, the above-ground insects' population was sampled to examine its correlation with soil types and rainfall patterns. Insects being the largest group in the animal kingdom are essential to agroecosystems in that some are pollinators of various economic crops and useful for the biological control of different pests. They are also important in the food chain and provide humans with valuable products like silk, honey, and wax. High insects' density and diversity in an ecosystem improves its diversity index and is a good indicator for environmental change (Gregory et al., 2009). Some insects also negatively affect crops production and yield by feeding on plants directly reducing plants density while others use plants as shelter and as secondary host for the transmission of diseases (Ziska et al., 2011; Thoeming et al., 2011). In the pea cultivar we principally we looked at the pea moth (*Cydia nigricana*) a famous pest on *Pisum sativum* (Fabaceae). This univoltin pest belongs to the family of Toticidae (Order Lypidoptera), found mostly in Europe, with a wingspan of 12-14 mm. The females lay their eggs on the underside of leaves 5-9 days after mating. The young emerging larvae travel to the young pea pods and bore into it. The larval developments

(L1-L5) occur inside pea pods. The L4 /L5 well feed larvae leave the pea and drop to the soil, where they spin into waterproof cocoons. They diapause for 4-6 weeks, followed by hibernation which last until the pupation in spring. The adult moths eclose from mid - May onward to start another generation. There is a linear correlation between the abundance of *C. nigricana* and amount of pea plant; also to reduce the larval infestation and moth flight significantly, a distance of at least 500m was necessary between a current pea field and the previous pea field. (Thöming et al. 2011) In this study, our focus with *C. nigricana* was to see how climate change induced rainfall patterns will affect its abundance and partial distribution on different soil types. For the wheat cultivar, the total arthropods density was independently sampled on each lysimeter for three successive months during the vegetative period using a commercial garden vacuum (Stihl SH 56-D, Dieburg, Germany). The taxa of the insects were identified, and their abundance on different soil types under both rainfall patterns was assessed.

Many studies have been carried out to investigate the effect of rainfall patterns on ecosystem properties; however little is known on how different soil types might alter ecosystem response. Moreover, most of these studies with rainfall patterns and soils were conducted in isolation with just one soil type. In this trial, we will examine how different soil types with different hydrological status will interact with future rainfall patterns and impact agroecosystems. We anticipate that soil types with different compositions in mineral and water contents are to response to these future rainfall patterns on agroecosystems in varied magnitude.

In this experiment, we selected two crops with different root and shoot architecture; field pea and winter wheat. They were sown successively for two vegetative periods on a huge lysimeter facility, and their NPP, AMF, insect pest and weed infestation investigated. Their impact on different soil types in triggering ecosystem response to future rainfall patterns was accessed. This study is unique in that it is the first time whereby different soil types have been examined at a specified location under a model future climate change scenario.

1.1 **Experimental layout and climatic scenarios**

The experiment was carried out at the outskirt of the city of Vienna (160 m a.s.l.; 48° 14' N, 16° 16' E) in lysimeters at the Austrian Agency for Health and Food Safety (AGES). There were altogether 18 lysimeters, each with an area of 3.02m^2 and 2.45 m soil depth. They were arranged on two rows of 9 lysimeters each, as shown on Figure 1.1

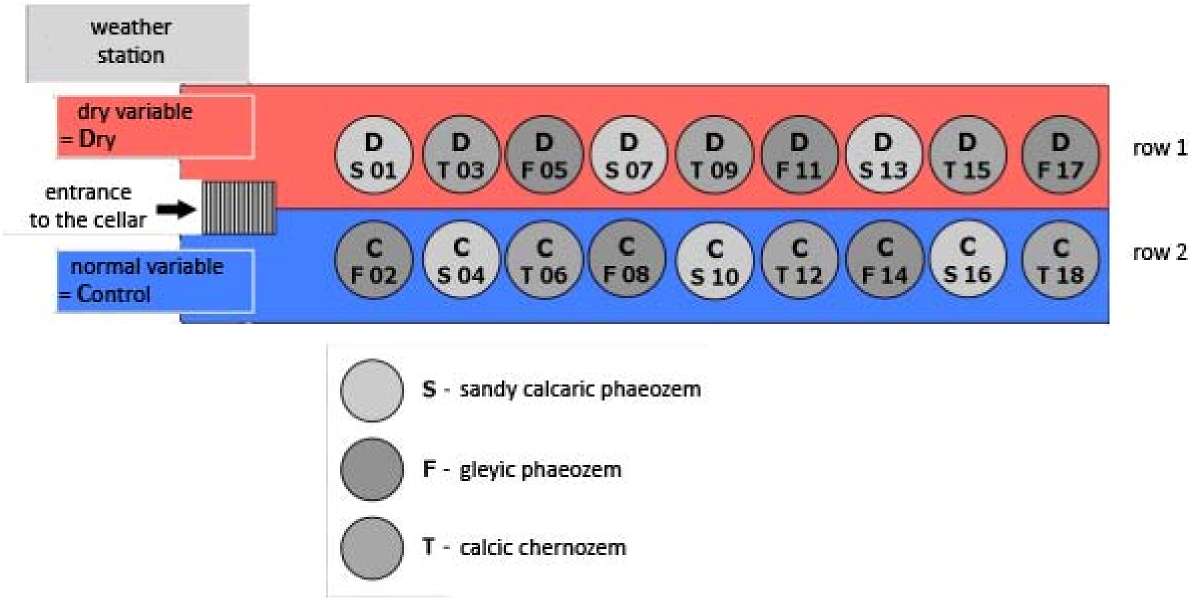

Figure 1.1: Experimental layout with the soil types sandy calcaric phaeozem (S), gleyic phaeozem (F) and calcic chernozem (T) arranged in two rows. Row1 was supplied with the dry variable rainfall pattern (D) and row 2 with the normal variable (control) rainfall pattern (C).

The soil types; calcaric phaeozem (S), gleyic phaeozen (F), and calcic chernozem (T) representing the majority of the soil types in Austrian most fertile crop growing region called Marchfeld were carefully transported from the fields into the lysimeters so that their original bulk density of 1.4 g cm^{-3} and soil profile layers were unaltered. The soil types were arranged orderly so that on each row each soil type occurred thrice successively. The soils were number alternatively among the two rows beginning with S soils (S 01) on row1 and ending with T soil (T 18) on row 2 (Figure 1.1). The various soils types were allowed in the lysimeter for 15 years without any agricultural practice and under natural precipitation to settle avoiding any influx property before the experiment started in the year 2011.

Two rainfall scenarios were used. On row 1 the future rainfall pattern (dry variable) was applied. This rainfall scenario was based on the prognosticated IPCC 2007 regionalised rainfall patterns for the years 2071-2100. For deriving this future rainfall pattern, climate change signals from the EC-project ENSEMBLES were used (Christensen & Christensen, 2007). These climate change signals were then transferred to daily precipitation using the weather generator LARS-WG version 3.0 software (Semenov & Barrow, 2002). The current rainfall pattern (normal variable) applied on row 2 was calculated by averaging the rainfall intensity and frequency the years 1971- 2000, gotten from a weather station 10 km from the experimental site. The lysimeter installation had it own weather station build adjacent to the dry row at the upper left side of its entrance for measuring the weather parameters inside the lysimeter facility. At the beginning of the two rows, in the middle was the entrance to the cellar, whereby underneath each lysimeter containers were hung to collect the leachate. A roof was built above the entire lysimeters to avoid natural precipitation from interfering with the experiment. The roof was covered with a transparent polythene film which also extended to the sides but open at both front and rear end for ventilation. The polythene film at the sides was programmed to open and closed depending on the air temperature and humidity.

Rainfall amounts were applied early in the morning by a hand sprinkler with an attached gauge using tap water, for the pea cultivar, while for the wheat cultivar, the system was upgraded so that watering was done automatically by spraying nozzles installed at 3 m height above each lysimeter. In both cases, the D variant received 1/3 less rainfall and 25% less dry days than the C variant.

2. Soil types will alter the response of arable agroecosystems to future rainfall patterns

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2.1 **Summary**

Climate change scenarios for central Europe predict fewer but heavier rains during the vegetation period without substantial changes in the total amount of annual rainfall. To investigate the impact of rainfall patterns derived from regionalized IPCC scenarios on agroecosystems in Austria, we conducted an experiment using 3-m^2-lysimeters where prognosticated rainfall patterns were compared with long-term current rainfall patterns on three agriculturally important soil types (sandy calcaric phaeozem, gleyic phaeozem and calcic chernozem). Lysimeters were cultivated with field peas (*Pisum sativum*) according to good farming practice. Prognosticated rainfall patterns decrease crop cover, net primary production (NPP) and crop yields, but increased root production and tended to decreased mycorrhization. Soil types affected NPP, crop density and yields, weed biomass and composition as well as the root production with lowest values commonly found in sandy soils while the other soil types showed almost similar effects. Significant interactions between rainfall patterns and soil types were observed for the harvest index (ratio crop yield vs. straw), yield per crop plant, weed density and weed community composition. Abundance of the insect pest pea moth (*Cydia nigricana*) tended to be higher under progn. rainfall, but was unaffected by soil types. These results show that (i) future rainfall patterns will substantially affect various agroecosystem processes and crop production in the studied region, and (ii) the influence of different soil types in altering ecosystem responses to climate change should be considered when attempting to scale-up experimental results derived at the plot level to the landscape level.

2.2 **Introduction**

Human-induced global warming is expected to affect the frequency, timing and intensity of precipitation (IPCC, 2007). In Europe, this will lead to higher winter precipitation in northern regions with drier and hotter summers in central Europe (Viner et al., 2006; Eitzinger, 2010) Accordingly, the regional climate scenario for eastern Austria (pannonian region), an important arable crop region, predicts fewer but heavier rains during the vegetation periods without substantial changes in the annual amount of rainfall (Eitzinger, 2010). We therefore conducted a lysimeter experiment to see how reduction in precipitation on different soil types will affect agroecosytem parameters.

Agroecosystem parameters affected by reduction in precipitation and associated drought from past studies include crop production, weed, arbuscular mycorrhizal fungi (AMF), and insect abundance. It has been demonstrated that reduction in precipitation reduces crop production (Martin & Jamieson, 1996; (Sanchez et al., 2001), increases weed invasibility (Kreyling et al., 2008) reduces the mycorrhization rates (Augé, 2001; Porcel et al., 2003, Smith & Read, 2008) and increases insects and invertebrate population (Ziska et al., 2011). Weeds are expected to be less reduced by droughts than cultivated plants due to their wide climatic or environment tolerance, short generation time, small seed size, uniparental reproduction capacity, high competitive ability, high growth rate and phenotypic plasticity (Whitney & Gabler, 2008; Clements & Ditommaso, 2011). AMF has also been shown to alleviate drought (Augé, 2001; Porcel et al., 2003), improving the crop yield and water use efficiency (Bolandnazar et al., 2007), while making plants less vulnerable to withstand various abiotic stresses (Koltai & Kapulnik, 2010). As AMF foster plants nutrient uptake it equally increases the soluble protein content improving plants quality for herbivores (Subramanian & Charest, 1998). Reduction in precipitation increases insect mortality, affecting its abundance, morphology and physiology (Moran et al., 1987; (Robinson et al., 2012)

Reduction in precipitation was tested on the soil types calcaric phaeozem ($S_{\text{-soils}}$), gleyic phaeozen ($F_{\text{-soils}}$), and calcic chernozem ($T_{\text{-soils}}$) representing 80 % of the agricultural soil in Austria most fertile region (region of Marchfeld). $S_{\text{-soils}}$ are highly sandy, with very low profile water and evaporation; $F_{\text{-soils}}$ have very high clay content, highly mottled subsoils, with high profile water and evaporation; while $T_{\text{-soils}}$ are highly silty with the highest profile water content (Table 1.1).

Soil types and its characteristics have been demonstrated to affect several processes in agroecosystems, such as the availability and supply of water to plants (Passioura, 1991), the and respiration and soil temperature (Koizumi et al., 1999), plant growth, vegetation cover and yield (Mako et al., 2008; Bestland et al., 2009; Genxu et al., 2009), the transfer and interaction of mineral nutrients (Echevarria et al., 2003; Matias et al., 2011), and the physical, chemical and biochemical properties of soils (Rhoton et al., 1993; Paz-Ferreiro et al., 2011), while higher soil sand content have been shown to improve AMF colonisation (Zaller et al., 2011).

Both, the effect of precipitation and soil types on agroecosystem processes have been studied in isolation; however it is unclear how these important factors interact. Based on previous findings we hypothesize that soil types with lower water holding capacities and/or nutrient availability like S_{-soils} will interact with lower precipitation disrupting nutrient and water transportation into and within the plants, slowing down plant's physiological activities like photosynthesis, subsequently reducing plants biomass, crop yields, and weeds abundance more than F_{-soils} and T_{-soils} with higher soil water content. Thus S_{-soils} are expected to have much lower groundcover and root biomasses which are indicators for soil water und nutrient availability. In the current study we tested the effects of current long-term average rainfall patterns vs. future prognosticated rainfall patterns based on regionalized global climate change models simultaneously on three different soil types in a large-scale lysimeter facility.

2.3 **Materials and methods**

2.3.1 **Experimental site**

This experiment was carried out in 2011 using 18 cylindrical steel (Cr/Ni 18/9) lysimeters each with a surface area of 3.02 m² and 2.45 m soil depth. Lysimeters were located in Vienna, Austria and situated under a 10 x 46 m tunnel covered with transparent polyethylene film (Figure 2.1). Tunnels were open at the front and back and had 2-m-high openings at both length sides to allow proper ventilation.

(A)

(B)

Figure 2.1: Above ground (A) and below ground (B) view of the lysimeter station where the current study was conducted.

The soil types (S_{-soils}, F_{-soils} and T_{-soils}) were filled each into 6 lysimeters. These soil profiles were carefully excavated from field sites and filled into the lysimeters with their natural bulk density of 1.4 g cm^{-3}. Each soil type was analysed in the laboratory and their different characteristics reported on Table 2.1

Table 2.1: Characteristics of the experimental soil types in the lysimeters (From soil analysis and partly from Steinitzer & Hoesch 2005).

Parameters	Sandy calcaric phaeozem (S_{-soils})	Gleyic phaeozen (F_{-soils})	Calcic chernozem (T_{-soils})
Profile water content (mm)	250-500	400-700	460-730
Infiltration (mm)	430	25	0
Evaporation (mm)	2800	3150	3150
PH-Value: $CaCl_2$	7.4	7.6	7.6
Calciumcarbonate (%)	0.143	0.260	0.106
Phosphor, CAL (mg/kg)	143	73	76
Potassium, CAL (mg/kg)	187	246	286
Magnesium, available (mg/kg)	83	273	277
Humus content	2.1	4.9	4.9
Nitrogen, mineralisation (mg/kg/7d)	56	57	68
Boron, available (mg/kg)	1.3	2.7	2.9
Iron, EDTA (mg/kg)	69	44	39
Manganese, EDTA (mg/kg)	81	34	33
copper, EDTA (mg/kg)	3.3	3.4	3.2
Zinc, EDTA (mg/kg)	4.6	4.6	4.7
Sand %	67.9	21.5	22
Silt %	19	50.67	55
Clay %	9.9	27.83	23
Cation exch. cap. mmol/100	11.29	25.13	26.00

Half of the lysimeters were subjected to the current rainfall pattern (treatment “curr.”), and the other half to the prognosticated rainfall pattern (treatment “progn.”). The current rainfall pattern was calculated by averaging the amount and frequency of precipitation between the years 1971-2000 from a weather station located 10 km from the experimental site. The prognosticated rainfall pattern was based on the regionalisation of the IPCC 2007 climate change scenario for the period 2071-2100, gotten from local climatology and climate change signal from the ensemble mean of the regional climate model scenarios from the EC-project ENSEMBLES (Christensen & Christensen, 2007). The weather generator LARS-WG version 3.0 (Semenov & Barrow, 2002) was used to transfer the derived local climate change signals to daily precipitation rates. Rainfall amounts were applied early in the morning by a hand sprinkler with an attached gauge using tap water. Rainfall treatment started 63 days after seeding whereby the prognosticated treatment received 1/3 reduced precipitation in longer duration (Figure 2.2). At the bottom of each lysimeter containers collected the leachate, of which the chemical data are presented on Table 2.2.

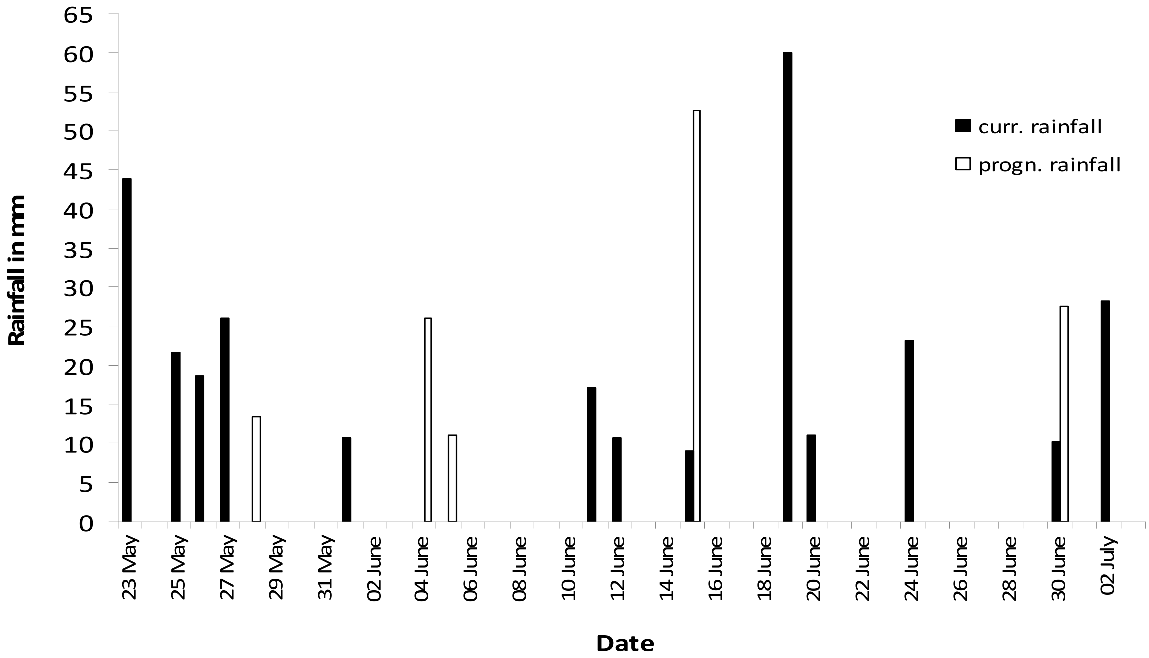

Figure 2.2: Current and prognosticated rainfall amounts applied onto field pea stands during the vegetative period from May to July 2011.

Lysimeters were sown with field peas (*Pisum sativum cf. Jetset)* on 23 March 2011. All lysimeters received 49 mm of natural rainfall before the simulation treatments started. Until the harvest of the crops on 03 July 2011, curr. treatments received 131 mm and progn. treatments 93 mm rainfall. Since our aim was to mimick the real-world situation for farmers, we analysed soil P and K nutrient concentrations in all lysimeters and fertilized the lysimeters according to official recommendations. Therefore, all F_{-soils} and T_{-soils} received 65 kg ha^{-1} P_2O_5 and all S_{-soils} 100 kg ha^{-1} K_2O, all F_{-soils} and T_{-soils} 50 kg ha^{-1} K_2O. No N- fertilizer was applied as lysimeters were planted with the nitrogen-fixing legume alfalfa (*Medicago sativa* L.) in the year prior to this experiment. No chemical weed control was applied during the course of the experiment.

Table 2.2: Chemistry of the flow through water (Leachate) on S_{-soils} (except sample 25on T_{-soil}).

