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Crop Water Stress Management in the Tropics and Subtropics (380)

Effect of Root Zone Temperature and Changes in Precipitation on Yield Components and Yield Formation in Spring Wheat (*Triticum aestivum* L. cv. Triso)

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Abstract

The climate change is an ongoing process and predictions for the near future in northern Europe and in general in high latitude show increase of the air and soil temperature and variation of the patterns and the amounts of the precipitation. This may impact the plant growth conditions leading to different crop productivity.

A field experiment was carried out in 2009 with two factors: 1- precipitation amount and precipitation frequency, and 2 – soil warming, on silty loam soil in Stuttgart – Germany. The precipitation manipulation included an ambient precipitation amount at normal precipitation frequency as a control treatment, a 25% decreased amount of precipitation at normal precipitation frequency, an ambient precipitation amount at 50% decreased precipitation frequency, and a 25% decreased precipitation amount at 50% decreased precipitation frequency. The soil warming treatments included ambient temperature as a control and 2.5°C elevated soil temperature. The applied soil warming lies in the range of the expected increase of the mean annual temperature by 2 to 3°C until 2100. Also over the same period precipitation is expected to decrease by 20 to 30 % in the summer and increased at the same level in the winter, followed with altered precipitation frequency. Fixed rain-out shelter and heating cables installed at the soil surface to heat the soil in 4 cm depth were used to realize the treatments.

Soil warming enhanced the yield-determining components leading to higher grain yield. This trend has been shown in all of the precipitation treatments. Despite the reduction of precipitation amount and/ or altering of the precipitation frequency soil warming leads to a high grain yield. Soil warming had no effect on the number of ear but increased the number of spikelet-bearing grain and reduced the number of the basal