Samples	Rainfall	Soil type	Permeability (µS/cm)	Phosphorus (mg/l)	NH_4 (mg/l)	NO_3 (mg/l)
1	Curr.	S	560	0.12	0.20	17
2	Curr.	S	620	0.07	0.00	26
3	Curr.	S	600	0.05	0.23	21
4	Curr.	S	490	0.06	0.14	14
5	Curr.	S	510	0.07	0.31	16
6	Curr.	S	570	0.07	0.00	22
7	Curr.	S	480	0.05	0.00	13
8	Curr.	S	500	0.06	0.00	15
9	Curr.	S	600	0.05	0.00	26
10	Curr.	S	430	0.02	0.14	12
11	Curr.	S	450	0.01	0.39	16
12	Curr.	S	570	0.02	0.32	29
13	Progn.	S	620	0.06	0.49	23
14	Progn.	S	620	0.04	0.00	23
15	Progn.	S	820	0.08	0.04	49
16	Progn.	S	690	0.06	0.06	35
17	Progn.	S	630	0.05	0.01	27
18	Progn.	S	750	0.10	0.00	47
19	Progn.	S	670	0.05	0.00	35
20	Progn.	S	590	0.05	0.09	24
21	Progn.	S	810	0.07	0.00	53
22	Progn.	S	600	0.02	0.24	33
23	Progn.	S	520	0.02	0.07	23
24	Progn.	S	840	0.05	0.45	59
25	Progn.	T	2500	0.06	0.00	25

2.3.2 **Measurements**

The groundcover was measured from images taken with a digital camera on a tripod located 1.6 m above a marked area (1.2 x 1.2 m) per lysimeter. We took images every week between days 13 to 70 after sowing and calculated percent ground cover using the freely available software ImageJ (http://rsbweb.nih.gov/ij/). The leaf area index (LAI) was measured using a ceptometer (SunScan type SS1, DELTA-T Device Cambridge UK), inserted eight times horizontally (2 cm above the soil surface) from outside to the center in sections of 45°; LAI was calculated by averaging the eight readings per lysimeter.

Root production was measured by using five randomly located ingrowth cores per lysimeter (diameter 5 cm, depth 20 cm). First, roots present in the soil cores were sorted out and the rootless soils refilled back into the bored holes. Then, 49 days later the same positions were resampled and all roots growing into these cores were washed out in a sieve (mesh size 0.5 mm) under a jet of tap water. Root-free soil was refilled and ingrowth cores were resampled after another 30 days and processed as described above. Of these roots one half was used to determine dry mass after oven-drying at 50°C for 48 hours. The other half of the root mass was stored in 50% ethanol and their colonisation with vesicular-arbuscular mycorrhizal fungi measured after ink-staining (Vierheilig et al., 1998) using a modified gridline intersection method under the dissecting microscope by counting at least 100 sections (Giovannetti & Mosse, 1980).

Weed infestation was measured on permanently marked 50 x 50 cm plot per lysimeter. Weeds growing within this area were successively removed, identified to plant family level, counted and their mass weighed after drying at 50°C for 48 hours; weeds growing on the remaining lysimeter area were pulled by hand and weighed. Total weed biomass of each lysimeter was calculated by adding the biomass of the permanent and the remaining plot area.

Field pea plants and weeds were harvested by hand cutting them 5 cm above the soil surface. Pea yield was obtained by threshing the sheets in the laboratory. Field peas and straw were ground and N content determined using an elemental analyser (LECO TruMac, St. Joseph, MI, USA). Crop P, K, and Mg contents were determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES, Thermo Scientific, icap 6000 series Waltham MA USA).

No insecticide was used and insect pest population was determined by direct sampling. At harvest abundance of the Pea moth *Cydia nigricana* Fabricius (Lepidoptera: Tortricidae) was counted in pea sheets on ten randomly chosen crop individuals per lysimeter. Pea moth abundance per m^2 was calculated by multiplying the abundance plant^{-1} with crop density.

2.3.3 **Statistical analyses**

First, we tested the normal distribution and variance homogeneity of each parameter using the Shapiro test and Kolmogorov-Smirnov, respectively. Parameters that did not meet criteria for parametric tests were transformed using Boxcox-transformations. Afterwards, all parameters (total biomass, pea, straw, weed, harvest index, plant density, root production, mycorrhization, root-shoot ratio, weed families, number of pea moth) were analysed using a two factorial analysis of variance (ANOVA) with precipitation (2 levels: curr. rainfall vs. progn. rainfall) and soil types (3 levels: $F_{\text{-soils}}$, $S_{\text{-soils}}$, $T_{\text{-soils}}$) as factors. We also performed correlations between LAI and biomass (Spearmans rank correlation coefficient) and pea yield and root production (Pearson correlation coefficient). All statististical analyses were performed using the freely available software R (Free Software Foundation, Inc., Boston, www.r-project.org).

2.4 **Results**

Future rainfall pattern reduced the NPP, weed abundance, pea biomass, and yield more on $S_{\text{-soils}}$ than on $T_{\text{-soils}}$ and $F_{\text{-soils}}$. The NPP, harvest index, pea biomass plant^{-1}, pea yield plant^{-1}, root production and root-to-shoot ratio were significantly affected by both rainfall and soil types (Table 2.3). The NPP under progn. rainfall was 29 % lower than under curr. rainfall patterns. $S_{\text{- soils´s}}$ NPP was 36% lower compared to $F_{\text{-soils}}$ and 43% lower than $T_{\text{-soils}}$; but insignificant between $F_{\text{-soils}}$ and $T_{\text{-soils}}$ biomass (Figure 2.3a). Groundcover was significantly reduced under progn. rainfall, however unaffected by soil types; LAI was marginally significantly affected by rainfall and soil type (Table 2.3).

Table 2.3: ANOVA results on effects of three different soil types (gleyic phaeozem - $F_{\text{-soils}}$, sandy calcaric phaeozem - $S_{\text{-soils}}$, calcic chernozem - $T_{\text{-soils}}$) and rainfall patterns (curr. rainfall vs. progn. rainfall) on agroecosystem variables in field peas. (DAS = days after seeding)

	Soil type		Rainfall		Soil type x Rainfall	
Variable	F	P	F	P	F	P
Ground cover (70 DAS, %)	1.359	0.294	16.474	0.002	0.556	0.588
LAI (90 DAS)	3.391	0.068	3.286	0.095	0.930	0.421
Net primary production (g/m²)	28.676	<0.001	13.3	0.003	0.937	0.419
Pea + Straw (g/m²)	4.492	0.035	2.951	0.111	0.754	0.491
Pea (g/m²)	12.486	0,001	3.979	0.069	0.081	0.922
Weed (g/m²)	9.602	0.003	2.692	0.127	0.228	0.800
Harvest index	119.093	<0.001	5.837	0.033	12.285	0.001
Plant density (ind./m²)	8.574	0.005				
Biomass per plant (g)	31.522	<0.001	11.093	0.006	1.616	0.239
Pea per plant (g)	71.842	<0.001	17.567	0.001	4.459	0.036
Root production, pre-treatment (g/m²)	16.590	<0.001				
Root production, treatment (g/m²)	11.769	0.001	8.438	0.013	0.449	0.648
Mycorrhization, pre-treatment (%)	1.583	0.238				
Mycorrhization, treatment (%)	0.121	0.887	3.736	0.077	0.193	0.827
Root/shoot ratio	23.508	<0.001	20.427	0.001	1.265	0.317
Weed density (ind./m²)	0.863	0.447	0.000	0.987	3.775	0.053
Pea moth infestation (ind./m²)	0.079	0.925	1.736	0.212	0.077	0.926

Pea biomass, yield and weed biomass were significantly affected by soil types, but not by rainfall patterns (Table 2.3). Harvest index, pea yield per plant and weed density showed significant interactions between soil types and rainfall (Table 2.3). The pea and straw biomass production in $S_{\text{-soils}}$ was 37% lower than $F_{\text{-soils}}$ and 35% lower than $T_{\text{-soils}}$ (Figure 2.3b). The pea yield per m² was significantly affected by soil type and marginally significantly affected by rainfall; $S_{\text{-soils}}$ produced the lowest pea yield being 63% lower compared to $F_{\text{-soils}}$ and 59 % lower than $T_{\text{-soils}}$, $F_{\text{-soils}}$ and $T_{\text{- soils}}$ had similar yields (Table 2.3, Figure 2.3c). Root production before implementing rainfall treatments was significantly different between soil types (Table 2. 3): S_{-soils} showed higher root production than F_{-soils} and T_{-soils}, while the root production between T_{-soils} and F_{-soils} was similar (data not shown). One month after implementing the rainfall treatments, root production was significantly affected by rainfall and soil types (Table 2.3; Figure 2.3d). Across all soil types the root growth under progn. rainfall was on average 53% higher than under curr. rainfall patterns. Root growth was significantly different among the various soil types. Between all soil types the root-to-shoot ratio differentiated significantly (data not shown).

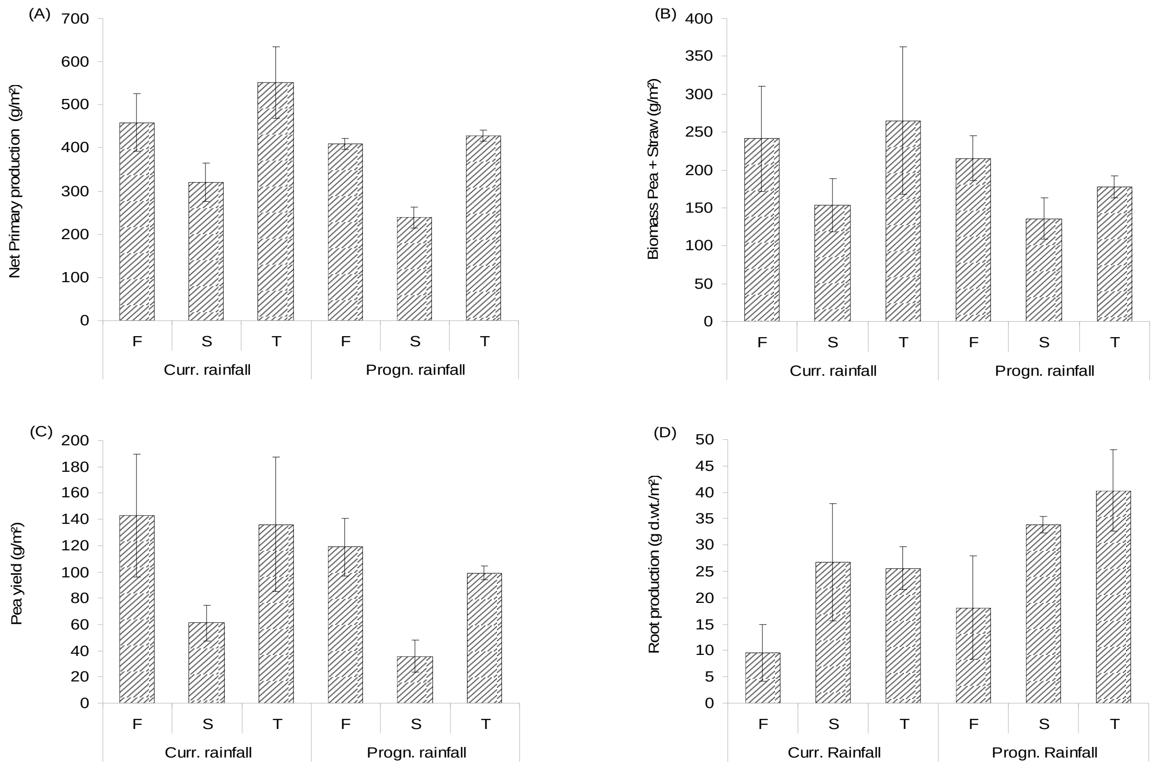

Figure 2.3: Net primary production (A), biomass of field pea + straw (B), pea yield (C) and root production (D) in field peas at different soil types (gleyic phaeozem - F_{-soils}, sandy calcaric phaeozem - S_{-soils}, calcic chernozem - T_{-soils}), under current and prognosticated rainfall patterns. Means ± SD, n = 3.

The harvest index was 9% lower under progn. rainfall patterns than under curr. rainfall patterns. S_{-soils} had the lowest harvest index and differentiated from the T_{-soils} and F_{-soils} by 39% and 42% respectively, while T_{-soils} had 6% lower harvest index than F_{-soils} (Figure 2.4). Root mycorrhizal colonisation rate was on average 22%, however was not affected by soil types; progn. rainfall showed a trend toward lower mycorrhization rates compared to curr. rainfall (Table 2.3; Figure 2.5).

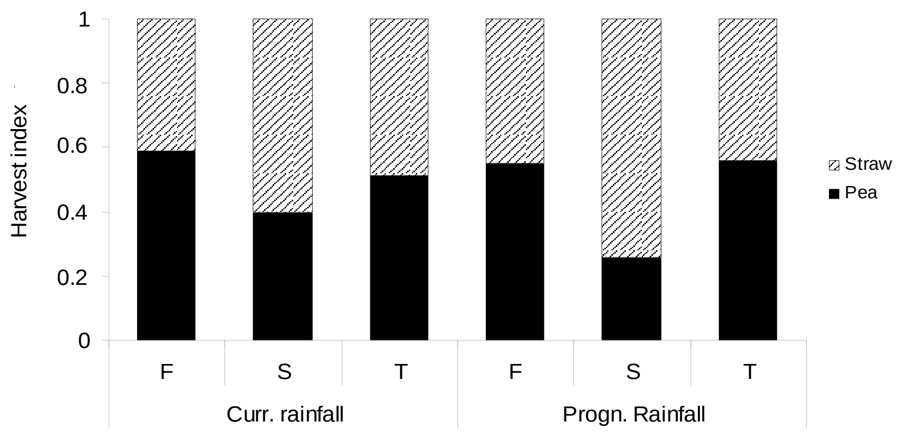

Figure 2.4: Harvest index in field peas at different soil types (gleyic phaeozen - F-soils, sandy calcaric phaeozem - S-soils, calcic chernozem - T-soils), under curr. and progn. rainfall patterns. Means, n = 3.

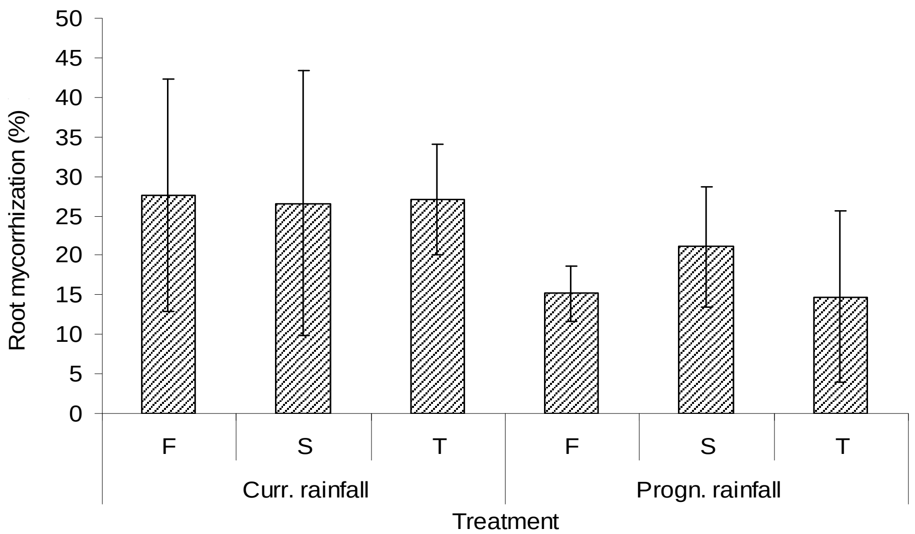

Figure 2.5: Mycorrhization of field pea roots at different soil types (gleyic phaeozem - F-soils, sandy calcaric phaeozem - S-soils, calcic chernozem - T-soils), under curr. and progn. rainfall patterns. Means ± SD, n = 3.

Weed production was significantly affected by soil types, with a trend towards decreasing weed production under progn. rainfall (Table 2.3). $S_{\text{-soils}}$ hat 50% less weed biomass than $T_{\text{-soils}}$ and 34% less weed biomass than $F_{\text{-soils}}$. Weed density was unaffected by rainfall or soil types (Figure 2.6A). Weed communities consisted of the families Asteraceae, Chenopodiace, Polygonaceae and Poaceae. The relative contribution of these families to the weed community was unaffected by rainfall or soil types (Figure 2.6B), although there were considerable changes in the contribution of these families to the weed communities.

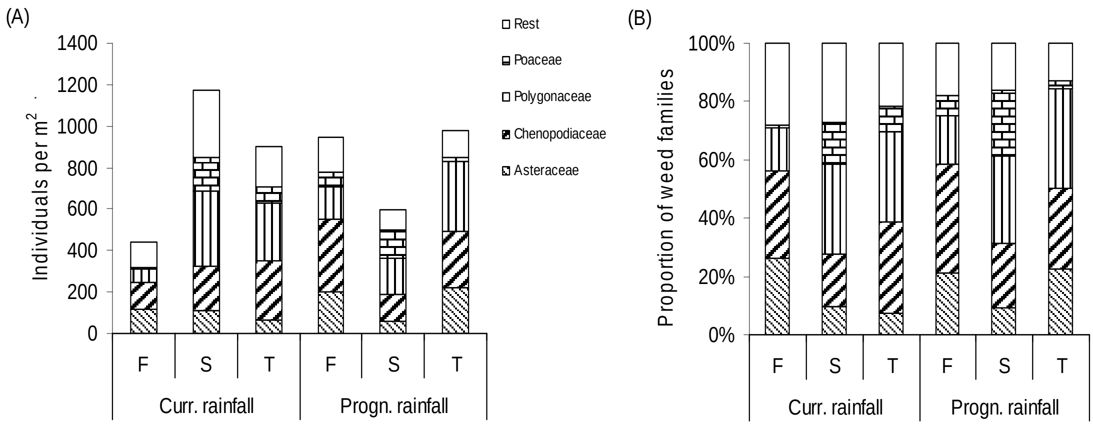

Figure 2.6: Absolute (A) and relative (B) abundance of weed families per m² in field peas at different soil types (gleyic phaeozen - $F_{\text{-soils}}$, sandy calcaric phaeozem - $S_{\text{-soils}}$, calcic chernozem - $T_{\text{-soils}}$), under current and prognosticated rainfall patterns. Means, n = 3.

Across soil types, the abundance of pea moth (*C. nigricana*) was on average 105% higher under progn. rainfall than under curr. rainfall, however this was not statistically significant; soil types had no influence on *C. nigricana* (Figure 2.7).

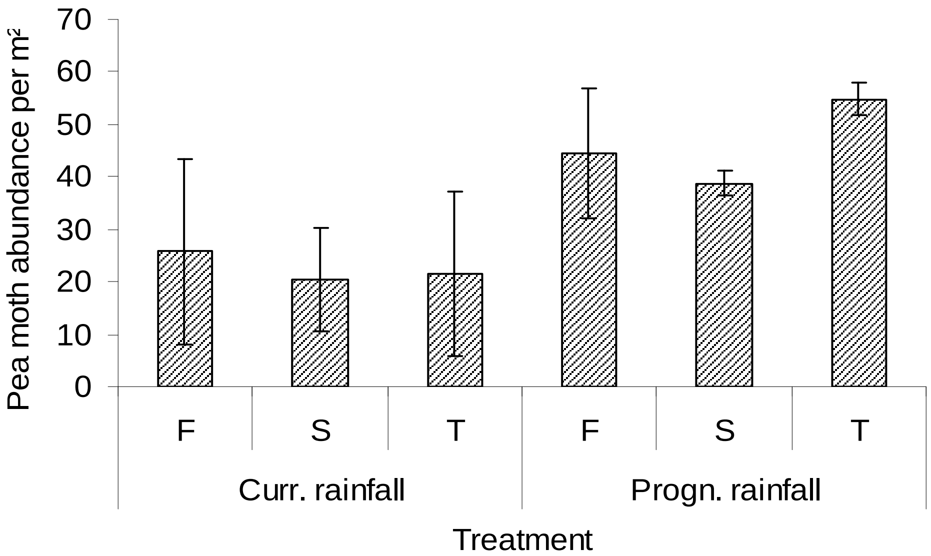

Figure 2.7: The abundance of pea month per m² in field peas at different soil types (gleyic phaeozem - $F_{\text{-soils}}$, sandy calcaric phaeozem - $S_{\text{-soils}}$, calcic chernozem - $T_{\text{-soils}}$), under current and prognosticated rainfall patterns. Means, n = 3.

LAI significantly correlated with pea biomass (r = 0.724, P = 0.024). There was no correlation between mycorrhization rate and the pea yield, root production or NPP (data not shown). Analysing the soil NH_4 and NO_3 contents from 0.1M Kcl soil extract showed strong increase in average NO_3 content from 0.416 to 2.225 µg/g on S_{-soil} under prognosticated climate (Table 2.4). By the end of the experiment no leachate was collected on F_{-soils} and barely one sample on T_{-soils}, while on S_{-soils} the leachate average NO3 content was almost twice as much with progn. treatment, while NH4 and P contents were almost the same for both treatments (Table 2.2).

Table 2.4: The average and standard deviation (SD) values of NH_4 and NO_3 content in the soil types (gleyic phaeozem - F_{-soils}, sandy calcaric phaeozem - S_{-soils}, calcic chernozem - T_{-soils}), under current and prognosticated rainfall patterns. Means ± SD, n = 3.

Rainfall	Soil type	NH_4 (µg/g)	SD - NH_4 (µg/g)	NO_3 (µg/g)	SD - NO_3 (µg/g)
C	F	1.597	0.147	2.314	2.543
	S	1.444	0.114	0.416	0.271
	T	1.728	0.107	1.564	1.715
D	F	1.477	0.411	2.770	1.780
	S	1.331	0.349	2.225	0.746
	T	1.391	0.306	1.981	1.047

2.5 **Discussion**

2.5.1 **Effects of rainfall patterns**

Simulated future rainfall patterns with 30% decreased rainfall amount during the vegetation period and 36% longer dry periods between rainfall events than the current long-term rainfall patterns affected several important processes within this agroecosystem. It was very interesting to observe most changes just about four weeks after implementing treatments which differ by only 38 mm rainfall. Field pea stands responded to future rainfall patterns with a reduced ground cover and aboveground production but increased root production. The allocation of production into roots is probably a stress reaction counteracting the induced drought by increasing the root surface area of water absorption likewise extending deeper to meet the underground available water (Masilionyte & Maiksteniene, 2011).

We attribute the reduction of NPP under progn. rainfall patterns to differences in the soil profile water content, infiltration and evaporation rates (Steinitzer & Hoesch, 2005). In a lysimeter experiment with seven different crops including field pea it was shown that the straw yield responded positively to moisture with an 21% increase for pea straw biomass under irrigation (Gan et al., 2009). The positive correlation between NPP and the LAI showed a stronger effect of the climate on the vegetative growth and confirms findings that induced drought being responsible also for the reduction in crop cover rate (Cui &Nobel, 1992; Augé, 2001; Echevarria et al., 2003; Porcel et al., 2003; Matias et al., 2011). Decrease in harvest index under progn. rainfall was in contradiction to the findings of Martin & Jamieson, (1996) associating increase in field pea harvest index to sensitivity in reproductive growth, but is in conformity with the findings of others contributing it to photosynthetic changes (Sanchez et al., 2001).

The observed increased root growth on all soil types under progn. rainfall indicates that soil conditions in the three soil types were still suitable for root extension (Passioura, 1991; Feiziene et al., 2011). Overall root AMF colonisation was low suggesting that AMF is not very important in this leguminous crop. Nevertheless, a trend towards reduced AMF colonisation under progn. rainfall could be attributed to the fact that water stress causes plants to be more metabolically perturbed. According to Augé (2001), the fungus strongly competes for root allocates with the onset of stress, leading to reduced mycorrhization rates in response to resist drought stress (Stahl &Christensen, 1982; Cui & Nobel, 1992; Subramanian & Charest, 1998; Augé, 2001; Bolandnazar et al., 2007). The reduced AMF trend observed on all soil types with reduced progn. rainfall could be attributed to reduced soil water content (Stahl & Christensen, 1982), contradicting the findings of (Cui & Nobel, 1992) who associated higher colonisation with improved water availability.

Overall, there were very few insect pests on the crops in the experimental year. Nevertheless, considerably more *C. nigricana* were collected under progn. rainfall than under curr. rainfall. Although this difference was not statistically significant due to high variation between lysimeters this indicates that pest species living in sheets benefitted from future rainfall patterns. It has long been known that pea moth is more abundant on pea varieties with later flowering dates and longer flowering duration (Nolte & Adam, 1962) and it could also be shown that the abundance of this pest species also correlates with the pea cropping area in the surroundings (Thoeming et al., 2011) as known for other crops (Zaller et al.,2008a)

2.5.2 **Effects of soil types**

The three soil types differed mainly in sand, silt, clay and humus contents, soil water capacity and cation exchange capacities. Overall, crops and weeds in sandy soils were most sensitive to rainfall manipulations. A general decrease in crop production, mycorhization and insect pests on soil types with progn. rainfall was observed while the response of weeds varied among soil types. Weed biomass production was unaffected by rainfall patterns, confirming the findings of Gan et al., 2009. Weed abundance decreased in $S_{\text{-soils}}$ and $T_{\text{-soils}}$ under progn. rainfall but was unaffected on $F_{\text{-soils}}$, indicating that soil types with higher sand and silt content are more prone to reduced rainfall than those with higher clay content. On plots with progn. rainfall weed density increased on $F_{\text{-soils}}$, decreased on $S_{\text{-soils}}$, while $T_{\text{-soils}}$ were almost unaffected. This could be attributed to the soil properties, the types of weed species and a better water use efficiency of individual weed families (Bolandnazar et al., 2007). Soil types influencing the abundance of plant communities is in conformity with most earlier research (Koizumi et al., 1999; Echevarria et al., 2003; Mako et al., 2008; Bestland et al., 2009; Clark et al., 2011; Matias et al., 2011; Feiziene et al., 2011), but differs from the finding of (Kreyling et al., 2008) that changes in the physical environment had the same effect on vegetation type and diversity level.

In the current experiment, $S_{\text{-soils}}$ had the lowest soil moisture and highest sand content, but here the smallest AMF reduction was observed implying that soil moisture alone cannot be the reason for the reduced AM trend. This is somewhat unexpected as a higher sand content has been shown to increase root colonisation with AMF (Zaller et al., 2011).

Weed production was significantly different between soil types although the contribution of different weed families to the weed community was not different. There was a trend towards more abundance of Asteraceae, Chenopodiace, and Polygonaceae under progn. rainfall on $F_{\text{-soils}}$ and $T_{\text{-soils}}$, however on $S_{\text{-soils}}$ they were all reduced. It appears that weed families with a broader root system, are more competitive that the cultivated *Pisum sativum*; this could also be reflected in the shift of the ratio of weed-to-crop biomass in towards of weeds. The abundance of the Poaceace family differed from the other weed families. It increased on $F_{\text{-soils}}$, decreased on $T_{\text{-soils}}$ and was almost unchanged on $S_{\text{-soils}}$, under progn. rainfall. This could be attributed to its C4-photosynthetic pathway, compared C3 pathway of other species.

No leachate on $F_{\text{-soils}}$ and barely one sample from $T_{\text{-soils}}$ could be attributed to their higher water holding capacities and lower sandy contents than $S_{\text{-soils}}$, indicating $S_{\text{-soils}}$ vulnerability to climate change

2.6 **Conclusions**

To our knowledge, results of this study demonstrate for the first time that different soil types can alter the impact of rainfall patterns on agroecosystem processes. The influence of different soil types in altering ecosystem responses should be considered when trying to scale–up experimental results derived at the plot level to the landscape level. These results also indicate that crops such as field peas where irrigation as an adaptation to climate change is economically not feasible may be especially prone to future rainfall patterns.

2.7 **Acknowledgements**

We are grateful to Lina Weissengruber and Nadja Santer for their help in the field, to Wolfgang Holzner and Gerhard Karrer for their advice on weeds, and to Wolfgang Wanek for lending us the ceptometer. This research was funded by the Austrian Climate and Energy Fund as part of the call “ACRP”.

3. Climate change induced rainfall patterns affect wheat productivity and agroecosystem functioning dependent on soil types

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3.1 **Abstract**

Wheat is a crop of global importance that supplies carbohydrates to more than half of the worlds' population. We examined whether climate change-induced rainfall patterns, which are expected to produce less frequent but heavier rain events, will alter the productivity of wheat and agroecosystem functioning on three different soil types. Therefore, in a full-factorial experiment, *Triticum aestivum* L. was cultivated in 3-m^2 lysimeter plots, each of which contained one of the following soil types: sandy calcaric phaeozem, gleyic phaeozem and calcic chernozem. Predicted rainfall patterns based on the calculations of a regionalised climate change model were compared with the current long-term rainfall patterns, and each treatment combination was replicated three times. Future rainfall patterns significantly reduced wheat yield, leaf area index, and plant height at the earlier growth stages; it equally decreased the arbuscular mycorrhizal fungi colonisation of roots and increased the stable carbon isotope signature ($\delta^{13}C$) of wheat leaves. Sandy soils with inherently lower mineralization potential negatively affected wheat growth, harvest index, and yield but stimulated early season root production. The interaction between rainfall and soil type was significant for the harvest index and early wheat development. Our results suggest that changes in rainfall intensity and frequency can significantly affect the functioning of wheat agroecosystems. Wheat production under future rainfall conditions will likely become more challenging as further concurrent climate change factors become prevalent.

3.2 **Introduction**

Wheat (*Triticum aestivum* L.) accounts for the largest agricultural area of land use, supplies the largest source of vegetable protein in human food, and provides nearly 55% of the carbohydrates and 20% of the food calories consumed globally (FAOstat 2012). Thus, securing wheat productivity under climate change is essential for human nutrition as well for meeting the growing demand of wheat to an increasing world population. As a consequence of human induced climate change, reports of the Intergovernmental Panel on Climate Change predict fewer but heavier rain events during the vegetation period in Central Europe (IPCC 2007, IPCC 2013), which is expected to affect wheat production since its yield is closely associated with precipitation (Rezaie and Bannayan 2012). While the majority of reports on effects of climate change on plant production focused on one particular soil type, very little is referred to different soil types with different mineralization potential and hydrological characteristics altering climate change effects on agroecosystems. Indeed, few studies show that soil types can alter the effects of climate change on plant production (Tabi Tataw et al. 2014; Nord et al. 2015). In this study we will examine how climate change induced alterations in precipitation distribution affect ecological functions in wheat agroecosystems growing on different soil types.

An important ecological function to be affected by climate change induced rainfall pattern is crop biomass production, whereby previous studies prove that wheat growth is affected by various environmental and ecological factors such as drought (Salinger et al. 1995; Alexieva et al 2001; Dodig et al. 2008; Dodig et al. 2010), temperature (Ludwig and Asseng 2006; Thaler et al. 2012), elevated atmospheric CO_2 levels (Blumenthal et al. 1996; Wang et al. 2013) and soil types (Firbank et al. 1990; Whalley et al. 2008; Itoh et al.2009; Arvidsson et al. 2013). The prognosticated precipitation patterns with fewer rainfall events could lead to reductions in biomass and grain yield (Oweis et al. 1998; Gooding et al. 2003) while heavier rainfall could lead to erosion, sediment transport, and thereby reducing wheat production (van Dijk et al. 2005; Schillinger 2011). The effects of future rainfall on wheat production could be altered by soil macrostructure, as well as sand and clay contents of different soil types affecting water retention and root penetration (Atkinson et al. 2009; Itoh et al.2009; Arvidsson et al. 2013). The soil water content especially has been shown to affect wheat morphology and physiology (Rimar and Mati 1992; Dandan et al. 2013) while the soil nutrient content in interaction with precipitation improves growth (Oweis et al. 1998; Masoni et al. 2007) and alters wheat nutrient concentration (Schimmack et al. 2004; Patil et al. 2010a).

Important components of the wheat plant interacting with precipitation and affecting biomass production are roots and leaves. Roots which anchor the plant and taking up water and nutrients have shown to reduce growth during drought scenarios while increasing water uptake rates (Asseng et al., 1998). Wheat leaves essential for photosynthesis and respiration have been shown to affect growth whereby the leaf area index (LAI) correlates positively with yield (Ren et al., 2010). Leaf stable isotope $\delta^{13}C$ signatures have also been shown to be a sensitive measure for transpiration efficiency and hence water limitation of a crop affecting photosynthesis and altering grain number and weight (Cordon et al. 1990; Hall et al. 1994; Werner et al. 2012). Other important underground determinants of wheat growth and grain yield are arbuscular mycorrhizal fungi (AMF). Symbiotic interactions between crop and AMF have been shown to influence the uptake of mineral nutrients (Vinichuk et al., 2013) thus improving wheat growth and grain yield (Al-Karaki et al., 2004), enhancing the adaptation to dry conditions and assisting as a bioremediation agent for root diseases (Ryan and Kirkegaard, 2012). Decreases in AMF colonisation as well as reductions in vesicles and arbuscules with future rainfall patterns have been reported (Martínez-García et al. 2012). AMF colonisation has also been shown to be affected by different soil types (Zaller et al. 2011).

In an earlier experiment investigating field peas, we found that even slight changes in rainfall variations can affect crop yields (Tabi Tataw et al. 2014) or other agroecosystem characteristics such as arthropod abundances (Zaller et al. 2014). There, rainfall patterns prognosticated for future decades with less frequent but heavier rainfall events reduced crop density, net primary production (NPP) and root AMF colonisation. In the current experiment we wanted further to assess whether rainfall effects for the legume field peas are similar to that of the cereal crop wheat. As field peas have a taproot system and wheat typically has a more homogeneous root system, different responses of these crops at different soil types can be anticipated. For wheat we hypothesized that plants under the predicted rainfall should have a lower NPP and AMF but higher $\delta^{13}C$ values for all soil types, as the plants would rather used their limited resources to withstand the induced water stress at the expense of vegetative growth. However, we also hypothesized that soil types with higher water and/or nutrient availabilities, such as gleyic phaeozem, should mitigate the adverse effects of climate change on wheat with its rather shallow root system.

3.3. Material and methods

3.3.1 **Study site and experimental facility**

This experiment was carried out in the lysimeter facility of the Austrian Agency for Health and Food Safety (AGES) at the edge of the city of Vienna (160 m a.s.l.; 48° 14' N, 16° 16' E). The lysimeter facility was established in 1995 and consists of 18 cylindrical steel (Cr/Ni 18/9) vessels, each with an area of 3.02 m² and a depth of 2.45 m arranged in two parallel lines of nine lysimeters. Lysimeters were filled with three different soils types (each replicated 6 times), namely sandy calcaric phaeozem (S), gleyic phaeozem (F), and calcic chernozem (T), representing the majority of soil types of Austrias' most fertile crop growing region, the Marchfeld. Field soil was layer-by-layer excavated and transferred into the lysimeters so that the soil profiles with their natural bulk density of 1.4 g cm^{-3} were retained. Each soil type occurred three times in each row of the lysimeters. The characteristics of the different soil types are shown in Table 3.1.

Table 3.1: Analysed differences of the experimental soil types reported in Tabi Tataw et al.2014

Parameters	Sandy calcaric phaeozem (S_{-soils})	Gleyic phaeozen (F_{-soils})	Calcic chernozem (T_{-soils})
Profile water content (mm)	250-500	400-700	460-730
Infiltration (mm)	430	25	0
Evaporation (mm)	2800	3150	3150
PH-Value: $CaCl_2$	7.4	7.6	7.6
Calciumcarbonate (%)	0.143	0.260	0.106
Phosphor, CAL (mg/kg)	143	73	76
Potassium, CAL (mg/kg)	187	246	286
Magnesium, available (mg/kg)	83	273	277
Humus content	2.1	4.9	4.9
Nitrogen, mineralisation (mg/kg/7d)	56	57	68
Boron, available (mg/kg)	1.3	2.7	2.9
Iron, EDTA (mg/kg)	69	44	39
Manganese, EDTA (mg/kg)	81	34	33
copper, EDTA (mg/kg)	3.3	3.4	3.2
Zinc, EDTA (mg/kg)	4.6	4.6	4.7
Sand %	67.9	21.5	22
Silt %	19	50.67	55
Clay %	9.9	27.83	23
Cation exch. cap. mmol/100	11.29	25.13	26.00

3.3.2 **Rainfall scenarios**

Two different rainfall scenarios were established (Figure 3.1). The dry variant (D) based on the IPCC (2007) predicted regionalised future rainfall patterns for the years 2071-2100, derived from local climatology and climate change signals from the ensemble mean of the regional climate model scenarios from the project ENSEMBLES funded by the European Commission (Christensen and Christensen 2007). The derived local climate change signals were transformed to daily precipitation using the stochastic weather generator LARS-WG (version 3.0 software; Semenov and Barrow 2002). The current variant (C) was based on the average precipitation amount and frequency between the years 1971-2000 for the village of Groß-Enzersdorf, located 10 km from the experimental site. Rainfall patterns of the current variant were also calculated using LARS-WG. To exclude natural precipitation from interfering in the experiment, a 40 x 46 m roof of transparent polythene film was build about 8 m above the lysimeters. The roof was open on all sides to allow proper ventilation. The plants were automatically watered from above using spraying nozzles. The spraying nozzles were installed at 3 m height so the size and strength of the water drops were similar to natural rain drops, and were focused on the entire lysimeter. One row was supplied the D rainfall pattern, and the other row was supplied the C rainfall pattern. The irrigation was controlled by a software programme so that during the vegetative period, the D row received 1/3 fewer but more intense rainfall events than the C row. The irrigation started on 23 March 2012 (= start date of the experiment) and wheats' growing stage was referred after this date as days after start (DAS).

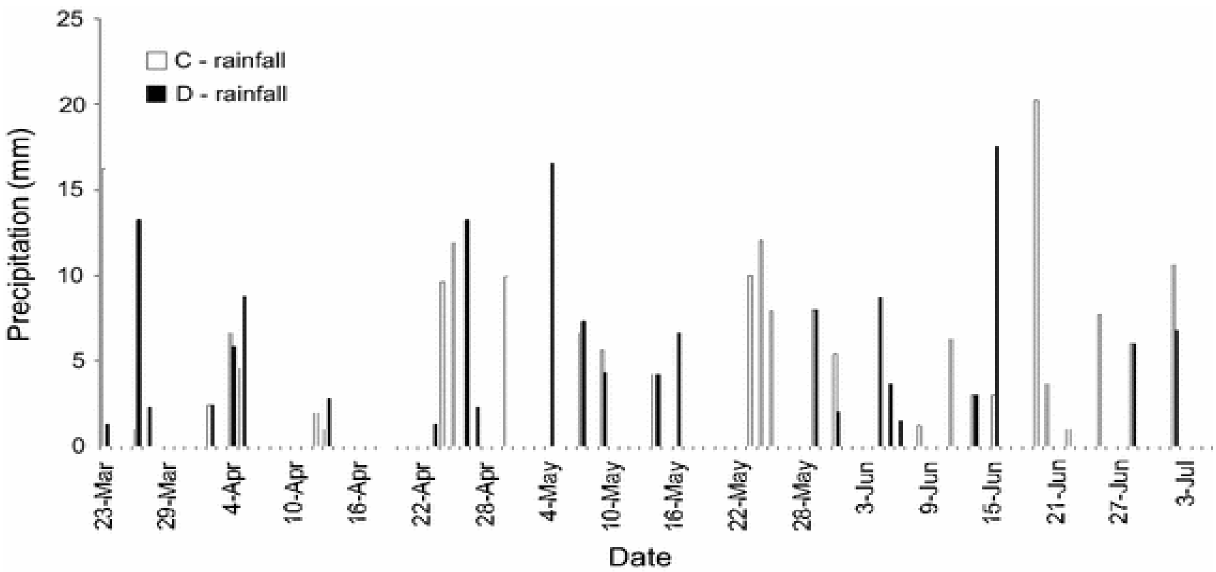

Figure 3.1: Amount of rainfall experimentally applied on the soils under the control scenario (C-rainfall) and under the prognosticated rainfall scenario (D - rainfall)

The lysimeters were cultivated with winter wheat (*Triticum aestivum cv. Capo*), at a seeding rate of 400 grains/m² on 11 November 2011. The herbicides Express (25 g/ha) and Starane XL (750 ml/ha), mixed with 300 l water/ha were applied on 30 March 2012 to control weed growth. After soil analysis, fertilisers were applied on different soil types according to recommendations of Austrian farmer extension service and to account for different nutrient mineralization potential of different soil types (Table 3.2). This approach was chosen in order to mimic the situation in the field where farmers would also apply different fertilisation on fields of different soil types.

Table 3.2: Fertilization per lysimeter in kg ha^{-1} on the sandy calcaric phaeozem (S), gleyic phaeozem (F) and calcic chernozem (T) soil types at the recommended rates after soil nutrient analyses.

Date	Type of fertilizer	Soil type		
		S	F	T
11 Oct. 2011	P_2O_5 - Triplephosphate	0	55	55
11 Oct. 2011	K_2O - Kali 60	40	0	0
08 Mar. 2012	N - NAC (Nitramoncal 27%)	25	40	40
12 Apr. 2012	N - NAC (Nitramoncal 27%)	30	40	40
16 May 2012	N - NAC (Nitramoncal 27%)	35	50	50

The maximum air temperature for the entire vegetative period (March-July 2012) varied from -1.8 - 36.8°C, with a daily average of 16.4 ± 7.3°C; soil temperature at 10 cm depth varied from 3.5 - 37.0°C with a daily average of 15.9 ± 5.3°C; soil temperature at 20 cm depth ranged between 5.3 - 29.4°C with a daily average of 15.3 ± 6.3°C. The mean air temperature in the lysimeter facility was similar to that measured outside of the facility (data not shown).

3.3.3 **Measurements**

Root production was measured by taking five random soil samples (5 cm diameter x 20 cm depth) per lysimeter using ingrowth cores on 3 April 2012, 7 May 2012 and 14 June 2012. The roots present in the cores were sorted out and the rootless soils were replaced into the same bored holes. The sorted roots were cleaned from attached soil using a sieve (mesh size 0.5 mm) under running tap water. Two samples per date were used to determine root production, while the remaining three samples per date were used for determining the mycorrhization rate. Therefore, the roots were cut into 1-cm-pieces, placed in H_20 for 6 hours, bleached in 10% KOH for 3 minutes, and then ink-stained for one minute as described by Vierheilig et al. (1998). The samples were stored in 60% ethanol, and the colonisation with mycorrhizal fungi was determined using the gridline intersection method under the microscope by counting at least 100 sections (Giovannetti and Mosse, 1980).

The leaf area index (LAI) was measured on 25 May 2012 (DAS 64) and on 26 June 2012 (DAS 97) using a ceptometer (SunScan type SS1, DELTA-T Device Cambridge UK). The measuring rod with 64 sensors was horizontally inserted 4 times in 90° sectors into the wheat stand. LAI was calculated by averaging the four measurements per date based on the manufacturer-derived algorithm developed for wheat.

Fifteen permanently marked plants per lysimeter were randomly selected for monitoring wheat growth stages (GS; Zadoks et al. 1974). Of these wheat plants heights (cm) were measured from the soil surface to the stem top excluding the awn on 24 April 2012 (DAS 29) at GS 31-32, on 23 May 2012 (DAS 59) at GS 56-59, and on 20 June 2012 (DAS 88) at GS 83-89. At harvest the fifteen marked wheat plants were cut at the soil surface using a pair of scissors and used for assessing wheat biomass production after drying at 50°C for six days. Afterwards the straw was cut from the ear, the grains picked out and weighed and also the empty ears were weighed. The remaining wheat plants were cut with scissors 5 cm above soil surface and processed in a laboratory thresher (LD 180, Wintersteiger, Ried, Austria). On these samples yield, straw-corn ratio (harvest index), hectolitre weight and thousand seed weight was measured. Wheat kernels and straw were ground and N content was determined using an elemental analyser (LECO TruMac, St. Joseph, MI, USA). Crop P and K contents were determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES, Thermo Scientific, iCAP 6000 series, Waltham, MA, USA).

To examine the water stress response of wheat, 10 young and 10 old leaves of wheat plants were randomly collected per lysimeter during the vegetative period (DAS 28, DAS 58, and DAS 89) to determine the leaf $\delta^{13}C$ signatures. The samples were dried at 45°C for 48 h using liquid nitrogen, ground, and analysed at the Austrian Institute of Technology (AIT, Tulln, Austria) using a MAT 251 ratio mass spectrometer (Finnigan MAT GmbH Bremen).

Soil matric potential (ψm, also called soil water potential) was measured using three pF sensors per lysimeter installed in 10 cm depth (ecoTech Umwelt- Messsysteme GmbH, Bonn, Germany). The soil matric potential was automatically measured every 15 min and represents the pressure it takes to pull water out of soil and increases as the soil gets drier. Daily pF values were calculated by averaging the individual readings of each lysimeter. Field capacity of soil types was pF = 1.8, permanent wilting point for crops pF = 4.2. A time course of the soil matric potential during the field season is published in Zaller et al. 2014

3.3.4 **Statistical analyses**

The analyses were performed using IBM SPSS Statistics for Windows (Version 21.0, 2012 release, IBM Corp., Armonk, NY, USA). First, all of the parameters were tested for normality and variance homogeneity using Kolmogorov-Smirnov’s and Levene’s tests, respectively. Then, using each parameter as a dependent variable, the general linear model and univariate analyses of variance (ANOVA) with soil types (three levels: F, S, and T) and rainfall (two levels: C and D) as fixed factors were performed. To test the rainfall effect on each parameter, post-hoc Tukey HSD and Bonferroni analyses was performed for each soil type. Correlations between the measured parameters were performed using the Pearson correlation coefficient.

3.4 **Results**

Wheat showed a significant reduction in grain yield, harvest index, LAI during ripening, root AMF colonisation and $\delta^{13}C$ of young and old wheat leaves under the future rainfall scenario (Table 3.3, Figure 3.2-3.6). Soil types also significantly affected wheat growth, early season root production, harvest index, grain yield, and wheat biomass production. The interaction between soil type and rainfall was only significant for the harvest index and wheat growth until anthesis (Table 3.3).

Table 3.3: Statistical results of the effects of soil types (sandy calcaric phaeozem, gleyic phaeozem, and calcic chernozem) and rainfall variations (current and prognosticated rainfall patterns) and their interaction on various parameters in winter wheat. The significant results are shown in bold; Average value = mean value across all growth stages, DAS = days after start, *F* = degree of freedom, *P* = probability values.

Variable	Growth stage	Soil		Rainfall		Soil x Rainfall	
		F	P	F	P	F	P
Wheat growth (cm)							
	DAS 29	18606	**< 0.001**	50874	**< 0.001**	8523	**0.005**
	DAS 59	14788	**0.001**	7503	**0.018**	5434	**0.021**
	DAS 88	16470	**< 0.001**	8400	**0.013**	3350	0.137
	Average value	1066	0.353	0.1	0.754	0.256	0.775
Root production ($g\ m^{-2}$)							
	DAS 8	4432	**0.036**	0.335	0.574	1754	0.215
	DAS 41	0.55	0.591	0.532	0.48	0.164	0.85
	DAS 78	0.495	0.622	2272	0.158	0.906	0.43
	Average value	2146	0.128	1025	0.317	0.395	0.676
Weed abundance (Individuals m^{-2})							
	DAS 6	16751	**< 0.001**	1651	0.223	0.03	0.97
	DAS 53	3471	0.065	0.034	0.855	1065	0.374
	DAS 85	4291	**0.039**	5202	**0.042**	2061	0.17
	Average value	4776	**0.013**	1273	0.265	0.235	0.792
Weed production ($g\ m^{-2}$)							
	DAS 6	4710	**0.031**	0.631	0.442	0.987	0.401
	DAS 53	0.393	0.683	1928	0.19	0.473	0.634
	DAS 85	0.678	0.526	1788	0.206	0.897	0.433
	Average value	2312	0.100	0.019	0.891	0.325	0.724
Mycorrhization (%)							
	DAS 8	3237	0.075	128535	**< 0.001**	1915	0.19
	DAS 41	0.315	0.735	28808	**< 0.001**	0.177	0.84
	Average value	1129	0.337	70588	**< 0.001**	0.425	0.657
LAI ($m^2\ m^{-2}$)							
	DAS 64	1539	0.254	0.65	0.436	0.621	0.554
	DAS 97	0.093	0.911	6860	**0.022**	0.565	0.583
	Average value	1254	0.300	2807	0.104	0.653	0.528
Harvest Index (%)							
	Harvest	13684	**0.001**	30452	**< 0.001**	7717	**0.007**
Grain yield (g $plant^{-1}$]							
	Harvest	6354	**0.013**	5372	**0.039**	1742	0.217
Wheat production [g $plant^{-1}$]							
	Harvest	5236	**0.023**	2257	0.159	2259	0.147
$\delta^{13}C$ old leaves							
	DAS 29	0.693	0.519	9440	**0.01**	0.249	0.783
	DAS 58	0.191	0.829	4831	**0.048**	1338	0.299
	DAS 89	0.059	0.943	7904	**0.016**	1581	0.246
	Average value	0.420	0.659	17733	**< 0.001**	1024	0.367
$\delta^{13}C$ young leaves							
	DAS 89	3583	0.06	10575	**0.007**	1871	0.196
Nitrogen ($\mu g\ g^{-1}$)		0.064	0.938	0.057	0.812	0.005	0.995
Calcium ($\mu g\ g^{-1}$)		0.026	0.975	0.101	0.752	0.009	0.991
Magnesium ($\mu g\ g^{-1}$)		0.182	0.835	2.547	0.121	0.000	1.000
Phosphorus ($\mu g\ g^{-1}$)		0.065	0.937	1.238	0.275	0.140	0.870

Focussing on individual soil types, the results showed that the growth per wheat plant was statistically lower on S soils with the lowest soil moisture content compared with F and T soils (Figure 3.2a, Table 3.1). At tillering (DAS 29), the growth per wheat plant was significantly lower ($P < 0.001$) than that observed during inflorescence emergence (DAS 59) and dough development DAS 88 (Figure 3.2a). At DAS 29 the average wheat height on F soil decreased from 35.1 cm under C rainfall pattern to 30.3 cm under D rainfall pattern, likewise on T soil the decrease was from 33.9 cm to 29.9 cm from C to D climate, respectively while on S soil the growth was almost the same under both rainfall patterns. The average plant height during inflorescence stages significantly increased from C to D treatment, from 49.2 cm to 54.8 cm on S soil and from 55.8 cm to 61.6 cm on T soil, likewise during the dough stages the increase was from 49.9 cm to 54.7 cm and from 56.4 cm to 61.4 cm on S and T soils, respectively (Figure 3.2a). Generally wheat growth was significantly higher under D than C rainfall pattern during inflorescence emergence ($P = 0.013$), as well as during dough development ($P = 0.018$). Wheat growth on F soils, from the inflorescence stages was almost similar under both rainfall patterns (Figure 3.2a).

At mid anthesis (DAS 64), wheat stands under future rainfall scenario had lower LAI on all soil types than under current rainfall (Figure 3.2b). During ripening (DAS 97), average LAI of all soils was 18% lower under the predicted rainfall. S soils during ripening had almost the same LAI under C and D treatments, whereas LAI under D rainfall was significantly lower ($P = 0.022$) on F and T soils (Figure 3.2b).

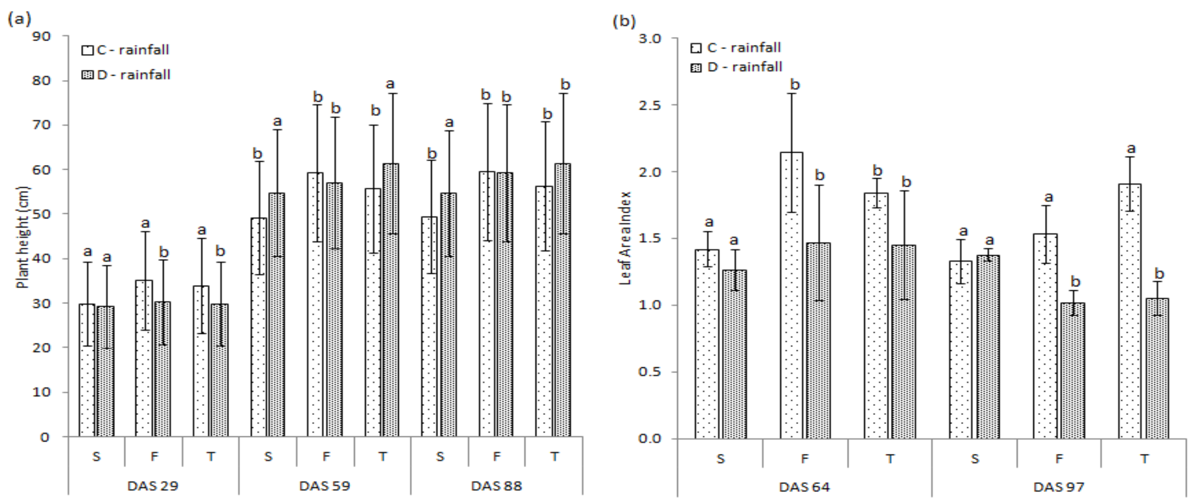

Figure 3.2: Wheat height growth (a) and leaf area index (b) under current (C) and predicted (D) rainfall patterns on sandy calcaric phaeozem (S), gleyic phaeozem (F) and calcic chernozem (T; left graph). Different letters above bars indicate significantly different rainfall effect ($P < 0.05$) within a particular soil type. DAS = days after start; Means ± SD, n = 3.

Across soil types, there was a general decrease in grain yield under the D rainfall pattern (*P* = 0.039, Table 2.3). The grain yield per plant was much lower on S soils than F and T soils (Figure 3.3). T soils had almost similar grain yields under both rainfall patterns, whereas the grain yields on S and F soils under the D treatment were much lower than those observed under the C treatment (Figure 3.3). On S soil the average total grains per lysimeter decreased from 519 g to 381 g, on F soils it decreased from 679 g to 546 g while on T soils the decrease was almost negligible from 667 g to 644 g from the C to D treatment, respectively (Figure 3.3).

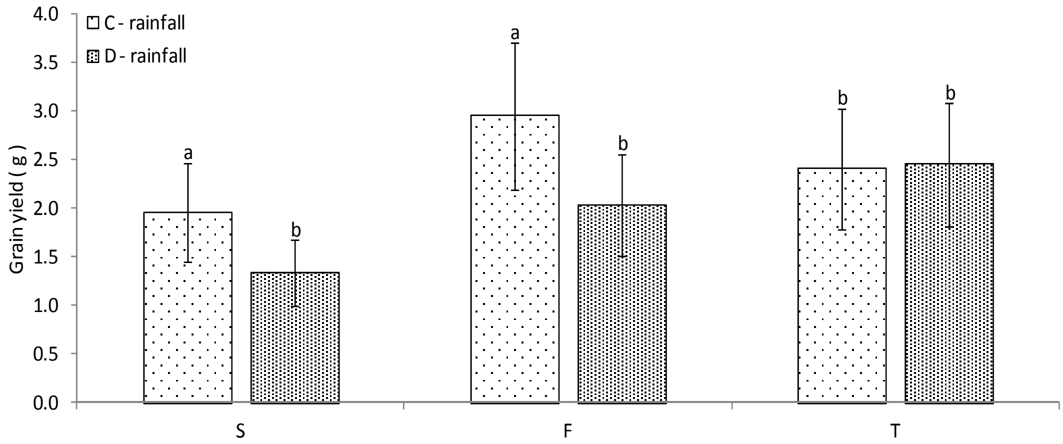

Figure 3.3: Wheat grain yield (in g per plant) under current (C) and predicted (D) rainfall patterns on sandy calcaric phaeozem (S), gleyic phaeozem (F) and calcic chernozem (T) soil types. Different letters above bar pair indicate significantly different rainfall effects (*P* < 0.05) with a particular soil type. Means ± SD, n = 3.

Wheat's biomass production (straw + grain) was significantly affected by soil type but not by rainfall (Table 3.3). The biomass production was much lower on S soils compared to F and T soils under both rainfall pattern (Fig 3.4a). The harvest index (i.e. straw to grain ratio) decreased from 1.76 to 1.28 under the D treatment on S soil. Overall, the harvest index on all soil types under the D treatment was lower than under the C treatment, whereby S soils under the D treatment had the lowest harvest index. On average T soils with the C treatment had the highest harvest index of about 43% (Figure 3.4b).

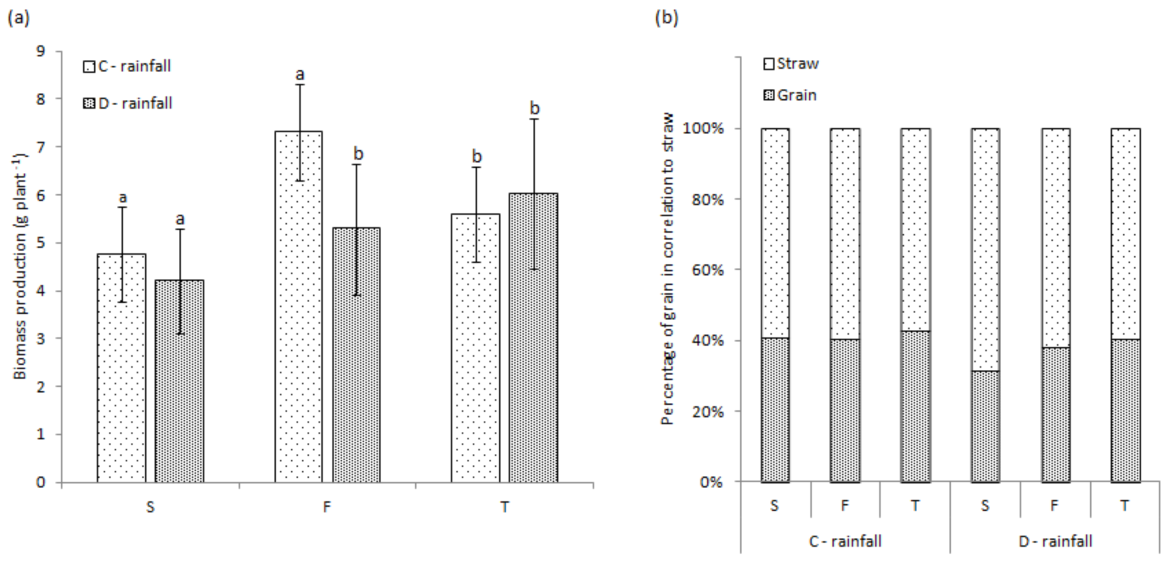

Figure 3.4: Wheat biomass production (a) and harvest index (b) under predicted (D) and current (C) rainfall patterns on sandy calcaric phaeozem (S), calcic chernozem (F) and gleyic phaeozem (T). Different letters above bars indicate significantly different rainfall effects ($P < 0.05$) within a particular soil type. DAS = days after start; Means ± SD, n = 3.

Plant nitrogen, calcium, phosphorus and magnesium content was neither affected by rainfall patterns nor soil types (Table 3.3; Table 3.4).

Table 3.4: Wheat plant nitrogen, calcium, phosphorus and magnesium contents on sandy calcaric phaeozem (S), gleyic phaeozem (F) and calcic chernozem (T) under current (C) and prognosticated (D) rainfall patterns; Mean ± SD, $n = 3$

Soil type	Rainfall	Nitrogen (µg g $^{-1}$)	Calcium (µg g $^{-1}$)	Phosphorus (µg g $^{-1}$)	Magnesium (µg g $^{-1}$)
S	C	2.05 ± 1.30	1.48 ± 0.86	0.25 ± 0.18	0.18 ± 0.02
	D	1.96 ± 1.26	1.38 ± 0.75	0.19 ± 0.15	0.16 ± 0.02
F	C	1.95 ± 1.22	1.49 ± 0.91	0.25 ± 0.16	0.18 ± 0.02
	D	1.79 ± 1.12	1.34 ± 0.78	0.14 ± 0.12	0.16 ± 0.04
T	C	1.86 ± 1.20	1.52 ± 0.94	0.23 ± 0.16	0.18 ± 0.02
	D	1.80 ± 1.67	1.47 ± 0.90	0.20 ± 0.15	0.17 ± 0.03

The highest root production rate at all growth stages was seen on S soils and were significantly different from that observed with F ($P < 0.001$) and T ($P = 0.003$) soils (Figure 3.5a). Root growth was much lower during the grain filling stages (DAS 78) than at earlier growth stages (DAS 6 and DAS 40). Root production during booting (DAS 40) on T soils was almost similar under the C and D rainfall patterns, though it was not significantly different from F and S soils. At an earlier growth stage (DAS 6), root growth on F soils was almost similar under both treatments but was significantly lower compared to S ($P = 0.023$) and T ($P = 0.029$) soils (Figure 3.5a). Root mycorrhization varied from 5 to 25% and was significantly lower with under D compared to C treatment ($P < 0.001$) from germination until harvesting (Figure 3.5b).

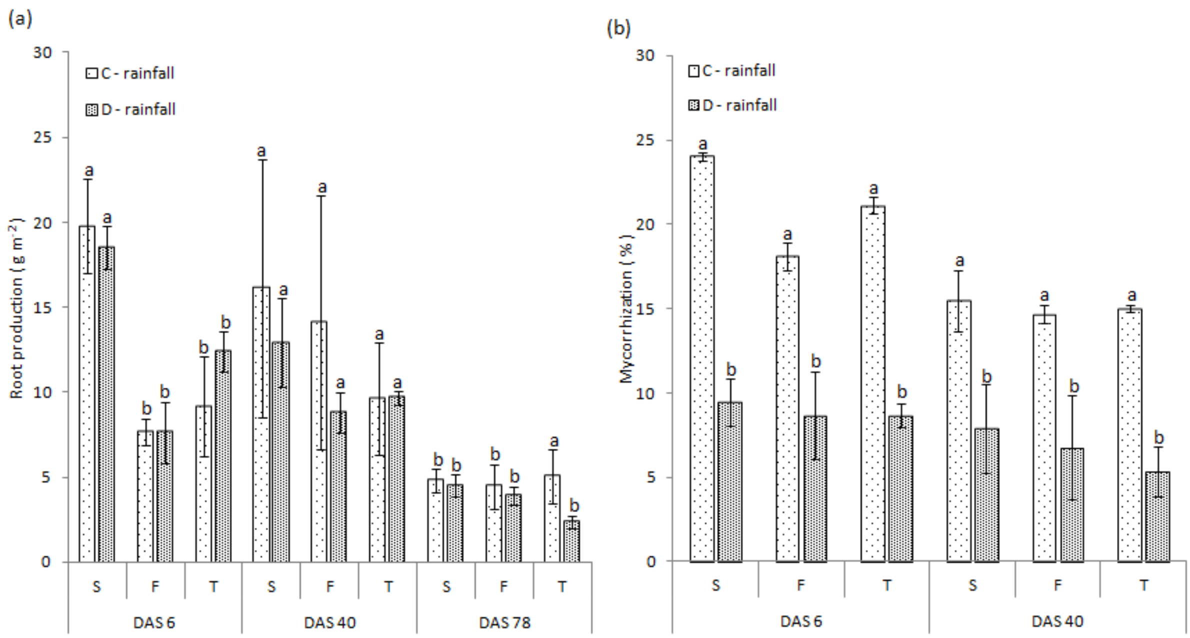

Figure 3.5: Root mass production (a) and mycorrhization (b) of winter wheat stands on sandy calcaric phaeozem (S), gleyic phaeozem (F) and calcic chernozem (T) under current (C) and predicted (D) rainfall patterns. Different letters above bars indicate significantly different rainfall effects ($P < 0.05$) within a particular soil type. DAS = days after start; Means ± SD, n=3.

Both for young and older wheat leaves, the $\delta^{13}C$ values were higher under the D than the C rainfall pattern (Figure 3.6a and Figure 3.6b). At the dough stages (DAS 89), the $\delta^{13}C$ values were smaller than during inflorescence (DAS 58) and tillering (DAS 29) stages (Figure 3.6a). The $\delta^{13}C$ values on T soils were almost similar under the C and D treatments for young leaves, whereas on S and F soils, the values obtained under the D treatment were significantly higher than those obtained with the C treatment (Figure 3.6b).

Wheat biomass production and LAI correlated significantly (r = 0.348, P = 0.004). Wheat plants under D treatments showed a positive significant correlation between grain yields and weed abundance (r = 0.378, P = 0.001), whereas a significant negative correlation (r = -0.274, P < 0.001) was observed under the C treatment (data not shown).

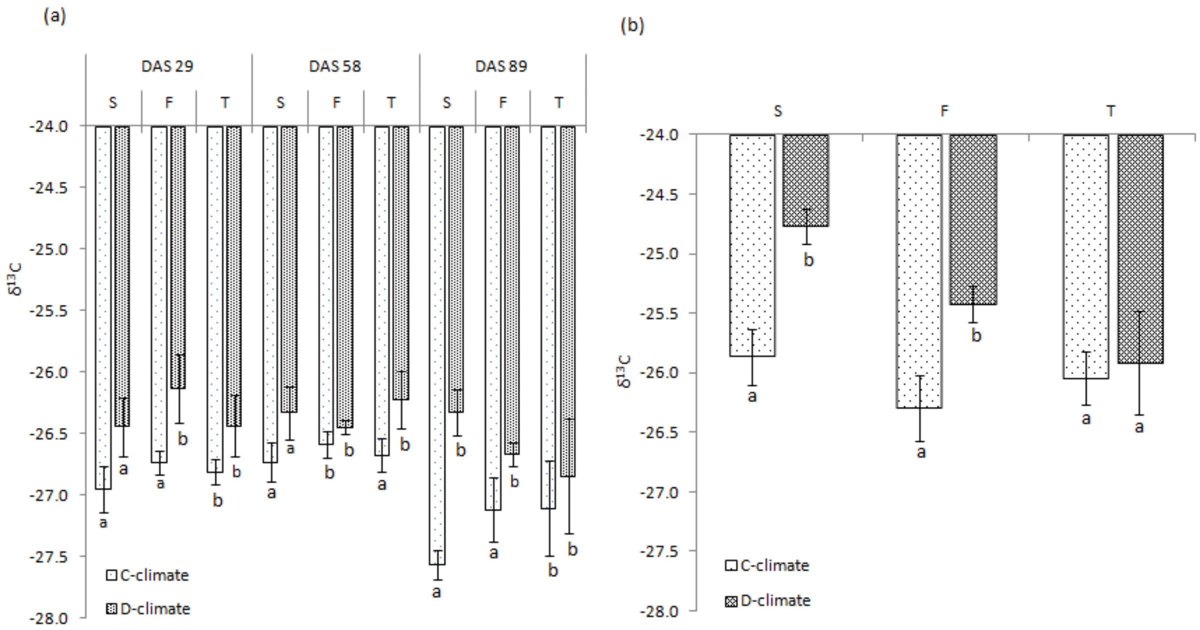

Figure 3.6: Old wheat leaf $\delta^{13}C$ (a) and young wheat leaf $\delta^{13}C$ (b) measured under predicted (D) and current (C) rainfall patterns on sandy calcaric phaeozem (S), gleyic phaeozem (F), and calcic chernozem (T) soil types on three different dates. Different letters above bars indicate significantly different rainfall effects (P < 0.05) within a particular soil type. DAS = days after start; Means ± SE, n =3.

3.5 **Discussion**

The wheat variety *Capo* used in this experiment is known to produce average grain yield even under rather dry conditions (Neacsu, 2011). Nevertheless, its growth and specific yield was significantly reduced under the predicted rainfall scenario, implying that climate change will severely affect its productivity, thus necessitating the breeding of wheat varieties with greater drought resistance.

Higher growth during the inflorescence and dough stages than during tillering (Figure 3a) can be interpreted as a physiological reaction of the plants to acquire more assimilates for the grain filling and ripening stages, explaining the significance of a higher leaf area at these stages. Similar phenological changes were observed by Dodig et al. (2010) for wheat under drought stress. Moreover, results of the current study demonstrate the importance of soil types in altering the response of wheat to climate change. The higher growth and biomass production on soil types with higher clay and silt content (i.e. T and F soils) than on sandy soils in the current study could further be attributed to combined effects of drought stress and reduced nutrient availability, since sandy soils had the lowest water and soil nutrient content resulting in a reduced vegetative growth. Thus, on soil types with reduced water holding capacities and associated nutrient availability like sandy soils a lower wheat production with the future rainfall variation could be anticipated. However, attributing higher growth on F and T soils than S soils to the higher amount of N fertilizer applied on these soil types (Zhu and Chen, 2002) do not seem to be appropriate here as wheat nutrient contents were unaffected by soil types (Table 3.3, Table 3.4).

The reduction in grain yield under future rainfall patterns could be interpreted as a result of the reduced soil water and nutrient availability (Oweis et al. 1998; Schimmack et al. 2004; Masoni et al. 2007; Guo et al. 2012; Razzaghi et al. 2012). Indeed, the significantly higher $\delta^{13}C$ signature of wheat leaves under the D climate confirmed water stress (Elazab et al. 2012). On S and F soils, drought caused an averaged 32% reduction in grain yield, which was similar to a 37% drought-induced reduction in grain yield reported by Dodig et al. (2008). Yield reductions under predicted rainfall patterns in the current experiment were similar to those observed in our previous experiment with field pea (-29%; Tabi Tataw et al. 2014). This similar response of legumes and cereals to rainfall treatments was unexpected because of the different root systems of these crops, implying a broader effect of reduced rainfall on crop production.

Reduction in grain yield during drought was explained by Ahmadi et al. (2009) that reduced precipitation triggers the remobilisation of pre-anthesis metabolites away from the grain and subsequently reduces grain yield. Indeed most studies show that reduced precipitation also reduces yield (Salinger et al. 1995; Alexieva et al 2001; Dodig et al. 2010; Tabi Tataw 2014). Contrarily there are fewer studies where yields were not affected (Patil et al. 2010b) or even increased with future rainfall patterns (Equiza and Tognetti 2002; Stratonovitch et al. 2012¸ Lobell et al. 2014). However most of these experiments were conducted with one soil type only and did not assess the impact of different soil types in triggering rainfall effects, as demonstrated in the current experiment. In the current experiment on deep chernozem soils, grain yield was almost the same for the predicted and current rainfall patterns (Figure 3.3). This could be explained by the fact that this soil type has the highest soil water content and water lost through transpiration and evaporation during drought was easily replaced by absorption from soil water, leaving the yield unaffected. Although in our experiment fertilisation was adjusted in response to soil nutrient analyses, the general reduction in LAI and root growth (Figure 3a and 3b) translated to a decrease in grain yield. This suggests that fertilisation alone will be insufficient to mitigate the response of wheat to future rainfall patterns. These reductions in biomass production with predicted rainfall is particularly important for ecosystem nutrient cycling as less nutrients would be returned under future rainfall scenarios. As a consequence of a specific fertilisation, wheat mineral content in the current study was similar among soil types indicating the high mineral use efficiency of the planted wheat variety (Table 3.3).

The soil type significantly affected root growth during the early crop development due to the necessity of essential mineral nutrients for establishment (Table 3.3). Whereas from the booting stage onward, these mineral nutrients were invested for growth and reproduction, which does not depend solely on the soil type but on other factors, such as the genotype x environment interaction (Dodig et al., 2008), precipitation (Ahmadi et al., 2009; Rezaie and Bannayan, 2012) or CO_2 level (Blumenthal et al., 1996; Wang et al., 2013). The comparatively high root production on sandy soils (Figure 3.5a) can be interpreted as a crops' reaction in order to increase the surface area for water absorption. Wheat growth was stimulated under reduced rainfall on T and S soils at DAS 59 and 88, whereas root growth did not reflect this trend, suggesting more biomass allocation into reproductive and above ground propagative growth than into roots.

Arbuscular mycorrhizal fungi are obligate symbionts which depend on its host carbohydrate for survival. Thus, the almost 50% reduced AMF colonisation rate at predicted rainfall (Figure 3.5b) could be attributed to reduced photosynthetic assimilates caused by drought. It has also been shown that reduced soil water content reduced AMF colonisation (Stahl and Christensen, 1982). On S soils with the highest sand content, the highest reduction was observed confirming the findings of Zaller et al. (2011), whereby higher sand contents improved AMF root colonisation. The reduction in AMF colonisation could also be attributed to the varied amount of fertilizers applied on different soil types to balance soil nutrient status as it is been proven that balanced mineralization reduces AMF density (Xiangui et al. 2012). These reductions in mycorrhization and yields imply that farmers will have to invest more on fertilisers and irrigation schemes in order to achieve sustainable yields under future rainfall conditions.

The $\delta^{13}C$ of all wheat leaves under the D climate was relatively higher, confirming the result of Elazab et al. (2012) that water stress increases the $\delta^{13}C$ of wheat. The increased $\delta^{13}C$ value of all plants under reduced rainfall showed its effectiveness as a physiological tool for assessing water use efficiency. Although the $\delta^{13}C$ values showed that wheat suffered drought stress on all soil types, wheat growth on S and T soils at DAS 59 and DAS 88 differed, probably due to the precise fertilizers applied on these soil types; however these discrepancies need further investigations. Climate change induced rainfall patterns will thus severely reduce crop yield and biomass production on soils with reduced water holding capacities, such as sandy soils, indicating the vulnerability of these soils compared with soils with higher water holding capacities.

3.6 **Conclusions**

The adverse effect of climate change induced rainfall pattern on agroecosystem exceeded remedial agricultural measures like fertilization or wheat's physiological and morphological response. Our results indicated that future rainfall patterns will likely lead to reduced grain yields, biomass production and AMF colonisation of wheat. If future wheat production aims to respond to the increase of the human population, additional measures like the use of more drought tolerant varieties coupled with irrigation programmes might be necessary. The similar yield reduction of crops with different root morphology to future rainfall pattern further indicated a more general response across different crop species. Our results further suggested that soil types with higher water and/or nutrient availabilities, such as gleyic phaeozem, could better mitigate the adverse effects of climate change on wheat than more sandy soil types. Clearly, predictions on the response of agroecosystems to climate change should also consider the role of soil types in triggering responses to climate change.

3.7 **Acknowledgements**

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4. Future rainfall variations reduce abundances of aboveground arthropods in model agroecosystems with different soil types

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4.1 **Abstract**

Climate change scenarios for Central Europe predict less frequent but heavier rainfalls and longer drought periods during the growing season. This is expected to alter arthropods in agroecosystems that are important as biocontrol agents, herbivores or food for predators (e.g. farmland birds). In a lysimeter facility (totally 18 3m^2-plots), we experimentally tested the effects of long-term past vs. prognosticated future rainfall variations (15% increased rainfall per event, 25% more dry days) according to regionalized climate change models from the Intergovernmental Panel on Climate Change (IPCC) on aboveground arthropods in winter wheat (*Triticum aestivum* L.) cultivated at three different soil types (calcaric phaeozem, calcic chernozem and gleyic phaeozem). Soil types were established 17 years and rainfall treatments one month before arthropod sampling; treatments were fully crossed and replicated three times. Aboveground arthropods were assessed by suction sampling, their mean abundances (± SD) differed between April, May and June with 20 ± 3 m^{-2}, 90 ± 35 m^{-2} and 289 ± 93 individuals m^{-2}, respectively. Averaged across sampling dates, future rainfall reduced the abundance of spiders (Araneae, -47%), cicadas and leafhoppers (Auchenorrhyncha, -39%), beetles (Coleoptera, -52%), ground beetles (Carabidae, -41%), leaf beetles (Chrysomelidae, -64%), spring tails (Collembola, -58%), flies (Diptera, -73%) and lacewings (Neuroptera, -73%) but increased the abundance of snails (Gastropoda, +69%). Across sampling dates, soil types had no effects on arthropod abundances. Arthropod diversity was neither affected by rainfall nor soil types. Arthropod abundance was positively correlated with weed biomass for almost all taxa; abundance of Hemiptera and of total arthropods was positively correlated with weed density. These detrimental effects of future rainfall varieties on arthropod taxa in wheat fields can potentially alter arthropod-associated agroecosystem services.

4.2 **Introduction**

Climate change will very likely cause a seasonal shift in precipitation in Central Europe resulting in less frequent but more extreme rainfall events during summer but increased precipitation during winter (IPCC, 2007; IPCC, 2013). Regionalisations of these climate models for eastern parts of Central Europe prognosticate little changes or even slight decreases in annual rainfall amounts until 2100 (Eitzinger et al., 2001b; Kromp-Kolb et al., 2008). Indeed, so far for eastern Austria no change in total yearly precipitation was measured during the last decades (Formayer and Kromp-Kolb, 2009). The direction, magnitude and variability of such changes in precipitation events and their effects on ecosystem functioning will depend on how much the change deviates from the existing variability and the ability of ecosystems and inhabiting organisms to adapt to the new conditions (Beier et al., 2012).

In many natural and agriculturally managed ecosystems arthropods are the most abundant and diverse group of animals (Altieri, 1999; Speight et al., 2008). Abundances of epigeic arthropods in an arable field can reach thousands of individuals m^{-2} comprising hundreds of species (Romanowsky and Tobias, 1999; Östman et al., 2001; Pfiffner and Luka, 2003; Batary et al., 2012; Frank et al., 2012; Querner et al., 2013). These arthropods play important ecological roles as herbivores and detritivores (Seastedt and Crossley, 1984), are valued for pollination, seed dispersal and predation (Steffan-Dewenter et al., 2001), are important predators and parasitoids (Thies et al., 2003; Drapela et al., 2008; Zaller et al.,2008b; Zaller et al., 2009) and are a food source for many vertebrates and invertebrates (Price, 1997; Brantley and Ford, 2012; Hallmann et al., 2014). As arthropods can have a strong influence on nutrient cycling processes (Seastedt and Crossley, 1984), they are also very important for ecosystem net primary production (Abbas and Parwez, 2012). Predicted longer drought intervals between rainfall events will increase drought stress for crops while changes in the amount and timing of rainfall will affect yields and the biomass production of crops (Eitzinger et al., 2001a; Alexandrov et al., 2002; Thaler et al., 2008). These changes in vegetation structure and quality will also affect associated arthropods (Andow, 1991). Moreover, it has also been shown that changes in the magnitude and variability of rainfall events is likely to be more important for arthropods than changes in annual amounts of rainfall (Curry, 1994; Speight et al., 2008; Singer and Parmesan, 2010). Most studies investigating potential effects of climate change on arthropods have focused on the effects of changes in atmospheric CO_2 concentrations or temperature rather than precipitation (e.g., Cannon, 1998; Andrew and Hughes, 2004; Hegland et al., 2009; Hamilton et al., 2012). However, changes in variations of rainfall are likely to have a greater effect on species' distributions than are changes in temperature, especially among rare species (Elmes and Free, 1994).

Surprisingly, very few studies investigated the effects of different rainfall variations on aboveground arthropod abundance in arable agroecosystems, although arable land is ecologically important in terms of its diverse arthropod fauna (Frampton et al., 2000; Tscharntke et al., 2005; Drapela et al., 2008) and its interaction with natural ecosystems in a landscape matrix (Tscharntke and Brandl, 2004; Frank et al., 2012; Balmer et al., 2013; Coudrain et al., 2014). Results from studies investigating the effects of rainfall variations on arthropods are not consistent ranging from increased spider activity to a reduced activity of Collembola under reduced rainfall (Lensing et al., 2005) while others showed little influence of rainfall on spiders (Buchholz, 2010). It also appears that even short rainfall events in spring can influence various groups of farmland arthropods for the following months (Frampton et al. 2000).

To the best of our knowledge, no study assessed the effects of rainfall variations on arthropods in wheat, one of the most important cereal crops worldwide. Moreover, experiments studying the effects of precipitation on ecosystems are usually conducted at different locations with different soil types, thus confounding location with soil types and making it impossible to test to what extent soil types can potentially buffer rainfall variations on ecosystem processes (Beier et al., 2012). The few studies investigating arthropod abundance in different soil types found a significant difference in soil fauna abundance and diversity (Loranger-Merciris et al., 2007) or invertebrate community composition between different soil types (Ivask et al., 2008; Tabi Tataw et al., 2014).

Hence, the objectives of the current study were to: (1) To examine effects of different rainfall variations on the abundance of aboveground arthropods in winter wheat, (2) to assess to what extent different soil types alter potential responses of aboveground arthropods to rainfall variations. The investigations were based on the hypotheses that differences in the amount and variability of rainfall alter the structure of winter wheat stands by either affecting growth of crops and/or weeds (Porter and Semenov, 2005) and consequently affecting the abundance and diversity of arthropods (Duelli and Obrist, 2003; Menalled et al., 2007). As the composition of arthropod communities changes during the season we expected that different arthropod taxa would be differently affected by rainfall variations (Price et al., 2011). Moreover, different moisture sensitivities/drought tolerances of arthropod taxa (Finch et al., 2008) will be affected by soil types with different water holding capacities and soil types will also modify the growth and structure of vegetation that will interact with rainfall variations in affecting arthropods.

4.3 **Materials and methods**

4.3.1 Study Site

The experiment was carried out in the lysimeter experimental facility of the Austrian Agency for Health and Food Safety (AGES), in Vienna, Austria (northern latitude 48˚15’11’’, eastern longitude 16˚28’47’’) at an altitude of 160 m above sea level. The facility is located in a transition area of the Western European oceanic (mild winters, wet, cool summer) and the Eastern European continental climatic area (cold winters, hot summers) ecologically referred to as the Pannonium region. Long-term mean annual precipitation at this site is 550-600 mm at a mean air temperature of 9.5 ˚C (Danneberg et al., 2001).

The lysimeter facility was established in 1995 and consists of 18 cylindrical vessels made of stainless steel each with a surface area of 3.02 m² and a depth of 2.45 m (Figure 4.1). The lysimeters are arranged in two parallel rows with nine lysimeter plots in each row; one row was subjected to current rainfall the other row to prognosticated rainfall. Within each row three soil types were randomized to ensure replicates of each soil type in each row (see below for more details on treatment factors); each treatment was replicated three times (n=3).

Figure 4.1: Experimental winter wheat plots containing three different soil types (calcaric phaeozem, calcic chernozem, gleyic phaeozem) subjected to long-time and prognosticated rainfall variations according to regionalized climate change models.

4.3.2 Experimental Treatments

4.3.2.1 Soil types

In 1995, the lysimeters were filled with three different soil types representing around 80% of the agriculturally most productive area in Austria (region Marchfeld; east of Vienna, Austria): calcaric phaeozem (S), calcic chernozem (T), and gleyic phaeozem (F; soil nomenclature after World Soil Classification, FAO, 2002). The soil material was carefully excavated from their native sites in 10 cm layers and filled into the lysimeter vessels retaining their original bulk densities of 1.4 g cm^{-3} (Danneberg et al., 2001). See Tabi Tataw et al. (2014) for further details on the soil characteristics. Briefly, the calcic chernozem and the calcaric phaeozem have a fully developed AC-profile, emerging from carbonate-fine siliceous material. The thickness of the A horizon is at least 30 cm, the humus form is mull with both 4.9% humus content (Nestroy et al., 2011). The calcic chernozem is moderately dry, the calcaric phaeozem is dry; both soil types consist of fine sediment to silt fine sand (Danneberg et al., 2001). The gleyic phaeozem is a soil of former hydromorphic sites with 2.1% humus content as mull; the fully developed AC-profile and the thickness of the A-horizon is at least 30 cm thick (Nestroy et al., 2011). This gleyic phaeozem is well supplied with water and consists of fine sediment to silt fine sand; its high lime content, gives this soil type neutral to slightly alkaline pH. Mean profile water contents are 375 mm, 595 mm and 550 mm for S, T and F soil, respectively.

4.3.2.2 Rainfall scenarios

Starting in 2011, the lysimeters were subjected to two rainfall regimes, one based on past local observations (“curr. rainfall”) and one based on a regionalization of the IPCC 2007 climate change scenario A2 for the period 2071-2100 (“progn. rainfall”; IPCC, 2007). Both the current and the future precipitation variations were calculated using the software LARS-WG (Version 3.0; Semenov and Barrow, 2002). In contrast to classic approaches using directly the projected climate time series as model input our approach with LARS-WG used only the delta values (Hoffmann and Rath, 2012; Hoffmann and Rath, 2013). The current long-term rainfall variations was based on the precipitation amount and frequency for a location in about 10 km distance from the study site (village of Großenzersdorf) between the years 1971-2000. The future rainfall scenario for the year 2071-2100 is based on the local climatology and the climate change signal from the mean of the regional climate model scenarios from the EU-project ENSEMBLES (Christensen and Christensen, 2007). This stochastic weather generator LARS-WG was used to transfer the derived local climate change signals to daily precipitation rates. To exclude natural rainfall the lysimeters were covered with a 5 m high roof of transparent plastic foil from March until December in each year, all sidewalls were open allowing ventilation and free movement of animals (Figure 4.1). During winter the facility was uncovered and all lysimeters received natural precipitation. Rainfall amounts (tap water) according to the model calculations were applied to nine lysimeters in a row using an automatic sprinkler system. Rainfall treatments started on 22 March 2012, until the harvest (see below) the last arthropod sampling on 18 June 2012 the curr. rainfall plots received 156.4 mm and the progn. rainfall plots 136.3 mm irrigation water (-13% less amount of rain). Averaged over the study period, the curr. rainfall plots received 3.7 mm per rain event vs. 3.2 mm per event for the progn. rainfall plots (13% difference); progn. rainfall had 25% more dry days than curr. rainfall treatments (Figure 2a). Irrigation was always performed in early morning at low sunlight; side walls of the transparent cover were automatically closed only during irrigation when wind speed was > 2.5 m s^{-1}. Weather stations (Delta-T Devices, Cambridge, UK) were installed between and outside of the lysimeters for monitoring air temperature (Figure 4.2b), wind speed and direction, global radiation and rainfall. Soil matric potential (ψm, also called soil water potential) was measured using three pF sensors per lysimeter installed in 10 cm depth (ecoTech Umwelt-Messsysteme GmbH, Bonn, Germany). The soil matric potential was automatically measured every 15 minutes and represents the pressure it takes to pull water out of soil and increases as the soil gets drier. Technically the pF sensor measure heat capacity in a porous ceramic tip that contains a heating element and temperature sensors. The correlations of pF values and measured heat capacity is achieved by a sensor-specific calibration curve (www.ecotech-bonn.de/en/produkte/Bodenkunde/pF-meter.html). The matric potential changes with the soil water content and commonly varies between different soil types. Soil matric potential is usually expressed in pF units which is the log of the soil tension in hPa (e.g. log of 10,000 hPa is equal to pF = 4). Daily pF values were calculated by averaging the individual readings of each lysimeter. Field capacity of soil types was pF = 1.8, permanent wilting point for crops pF = 4.2.

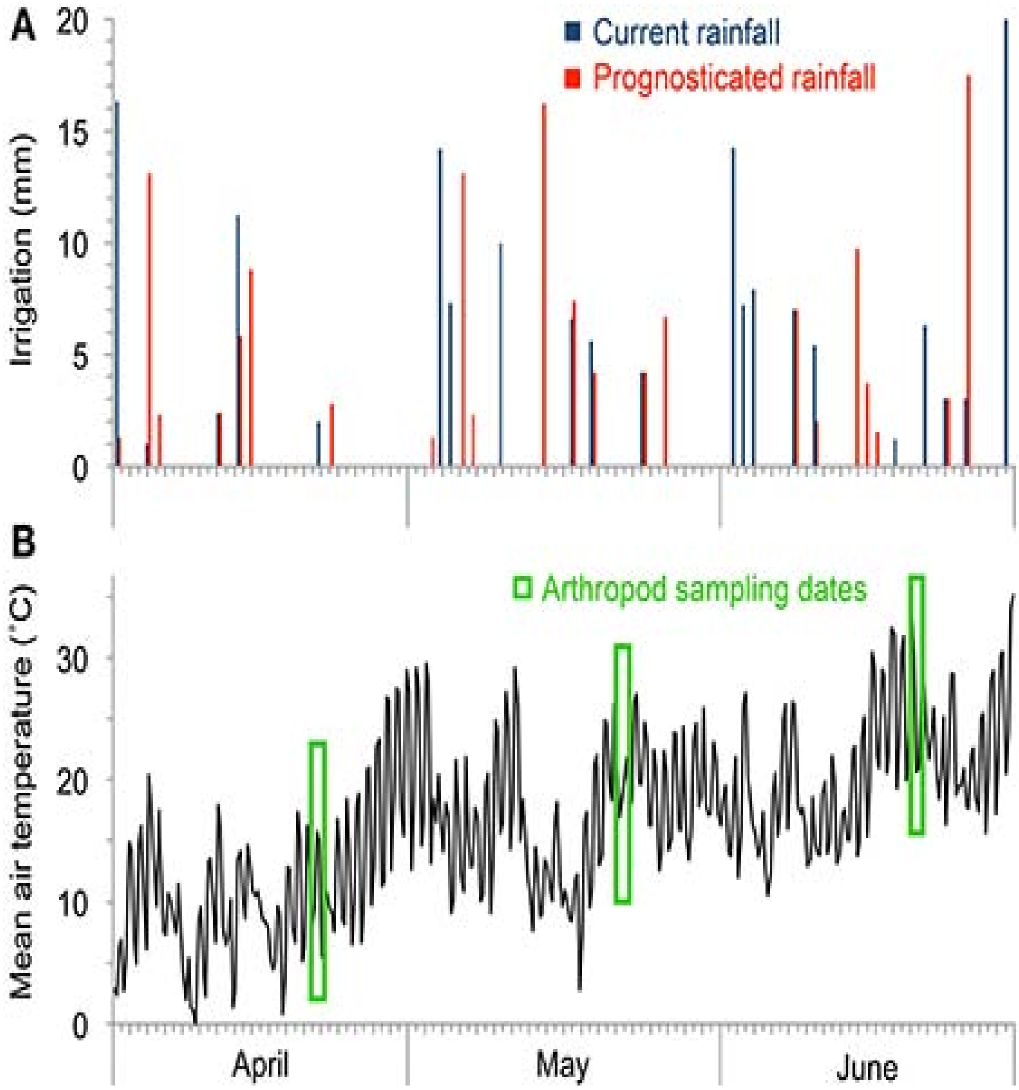

Figure 4.2: Amount of applied rainfall applied onto treatment plots (a) and mean air temperature (2 m above ground) during the course of the experiment.

4.3.3 Crop wheat

Winter wheat (*Triticum aestivum* L. cv. Capo) was sown at a density of 400 seeds m^{-2} on 11 October 2011 after the precrop white mustard. Weeds in the treatment plots were controlled by spraying a mixture of the herbicides Express-SW (active ingredient: tribenuronmethyl; Kwizda Agro, Vienna, Austria) at 25 g ha^{-1}, Starane XL (a.i.: fluroxypyr and florasulam; Dow AgroSciences, Indianapolis, IN, USA) at 750 ml ha^{-1} and water at 300 l ha^{-1} on 30 March 2012. Fertilization was applied according to recommendations for farmers after soil analyses (Table 4.1).

Table 4.1: Fertilization of winter wheat crops in lysimeter plots with different soil types (S – calcaric phaeozem, F – gleyic phaeozem, T - calcic chernozem) in lysimeters.

Fertilizer type	Fertilizer amount per soil type ($kg\ ha^{-1}$)			Date
	S	*F*	*T*	
P_2O_5–Triplesuperphosphate	0	55	55	11 October 2011
K_2O–Kali 60	40	0	0	11 October 2011
N–NAC (Nitramoncal 27%)	25	40	40	08 March 2012
N–NAC (Nitramoncal 27%)	30	40	40	12 April 2012
N–NAC (Nitramoncal 27%)	35	50	50	16 May 2012

Wheat growth was measured from the soil surface to the tip of the spike on 10-15 marked crop plants per lysimeter around the arthropod sampling dates (see below). Additionally, the number of weed individuals per lysimeter (weed density) was counted during these dates. Lysimeters were harvested on 5 July 2012 by cutting all vegetation (winter wheat and weeds) by hand at 5 cm above surface. Crop and weed plants were separated, crop plants devided in straw and spikes and everything was weighed after drying at 50°C for 48 hours. In order to avoid boundary effects all measurements on crops were conducted in the central area of each lysimeter up to 20 cm distance from the edge of each lysimeter.

4.3.4 Arthropod sampling

All arthropods dwelling on the soil surface and on the vegetation in each of the 18 lysimeters were collected using a commercial garden vacuum (Stihl SH 56-D, Dieburg, Germany) equipped with an insect sampling net. For sampling, the suction tube was carefully moved between the crop plants across the lysimeter area in order to avoid that the sampling efficiency is too much influenced by vegetation structure, height and density (Southwood, 1978; Brook et al., 2008). To impede the escape of the arthropods, a 1 m high barrier made of plastic film was attached to the borders of the lysimeter vessels. Suction sampling was performed for 5 min in each lysimeter; afterwards, each plot was thoroughly inspected for another 20 min for remaining arthropods. This sampling procedure was performed on April 24-25, May 22-23 and June 19, 2012. Air temperature during arthropod sampling dates was on average 18.2˚C on the first sampling event, 23.3˚C on the second, and 30.4˚C on the third sampling event (Figure 4.2). Sampling was carried out only when the vegetation and soil surface was dry. After collection, the arthropods were sorted out, cleaned from attached soil, preserved in 80% ethylene alcohol and identified at the level of taxonomic order or families (Bellmann, 1999; Bährmann and Müller, 2005). Taxa with less than 0.3 individuals m^{-2} were lumped together in a group of rare individuals. Arthropod abundance was expressed in individuals m^{-2} and relative abundance of the identified groups to the arthropod community present in each lysimeter was calculated in percentage based on the m^{-2} values.

4.3.5 Statistical Analyses

First, all measured parameters were tested for normal distribution and variance homogeneity using the Kolmogorov-Smirnov-Test and Levene-Test, respectively. The two parameters that did not meet the requirements of parametric statistics, Hemiptera and total individuals from the May sampling, were Boxcox transformed. Secondly, for all arthropod abundance parameters, repeated measurement analysis of variance (ANOVA) with the factors Rainfall (two levels: longtime current rainfall variations vs. prognosticated rainfall variations), Soil type (three levels: F, S and T soils) and Sampling date (three dates: April, May, June sampling) were conducted. Additionally, to test for treatment effects at each sampling date separately, two-factorial ANOVAs with the factors Rainfall and Soil type and their interactions were conducted for arthropod taxa and for soil pF values. As a measure of community diversity the Simpson and the Shannon index were calculated and also tested with a two-factorial ANOVA for each sampling date separately (Rosenzweig, 1995). Pearson correlations were performed between arthropod abundance, crop height, crop and weed biomass and weed abundance. All statistical analyses were performed using the freely available software "R" (version 3.0.2; R Core Team, 2013). Statistical results with $P > 0.50 < 0.10$ were considered marginally significant. Values within the text are means ± SD.

4.4 Results

Soil matrix potential was significantly affected by rainfall ($P < 0.001$) and soil types ($P < 0.001$; rainfall x soil type interaction: $P < 0.001$) with sandy soils showing the lowest and F and T soil the highest pF values under both rainfall treatments (Figure 3.3).

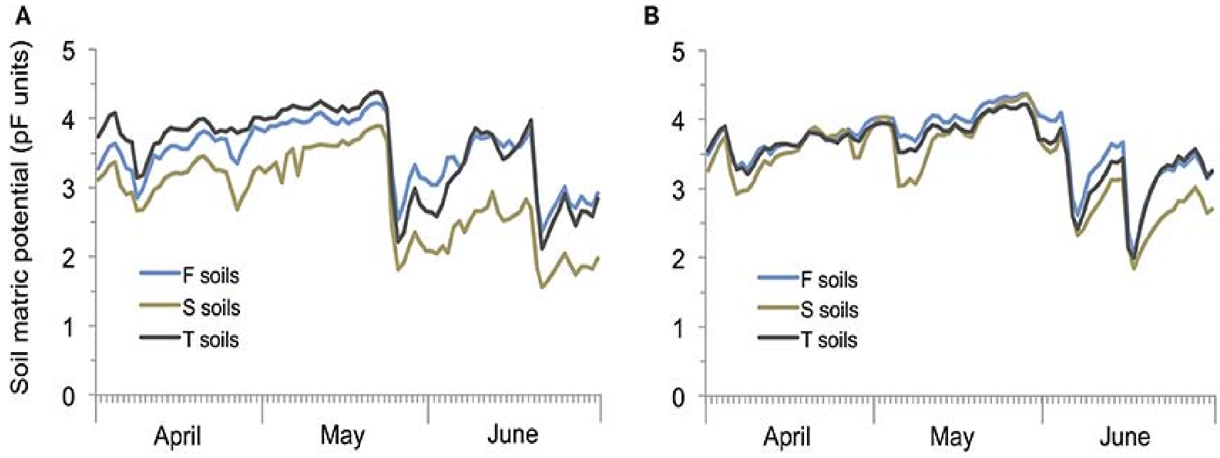

Figure 4.3: Mean soil matric potential in pF units in winter wheat cultivated under current (a) and prognosticated rainfall variations (b) at the different soil types calcaric phaeozem (S), calcic chernozem (T) and gleyic phaeozem (F).

Arthropod abundances differed highly significantly between sampling dates; rainfall variations significantly affected arthropod abundances at different sampling dates (i.e., rainfall x sampling date interaction; repeated measures ANOVA, Table 3.2, Figure 4.4). Averaged across rainfall variations and soil types total arthropod abundance in April was 20.38 ± 3.24 m^{-2}, in May 89.62 ± 34.74 m^{-2} and in June 289.23 ± 92.84 m^{-2} (Figure 4.4). Overall, Hymenoptera was the dominant order in April; Hemiptera, Hymenoptera and Acari were dominant in May and Hemiptera were the most dominant group in June; especially the abundance of Hemiptera, Collembola and Acari increased from April to June.

Table 4.2: Summary of repeated measurement ANOVA results of the influence of rainfall patterns (current and predicted rainfall), soil types (calcaric phaeozem, calcic chernozem and gleyic phaeozem) and sampling date (April, May, June 2012) on total abundance of arthropods in winter wheat. Significant effects are in bold.

Factor	*F*	*P*
Rainfall	4.36	0.059
Soil type	0.04	0.961
Sampling date	20.87	**<0.001**
Rainfall × Soil type	1.00	0.398
Rainfall × Sampling date	6.33	**0.006**
Soil type × Sampling date	0.39	0.815
Rainfall × Soil type × Sampling date	0.44	0.776

Significant effects are in bold.

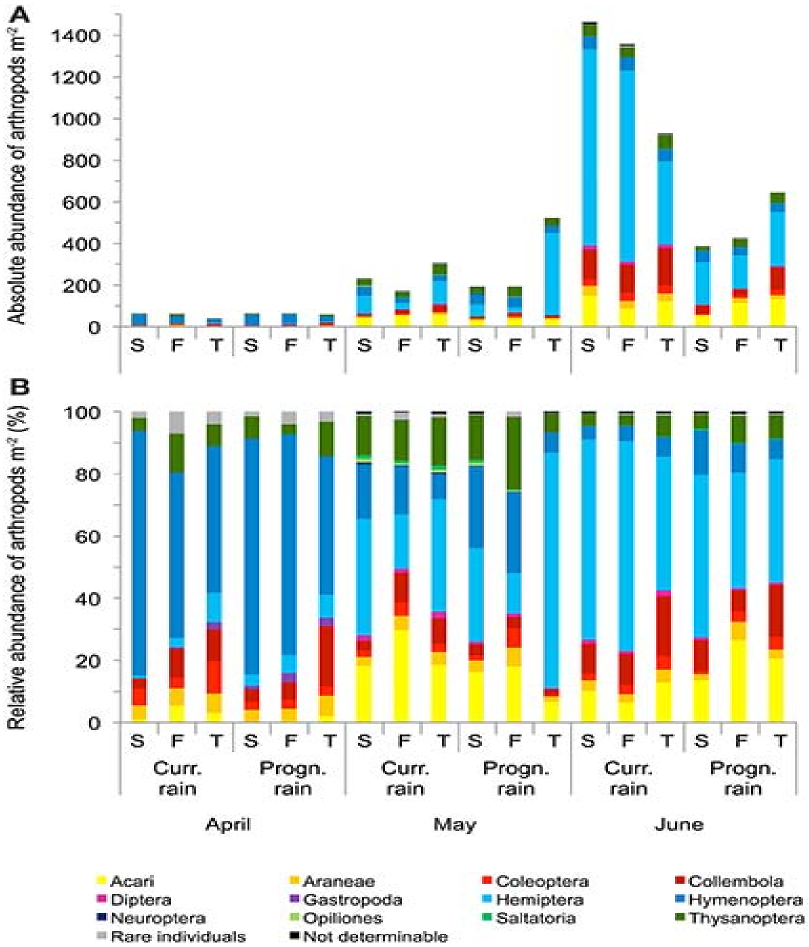

Figure 4.4: Mean absolute (a) and relative (b) abundance of arthropods per m² at the three sampling dates in winter wheat cultivated under current and prognosticated rainfall variations at the different soil types calcaric phaeozem (S), calcic chernozem (T) and gleyic phaeozem (F).

When analyzing the arthropod abundances separately for each sampling date using two-way ANOVAs, prognosticated rainfall in April significantly reduced abundances of Gastropoda by 69% and of Auchenorrhyncha by 61% (Table 4.3, Figure 4.4). In May, prognosticated rainfall significantly reduced Collembola by 53%, Diptera by 59%, Neuroptera by 73% and Saltatoria by 70% (Table 4.3, Figure 4.4). In April and May, soil types had no effect of the abundance of arthropods (except for the group of not determinable arthropods; Table 4.3). In June, prognosticated rainfall significantly reduced Araneae by 56%, Auchenorrhyncha by 47%, Coleoptera and Collembola each by 62%, Chrysomelidae by 66%, Diptera by 77% and total individuals by 61% (Table 4.3, Figure 4.4). All other arthropod taxa were not affected by rainfall. In June, soil types had no effect on arthropod abundance except for Auchenorrhyncha (Table 4.3).

Table 4.3: Summary of ANOVA results of the influence of rainfall patterns (long time current vs. prognosticated rainfall patterns) and different soil types (calcaric phaeozem, calcic chernozem and gleyic phaeozem) on abundance of arthropods in winter wheat at different sampling dates. No interaction between rainfall patterns and soil type were detected (except Saltatoria in May P = 0.030). Data for individual sampling dates were analysed using two ANOVAs, data across dates were analyses using repeated measurement ANOVAs. Significant effects are in bold.

	April sampling				May sampling				June sampling				Across dates			
Arthropod	**Rainfall**		**Soil types**		**Rainfall**		**Soil types**		**Rainfall**		**Soil types**		**Rainfall**		**Soil types**	
Taxa	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Acari	1.274	0.281	0.673	0.529	2.043	0.178	0.228	0.800	0.298	0.595	0.234	0.795	0.992	0.339	0.347	0.714
Araneae	0.000	1.000	0.072	0.931	0.000	1.000	3.276	0.073	11.927	**0.005**	0.056	0.946	12.844	**0.004**	0.367	0.700
Coleoptera	1.960	0.187	0.270	0.768	0.041	0.843	0.985	0.402	21.519	**0.001**	3.227	0.075	14.757	**0.002**	2.999	0.088
Carabidae	4.050	0.067	1.050	0.380	3.559	0.084	0.912	0.428	0.966	0.345	0.490	0.624	6.169	**0.029**	1.518	0.258
Chrysomelidae	0.333	0.574	1.000	0.397	0.125	0.712	1.000	0.397	15.591	**0.002**	2.187	0.155	16.248	**0.002**	2.624	0.113
Collembola	0.865	0.371	2.758	0.103	6.019	**0.030**	2.480	0.125	10.219	**0.008**	1.750	0.215	13.750	**0.003**	2.919	0.093
Diptera	2.286	0.156	1.000	0.397	5.831	**0.032**	1.241	0.324	11.794	**0.005**	0.240	0.791	13.945	**0.003**	0.426	0.663
Gastropoda	6.750	**0.023**	2.583	0.117	0.152	0.704	4.581	**0.033**	1.333	0.271	2.083	0.167	0.107	0.749	3.663	0.057
Hemiptera	1.768	0.208	2.268	0.146	0.639	0.440	1.680	0.227	4.403	0.058	0.342	0.717	2.495	0.140	0.026	0.975
Heteroptera	0.000	1.000	0.250	0.783	0.305	0.591	1.622	0.238	0.000	1.000	0.906	0.430	0.152	0.704	1.570	0.248
Auchenorrhyncha	5.042	**0.044**	3.792	0.053	3.018	0.108	0.031	0.969	10.670	**0.007**	4.227	**0.041**	8.119	**0.015**	2.016	0.176
Hymenoptera	0.211	0.655	1.609	0.240	1.267	0.282	0.616	0.556	1.727	0.213	0.190	0.830	0.019	0.894	1.111	0.361
Not determinable	0.133	0.721	1.233	0.326	0.563	0.468	7.000	**0.010**	3.879	0.072	0.010	0.990	4.196	0.063	0.036	0.965
Neuroptera	–	–	–	–	7.111	**0.021**	0.778	0.481	0.143	0.712	1.000	0.397	–	–	–	–
Opiliones	1.333	0.271	2.333	0.139	2.128	0.170	1.340	0.298	4.500	0.055	0.722	0.506	3.641	0.081	0.323	0.730
Rare individuals	0.590	0.457	2.967	0.090	1.393	0.261	1.877	0.195	4.440	0.057	1.908	0.191	2.701	0.126	3.665	0.057
Saltatoria	1.000	0.337	2.250	0.148	12.893	**0.004**	1.750	0.215	0.098	0.760	1.390	0.286	2.691	0.127	2.161	0.158
Thysanoptera	0.000	1.000	0.247	0.785	0.111	0.744	1.192	0.337	3.499	0.086	1.319	0.304	2.626	0.131	3.031	0.086
Total individuals	0.268	0.614	0.552	0.590	0.237	0.636	0.600	0.565	6.612	**0.024**	0.076	0.930	Detailled results in **Table 2**			

No interaction between rainfall patterns and soil type were detected (except Saltatoria in May P = 0.030). Data for individual sampling dates were analyzed using two ANOVAs, data across dates were analyzed using repeated measurement ANOVAs. Significant effects are in bold.

– No data available for this date.

Considering the relative abundance (i.e., percentage contribution to arthropod community) of the identified arthropod groups for each sampling date, rainfall variations significantly affected Collembola (P = 0.036) and Neuroptera (P = 0.041) in May and Diptera (P = 0.041) in June; with the exception of the relative abundance of rare individuals in April (P = 0.027) the composition of arthropod communities was not affected by soil types (Figure 3.4). Across sampling dates, absolute abundance of Araneae (-43%), Coleoptera (-48%), Carabidae (-41%), Chrysomelidae (-64%), Collembola (-58%), Diptera (-75%), Auchenorrhyncha (-39%) and Neuroptera (-73%) were significantly reduced under prognosticated rainfall, also total arthropod abundance were marginally significantly lower under prognosticated rainfall than under current rainfall (Table 4.3, Figure 4.5). Only the abundance of Gastropoda increased by 69% in the prognosticated rainfall compared to current rainfall (Figure 3.6). There was no effect of soil types on any of the identified arthropod groups across sampling dates (Table 3.3, Figure 3.6). Considering the relative abundances across sampling dates, only the relative abundance of Diptera (P = 0.027) and Gastropoda (P = 0.031) were significantly affected by rainfall; soil types only significantly affected the relative abundance of rare individuals (P = 0.010). Hemiptera showed the highest relative abundance in all fields (Figure 3.6). Rainfall variations and soil types had no effect on the diversity indices of arthropod communities (data not shown).

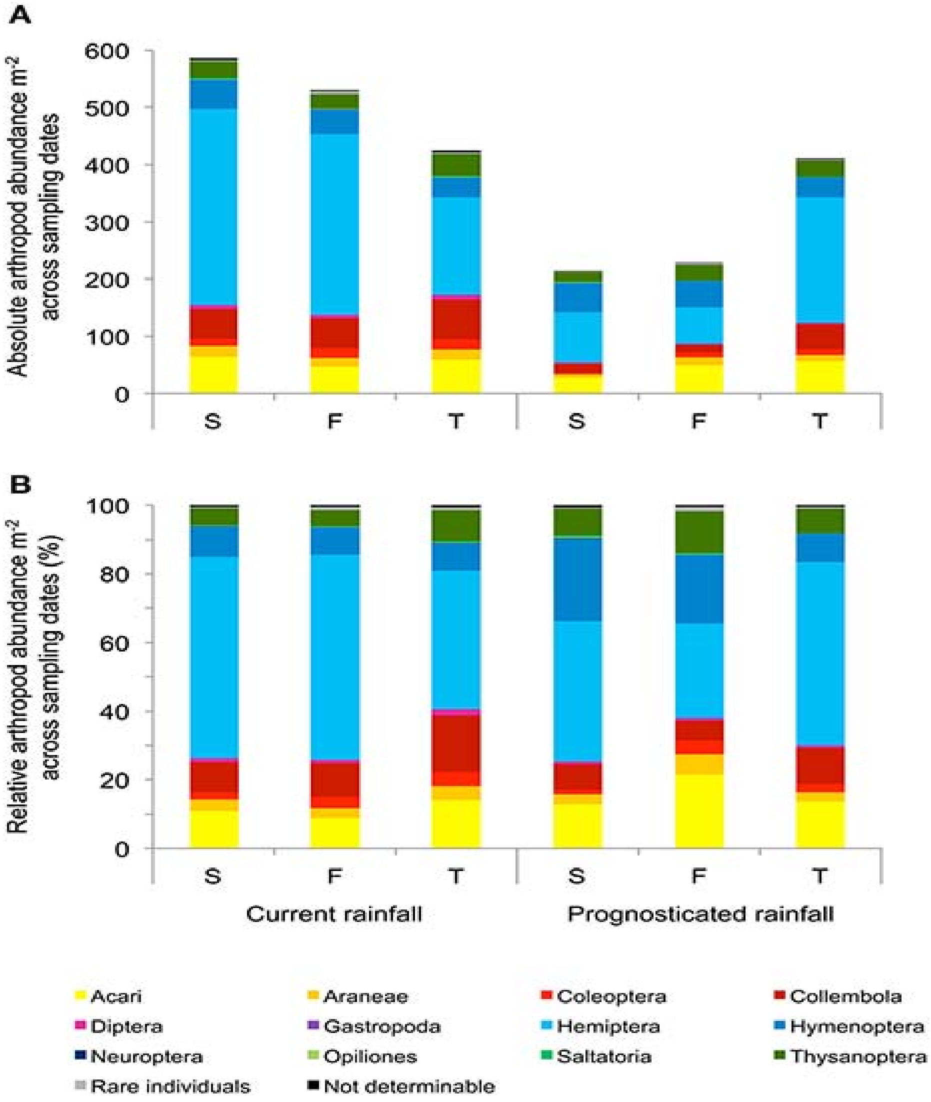

Figure 4.5: Mean absolute (a) and relative (b) abundance of arthropods per m² across the three sampling dates (April, May, June) in winter wheat cultivated under current (C) and predicted (D) rainfall variations at the different soil type’s calcaric phaeozem (S), calcic chernozem (T) and gleyic phaeozem (F).

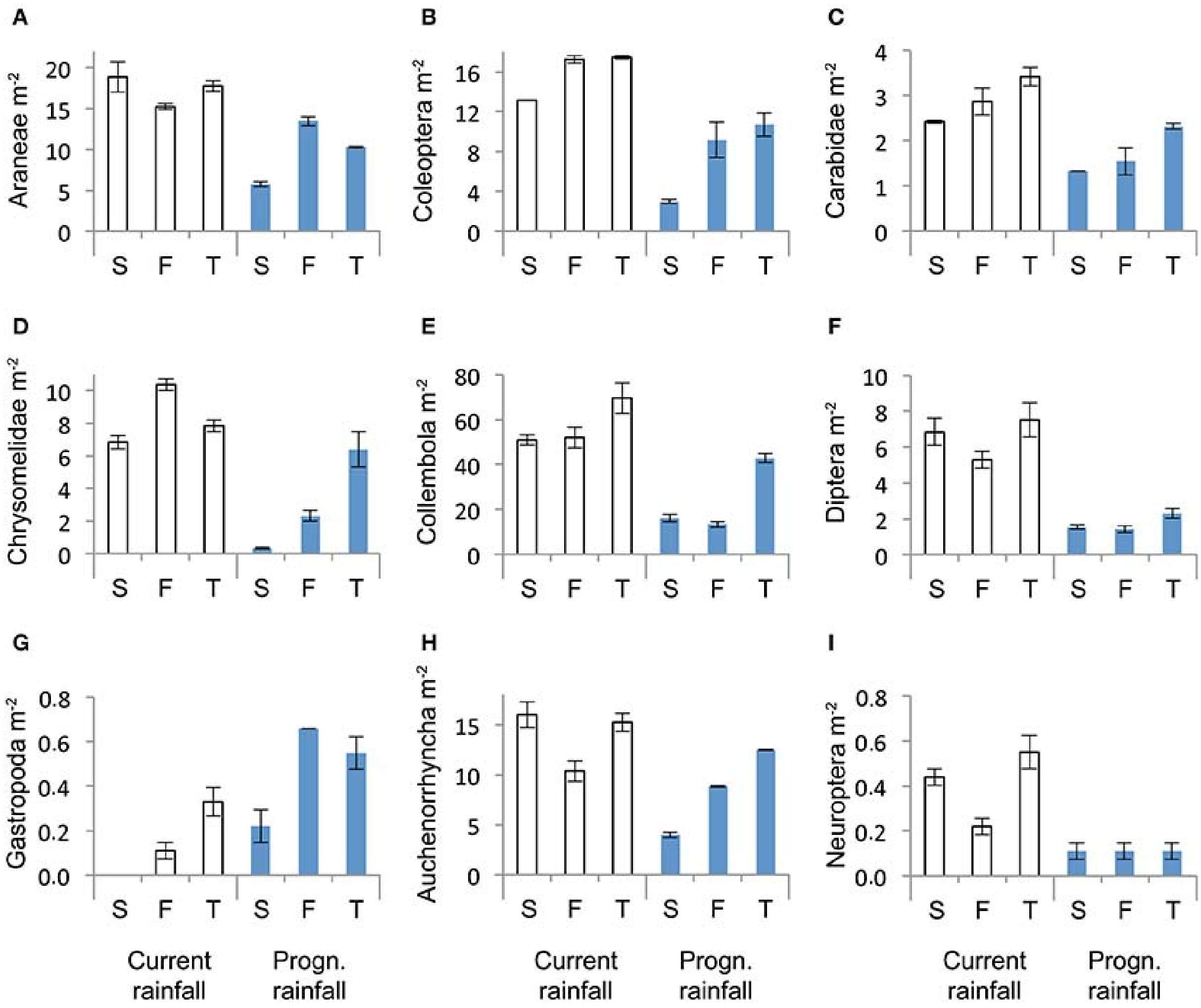

Figure 4.6: Abundance of Araneae (a), Coleoptera (b), Carabidea (c), Chrysomelidae (d), Collembola (e), Diptera (f), Gastropoda (g), Auchenorrhyncha (h) and Neuroptera (i) in winter wheat across the three sampling dates (April, May, June) under current (C) and predicted (D) rainfall cultivated in the soil types calcaric phaeozem (S), calcic chernozem (T) and gleyic phaeozem (F). Means ± SE, n = 3.

Wheat height was across sampling dates not affected by rainfall but significantly affected by soil types with lowest heights in the S soils and similarly high wheat plants in F and T soils (significant rainfall x soil type interaction; Table 4.4). Wheat straw biomass across sampling dates was significantly affected by rainfall and soil types (significant rainfall x soil type interaction; Table 4.4). Weed abundance across sampling dates was marginally significantly affected by rainfall variations and highly significantly affected by soil types (no rainfall x soil types interaction; Table 4.4). Weed biomass across sampling dates was only significantly affected by soil types with lowest weed biomass values in F soils and highest weed biomass in S soils (Table 4.4). Arthropod abundance was unrelated to winter wheat straw biomass (Table 4.5) wheat height or weed abundance (data not shown). However, abundances of Acari, Araneae, Collembola, Diptera, the group of not determinable arthropods and Thysanoptera was positively correlated with weed biomass (Table 4.5).

Table 4.4: Wheat height, wheat straw mass, weed abundance and biomass (all averaged across several sampling dates) in lysimeters cultivated with wheat in response to current vs. prognosticated rainfall variations and different soil types (S - calcaric phaeozem, F - gleyic phaeozem, T - calcic chernozem). Means ± SD. Statistical results from two-way ANOVAs, significant effects are in **bold**.

Parameter/Soil type	Treatments Current Rainfall	Progn. Rainfall
WHEAT HEIGHT (cm)		
S soil	42.8 ± 0.7	46.3 ± 0.9
F soil	51.3 ± 0.3	48.9 ± 2.5
T soil	48.7 ± 0.7	50.9 ± 1.9
ANOVA RESULTS FOR WHEAT HEIGHT		
Rainfall	$P = 0.121$	
Soil types	$\mathbf{P < 0.001}$	
Rainfall × Soil types	$\mathbf{P = 0.009}$	
WHEAT STRAW BIOMASS (g m^{-2})		
S soil	49.2 ± 1.1	54.8 ± 3.0
F soil	59.3 ± 0.5	57.2 ± 3.6
T soil	55.8 ± 1.1	61.4 ± 3.0
ANOVA RESULTS FOR WHEAT STRAW BIOMASS		
Rainfall	$\mathbf{P = 0.018}$	
Soil types	$\mathbf{P < 0.001}$	
Rainfall × Soil types	$\mathbf{P = 0.021}$	
WEED ABUNDANCE (ind. m^{-2})		
S soil	345.8 ± 104.8	239.6 ± 68.1
F soil	118.1 ± 48.9	87.5 ± 11.6
T soil	191.7 ± 50.6	156.9 ± 40.7
ANOVA RESULTS FOR WEED ABUNDANCE		
Rainfall	$P = 0.070$	
Soil types	$\mathbf{P < 0.001}$	
Rainfall × Soil types	$P = 0.503$	
WEED BIOMASS (g m^{-2})		
S soil	15.1 ± 3.2	18.9 ± 2.8
F soil	8.5 ± 5.8	8.8 ± 3.3
T soil	12.3 ± 3.7	9.6 ± 3.7
ANOVA RESULTS FOR WEED BIOMASS		
Rainfall	$P = 0.807$	
Soil types	$\mathbf{P = 0.008}$	
Rainfall × Soil types	$P = 0.382$	

Means ± SD. Statistical results from Two-Way ANOVAs, significant effects are in bold.

Table 3.5: Correlation between arthropod abundance (June sampling) and straw and weed biomass (Pearson's product-moment correlation). Significant correlations in **bold**.

	Straw biomass		Weed biomass	
	R	*P*	*R*	*P*
Acari	−0.292	0.240	0.576	**0.012**
Araneae	0.120	0.635	0.517	**0.028**
Coleoptera	0.338	0.170	0.396	0.103
Collembola	0.168	0.505	0.542	**0.020**
Diptera	−0.002	0.995	0.687	**0.002**
Hemiptera	0.048	0.849	0.360	0.143
Hymenoptera	−0.181	0.471	−0.355	0.148
Not determinable	−0.013	0.960	0.607	**0.008**
Rare individuals	0.381	0.119	0.340	0.167
Saltatoria	−0.226	0.368	0.091	0.720
Thysanoptera	0.135	0.593	0.745	**<0.001**
Total individuals	0.029	0.908	0.451	0.060

Significant correlations in bold.

4.5 **Discussion**

Results of this study show substantial reductions in the abundances of various arthropod groups but no changes on the diversity of arthropod communities under rainfall variations prognosticated for the years 2071-2100. Given the average 45% reduction of total arthropod abundance under prognosticated rainfall means that instead of 86 m^{-2} only 48 m^{-2} arthropod individuals would be inhabiting these wheat agroecosystems. Arthropod abundance data from the current study fit well with those from a conventional cereal field in Denmark also assessed with suction sampling in late June over two years (Reddersen, 1997): Araneae (5.4-17.8 m^{-2}), Collembola (0.65-155.9), Hemiptera (14.1-2,146 m^{-2}), Hymenoptera (13.5-23.9 m^{-2}), however much more Coleoptera (51.5-110.4 m^{-2}), Diptera (66.3-104.1 m^{-2}) and Lepidoptera (0.43 m^{-2}) were reported. Similar to our study, Moreby and Sotherton (1997) also found low abundances of Diptera (5.4 m^{-2}), Carabidae (0.82 m^{-2}) and Chrysomelidae (1.36 m^{-2}) in conventional winter wheat fields in southern England with suction samplings in June and July. Reasons for differences in arthropod abundances in different studies reflect climatic differences, effects of surrounding landscape structure, influence of different insecticide usage or differences in wheat varieties. The finding that mainly abundances but not diversity was reduced suggests that the size of arthropod populations seem to be the sensitive parameter responding to rainfall variations. Whether effects of rainfall variations on arthropod abundances have consequences on how fast arthropod populations can react to environmental changes remains to be investigated by a specific experiment. We also found great differences in arthropod abundances between sampling dates from April to June reflecting the natural fluctuations due to different seasonal development of the various arthropod taxa (Frampton et al., 2000; Afonina et al., 2001; Abbas and Parwez, 2012).

4.5.1 **Arthropod abundances as influenced by rainfall**

Predicted rainfall variations reduced arthropod abundances mainly in June but had little influence in April and May. We explain this by the fact that rainfall treatments were established only one month before the first arthropod sampling and by the relatively small difference between the rainfall scenarios in April and May that may have been insufficient to cause shifts in arthropod abundance. Moreover, until the first arthropod sampling in April the prognosticated rainfall plots (38 mm) received even more rainfall than the current rainfall plots (33 mm rainfall). Until the second sampling date in May the current rainfall plots received 91 mm and the prognosticated rainfall plots 81 mm. Even, until the June sampling the difference between the two rainfall treatments was only 20 mm, however rainfall amount combined with extended dry periods was obviously enough to lead to several significant differences in arthropod abundances. Moreover, the increased soil matric potential in the prognosticated rainfall plots showed that soil water was less available than under the current rainfall treatment affecting wheat biomass production and weed abundance. Further, rainfall showed different effects on the availability of water in different soil types as indicated by a significant interaction between rainfall and soil types for soil matric potential.

Despite the small differences in rainfall it was interesting to see significant differences in abundances of Gastropoda and Auchenorrhyncha in April. However, given the small abundances of these taxa (0.31 m^{-2} for Gastropoda and 0.46 m^{-2} for Auchenorrhyncha) results should be interpreted with caution. On the other hand, the predicted rainfall plots received more precipitation than the current plots until April and Gastropoda are known to be very sensitive to rainfall (Choi et al., 2004) and might thus be sensitive indicators for changes in moisture. In our experiment Auchenorrhyncha (e.g., cicadas) also seemed to be sensitive to rainfall, although others found no differences in the abundance in summer drought plots compared to plots under ambient climate condition (Masters et al., 1998). Collembola, Diptera, Neuroptera and Saltatoria responded to rainfall scenarios in May. This can be explained by a higher sensitivity to changes of these four orders, so that small differences in rainfall amounts (9.8 mm) and variation were effective, whereas the other orders appear to be more tolerant against changes in rainfall. Others also found that mites were not responsive to precipitation treatments, but Collembola were (Kardol et al., 2011).

In June eleven of the 18 arthropod groups investigated were affected by rainfall treatments suggesting that 20 mm difference in the amount of rainfall and 25% more dry days were enough for these taxa to respond. Finding that certain arthropod taxa were affected by rainfall treatments in one month but not in the other (e.g., Gastropoda, Saltatoria) can be explained by spatial and temporal variations of arthropod distribution between agroecosystems and the surrounding landscape (Afonina et al., 2001; Tscharntke et al., 2002; Zaller et al.,2008a). Clearly, to better understand the mechanisms underlying the relationship between rainfall amounts/variations and arthropod abundances an analysis at the species level would be desirable. However, it can be concluded from the current study that changes in rainfall variations with a slightly decreased amount of rainfall, more dry days and more intensive rainfall events will most likely decrease the abundance of aboveground arthropods in winter wheat crops.

Vegetation structural complexity, including crop biomass and weed abundance which differed between the rainfall treatments, is an important determinant of arthropod abundance and diversity in agroecosystems (Honek, 1988; Lagerlöf and Wallin, 1993; Frank and Nentwig, 1995; Kromp, 1999). Correlations between arthropod abundance and crop and weed biomass suggest that the rainfall effects indirectly affect arthropods by changes on crops and weeds. Many studies describe the interrelation between weeds and arthropods, in which greater weed density and diversity is associated with higher numbers of arthropods (Moreby and Sotherton, 1997; Moreby and Southway, 1999; Marshall et al., 2003). In the current study, 45% less weed biomass were found in the predicted rainfall plots than in current plots and thus the significant correlations for the abundance of arthropods (Acari, Araneae, Collembola, Diptera and Thysanoptera) and weed biomass are not surprising. However, it is somewhat counterintuitive, that there was no correlation between numbers of individuals of weeds and abundance of arthropods, except for Hemiptera and total individuals in May. Also in contrast to other studies is the lack of a correlation between arthropod abundance and crop height (Frampton et al., 2000; Perner et al., 2005) indicating that our treatment factors rainfall and soil types influenced relationships between arthropods and plants. For example, the observed increased soil matric potential under progn. rainfall suggests that crop and weed plants in these treatments had soil water less easily available than plants in curr. rainfall treatments which could have affected the nutritional quality and structure of the crop-weed communities for arthropods (Masters et al., 1998). Plant responses to soil water availability can influence herbivore population dynamics with implications for multitrophic arthropod-plant interactions (Masters et al., 1993; Gange and Brown, 1997). Plant-mediated indirect effects of rainfall on arthropods have been described in detail for aphids where the performance of aphids on drought-stressed relative to healthy plants was increased, decreased or unchanged depending on the aphid species, host-plant, timing and severity of the drought stress (Pons and Tatchell, 1995). Whatever the causal mechanisms are, the decrease in arthropod abundance can have potential consequences for ecosystem function such as biological control, nutrient cycling, pollination, seed dispersal, plant decomposition and soil alteration (Price, 1997; Bokhorst et al., 2008; Brantley and Ford, 2012). Arthropods control populations of other organisms and provide a major food source for other taxa, like birds or amphibia. Many farmland bird species are declining in Europe, and one reason could be a decreasing availability of arthropods (Moreby and Southway, 1999; Wilson et al., 1999; Hallmann et al., 2014). Insects are also an important supplementary human food source in many regions of the world, but as arthropods can also cause damage through feeding injury or transmission of plant-diseases, natural biological control in form of antagonistic arthropods are crucial for agricultural systems worldwide (Foottit and Adler, 2009). Our study also indicates that prognosticated rainfall variations might have little influence on biological control within the wheat agroecosystem as both important antagonists for pests (Araneae, Carabidae) and pests themselves (Chrysomelidae, Auchenorrhyncha) are reduced. However, the influence of rainfall on these pest-antagonist interactions demand more detailed investigations.

When interpreting our data one has to keep in mind that in climate change models temperature and precipitation are closely linked. Since we only investigated rainfall effects while leaving temperature unchanged, different impacts that the ones reported here could occur when both factors, temperature and precipitation, are studied simultaneously.

4.5.2 **Arthropod abundance little influenced by soil types**

Unlike expected, the soil types had no effect on arthropod abundances despite of clear differences in the availability of soil water as measured by the soil matric potential. Surprisingly, also orders which live in soil for most of its life cycle such as Collembola did not respond to soil types and the availability of soil water indicating that these taxa are rather tolerant to environmental conditions. As the factor soil type was rarely considered in studies on arthropods there is little literature to compare with. Differences in soil matric potential could also influence communities of soil bacteria and fungi and indirectly affect mycophagous and detritivorous arthropod species; however this remains to be investigated. Our current results of little influence of soil types on arthropods are in contrast with those who found significant differences in the abundance of spiders, carabides and Heteroptera in three different types of Estonian cultivated field soils; but there was also no difference between soil types regarding the number of Coleoptera (Ivask et al., 2008). When comparing those data one has to keep in mind that in the former study pitfall traps were used as opposed to suction sampling in the current study; moreover different times of the year in very different climatic regions were studied. In our study soil types influenced wheat height and weed abundance and the finding that some arthropod taxa were correlated with vegetation density suggests some relationship (Chapman et al., 1999). However, other factors, including competition between arthropod taxa from different trophic levels (Perner et al., 2005) might have overruled possible effects of soil types. In order to interpret these data in more detail, further studies investigating interactions between crop species and soil types would be necessary.

4.6 **Conclusion**

Taken together, this study suggests that future rainfall variations with less rainfall and longer drought periods during the vegetation period will significantly reduce the abundance of aboveground arthropods in winter wheat fields. The lack of significant effects of soil types suggests that rainfall variations most likely will have similar effects on different soil types. Weeds associated with winter wheat were shown to play an important role in promoting arthropod abundance while effects of rainfall on crop growth seemed to be of minor importance. The strong response of arthropod abundances to only small differences in rainfall amounts demands more appreciation of the effects of rainfall variations when studying climate change effects on ecological interactions in agroecosystems. As this is among the first studies investigating the combined effects of rainfall variations and soil types on the abundance of aboveground arthropods, more research is needed to get a better understanding of their consequences on ecosystem functioning and services.

4.7 **Acknowledgements**

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5. General discussion

The effects of the future rainfall patterns on different soil types were clearly seen just about a month after application on various agroecosystem parameters. The biomass production of both pea and wheat were significantly reduced by both soil types and rainfall pattern, with lowest values under the future rainfall pattern frequently occurring on S soils. The future rainfall pattern, however, stimulated pea root growth, and significantly increased wheat root development. Soil types also significantly affected both pea root growth and the early wheat root growth with a tremendous increase in root development on sandy soils. Both crops showed reduced mycorrhization rate with the future rainfall patterns but were unaffected by soil types

The LAI of both pea and wheat were reduced under future rainfall pattern as counter drought reaction to reduce the surface area of water lost. The significant increases in root growth of both crops on S soils are counter drought reaction to increase the surface area for water absorption as well an extension to meet the underground water level. Future rainfall patterns significantly reduced the NPP of field pea and the growth of wheat during the tillering stages. These reductions could be attributed to the induced drought created by the future rainfall patterns with fewer rainfall events, which led to the increase in the $\delta^{13}C$ values of wheat, which is a good indicator of plant stress (Werner et al. 2012).

5.1 **Biomass production**

On both pea and wheat cultivars, the future rainfall patterns reduced the crops development, yield, and the harvest index significantly. These reductions could be attributed to the induced drought created by the future rainfall patterns. Drought reducing vegetative growth has also been observed in many experiments (Schimmack et al. 2004; Masoni et al. 2007; Guo et al. 2012; Gan et al., 2009; Razzaghi et al. 2012). The biomass production of both crops was also significantly affected by soil types, with lowest values under future rainfall patterns always occurring on S soils. This low growth rates on S soils could be attributed to the little nutrient and profile water content, likewise the high sandy content thus high water infiltration rate (Steinitzer & Hoesch 2005). On the pea cultivar, the NPP on both F and T soils under future rainfall patterns were almost similar, which could also be attributed to the high soil water content on this soil type, implying that soil types with higher moisture content could mitigate the adverse drought effect created by climate change. The fact that wheat growth was stimulated after the post-anthesis stages on S and T soils could be attributed to the fact that the plants at these stages have already completed their reproductively active phases thus invested more metabolite for the above ground growth.

Wheat LAI was significantly reduced by the future rainfall patterns but was unaffected by soil types. The LAI of pea were also narrowly significantly reduced by the future rainfall patterns and soil types (P = 0.06). These reductions could be attributed to the induced drought created by the future rainfall patterns thus; the $\delta^{13}C$ of both young and old wheat leaves were significantly increased as it has been proven that plants increase their $\delta^{13}C$ values during drought (Werner et al. 2012). However, the increase in wheat height during drought at the inflorescence and dough stages on S and T soils was unexpected but also portrays a higher water use efficiency of the cultivated wheat. Wheat growth on S soils was significantly lower than that of F and T soils. These growth reductions could be attributed to the reduced water and nutrient content of these soils, as was also observed in many past experiments (Cui &Nobel, 1992; Porcel et al., 2003; Matias et al., 201; Razzaghi et al. 2012). On F and T soils, more nitrogen fertilizers than were applied than on S soils and according to Zhu and Chen (2002) higher nitrogen mineralisation favours growth. However, the analyses of wheat nitrogen content, as well as other nutrients were insignificance on all soil types indicating that fertilization did not gear the increased growth rate of these soil types.

The grain yields of both crops were significantly reduced with the future rainfall patterns whereby more reductions were observed on S soils. These reductions in crop production with future rainfall patterns will threaten the increasing human population except counter climate change measure like the reduction in global pollution, and investments in scientific research to increase food production are implemented.

Though the straw and leaf growth of pea were reduced under future rainfall patterns, the root growth increased on all soil types. This allocation of assimilates to the roots could be a counter stress reaction for the assimilates to be remobilised to the above ground organs during favourable conditions. Wheat root growth was significantly higher on S soils than the other soil types. Since this soil type has the lowest soil water and nutrient content, the higher root growth could be a counter drought reaction to increase the surface area for water and nutrient absorption.

Fertilizers were applied to stimulate growth in both cultivars, but the analyses of wheat mineral contents were insignificant on all soil types indicating a higher mineral use efficiency of the cultivated wheat. The reduction in growth even with the application of fertilizers shows that fertilization alone will be insufficient to mitigate the adverse effect of climate change on agroecosystems. The general biomass reduction on all soil types during drought on pea cultivar was shown in the significant decrease in the groundcover rate, plant density and the root to shoot ratio. On wheat, however, these reductions depended mostly on the growth stage, with significant reductions during the early growth stages and growth stimulation after the post- anthesis stages.

Soil types also significantly affected pea yield and wheat grain yield with always significant reductions during drought on S soils. These low yields with future rainfall patterns on S soils indicate the vulnerability of this soil type to climate change. Thus, for future crop production on this soil type to be significant, irrigations and improved management strategies must be implemented.

5.2 **AMF colonization**

The substantial reduction in wheat mycorrhization rate on all soil types likewise its reduction trend in pea cultivar to future rainfall patterns indicates a weakening of the crops assistance underneath the soil contributing to the decline in yields. These reductions in mycorrhization with the future rainfall patterns could be attributed to the reduced soil water content as it has been proven that reduced soil moisture reduces AMF colonisation (Stahl and Christensen, 1982). These reductions could also be attributed to the added fertilizers applied to the crops after soil analysis to balance the mineralisation as it has also been proven that balanced mineralisation reduces AMF colonisation (Xiangui et al. 2012). The stronger response of wheat than peas to AMF colonisation was in confirmation of the finding on (Eschen et al., 2013) who also observed more declined in AMF colonisation of grasses than legumes with reducing nutrient availability even though grasses had lower colonisation level than legumes. These reductions in colonisation rates are detrimental to the plants since the AMF supplies up till 1000 time more water to its host and efficiently help plants to resist unfavourable soil conditions (Augé, 2001; Bolandnazar et al., 2007). These reductions in AMF colonisation with drought could also be a compensation reaction of the fungus to reduce its nutrient demand from its host which is under stress. AMF vividly assist it host during unfavourable conditions by increasing the surface area for water and nutrient absorption, likewise defending its host from pathogen invasion, (Augé, 2001), thus, the addition of commercial inoculums of mycorrhizae to future cultivars is strongly recommended.

The AMF colonisation of pea cultivars were almost significantly reduced by soil types (P = 0.07) with a higher value on S-soils. Likewise for wheat, soil types significantly affected

AMF colonisation, with significantly higher values on S-soils during the early growth stages, as well as high rates at other growth stages. These higher mycorrhizations on soil types with higher sandy content was in agreement with the findings on Zaller et al. (2011) who equally observed that soil types with higher sandy content improve AMF colonisation.

5.3 **Weeds**

On pea and wheat cultivar, the abundance of several weed families was significantly affected by soil types and rainfall patterns. Weed composition and density decreased for both cultivars under future rainfall patterns. Soil types significantly changed the weed density in both cultivars with at least 34% less biomass on S soils than T and F soils. The weeds composition on pea cultivar was from the families of Asteraceae, Chenopodiace, Polygonaceae and Poaceae. On the wheat cultivar at (DAS 6) before the application of herbicide, the dominant weed species were *Consolida regalis, Veronica hederifolia, Papaver rhoeas* and *Stellaria media*. These species are typical weeds for winter wheat with average competitiveness and higher weed density on S than F and T soils. After herbicide application, the weeds composition changed with *Convolvulus arvensis, Polygonum aviculare, Chenopodium album* and *Festuca rubra*, being the dominant species and with still more individuals on S than F and T soils. This change in species composition could be attributed to the weed species' phenology and physiology as well as the type of herbicide used. On all soil types, the weed species reduced with the predicted rainfall even before herbicide application, implying that drought reduces weed density as has also been observed in other experiments (Jug et al., 2009; Molnar et al., 2003).

Soil types influencing the abundance and biomass of weed communities was in agreement with earlier findings (Firbank et al., 1990; Jug et al., 2009; Molnar et al., 2003). These interactions were later explained by (Gomaa, 2012) to be from the variation in soil texture due to differences in the humus, silt and clay contents. This finding, however, contradicts the findings reported by (Pysek et al., 2005), who demonstrated that the soil type has no direct influence on species abundance.

The fact that on the same location for two consecutive years the weed communities on the pea cultivar were entirely different from that of the wheat cultivar indicates a richer biodiversity index. It could also be attributed to the invasibility of the weed species due to climate change (Whitney & Gabler, 2008; Clements & Ditommaso, 2011).

These reductions in weed density with the future rainfall patterns also reflect the relatively high competitive nature of the planted winter wheat. Since most terrestrial animals depend on plant production for nutrition and habitat, these reductions in weed density with predicted rainfall will profoundly alter ecosystems and ecological processes.

5.4 **Insect pest**

Insect pests accessed in pea cultivars by direct sampling of pea moth showed that its density was increased on plots with the future rainfall patterns, also the interaction between soil types and rainfall almost significantly (P= 0.07) increased the pest density. This increase in insect pest density with future rainfall patterns will pose an enormous challenge to agriculture since farmers will have to invest heavily in pesticides and management strategies for crop protection to attend sustainable yields.

On the pea cultivar, more pea moths were sampled on S soils with the future rainfall patterns than other soil types. On S soils also, the crops growth and yields were significantly lower. Thus, the increase in pea moth density could have contributed to the reduced biomass production since it has been proven that increases in insect pests reduce biomass production (Gregory et al. 2009; Robinson et al., 2012).

On the wheat cultivar, the major arthropods taxa were Araneae, Auchenorrhyncha, Coleoptera, Carabidae, Chrysomelidae, Collembola, Diptera, Neuroptera, Gastropoda, Hemiptera, Acari, Hemiptera, Heteroptera, Hymenoptera, Opiliones, Saltatoria, and Thysanoptera. The abundance of almost all of these Arthropods taxa was at least 39% reduced under the future rainfall patterns except for the Gastropoda, which increased with the future rainfall patterns. These reductions in arthropods density with future rainfall patterns are in agreement with other studies (Frampton et al., 2000; Perner et al., 2005). The explanation could be that as the future rainfall patterns reduced both the crop and weed density, the quality and quantity of nutrition to these arthropods were negatively affected which led to reductions in their population dynamics. The abundance reduction of various beneficiary arthropods like the Carabidae and the Araneae with the future rainfall patterns are detrimental and could also hamper agriculture since they are essential for the biological control of various pests.

The weeds density and arthropods abundance both reduced with the future rainfall patterns and correlated positively. The reduction was in agreement with other studies whereby increases in arthropod number with high weed biomass were observed (Moreby & Southway, 1999; Marshall et al., 2003; Bokhorst et al., 2008),

The almost 70% increased abundance of the Gastropoda with future rainfall patterns could be seen as its avoidance of moisture as it has been shown that the Gastropoda are very sensitive to precipitations (Choi et al., 2004).

The population dynamics of arthropods under mimicked climate change scenarios need in future studies to be monitored diligently, to consolidate these changes in arthropods density.

6. Synthesis and conclusion

This study is the first time after thoroughly reviewing past experiments, where different crops were investigated under a mimicked climate change scenario. The future climatic scenario with reduced rainfall intensity and durability significantly reduced the crops yield and biomass production thus, cultivars which rely on irrigation for substantial yields may be more vulnerable to future rainfall patterns. Plants physiological and morphological adaptations to alleviate the adverse impact of reduced precipitation are inadequate to provide significant yields to meet an increasing world demand, thus additional scientific measures like irrigation, breeding of higher drought tolerant varieties and improved management strategies have to be implemented. The reductions in yield even with the addition of fertilizers indicate that fertilization alone as a measure to counteract the adverse impact of climate change on agroecosystems will be inadequate. Crops with different root structures had almost similar yield reduction, indicating a broader effect of climate change on various crop species. The decreased AMF colonisations of both crops with future rainfall patterns are detrimental to the plants survival thus, the addition commercial inoculums of mycorrhizae to future cultivars are recommended. Slight variation in rainfall intensity significantly altered the aboveground arthropods abundance indicating that future rainfall patterns could change insects' ecological interactions in agroecosystems.

In both pea and wheat cultivars, soil types with lower water and nutrient contents like sandy calcaric phaeozem produced significantly lower yields. However on soil types like gleyic phaeozem with high water and nutrient contents, these reductions were minimal; thus, it is strongly recommended that impact of soil type should be considered when evaluating the effects of future climate on agroecosystems.

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2002– 2008 Mitarbeiter am Institute für Forstenthomologie, Forstpathologie und Forstschutz der Universität für Bodenkultur Wien. Diplomarbeit mit dem Titel "UNTERSUCHUNGEN ZUM AUFTRETEN DER FICHTENBLATTWESPEN IM RAUM LAMBACH (OBERÖSTERREICH) IN DEN JAHREN 2003 UND 2004: EINFLUSS VON KLEINRÄUMIGEN BESTANDESPARAMETERN AUF DIE ABUNDANZ VERSCHIEDENER FICHTENBLATTWESPEN ARTEN" betreut von Univ. Prof. Dr. Axel Schopf

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Italienisch (Grundkenntnisse)

EDV: Ausgezeichnete Kenntnisse in MS Office (Word, Excel, Powerpoint), AutoCAD , SPSS, SAS, Adobe, Photoshop, Zotero, Internet

Beruflicher Fähigkeiten

Sehr lernwillig und motiviert neue Erfahrungen anzustreben

Bewahre auch in Stresssituationen den Überblick

Sehr fleißig und große Verlässlichkeit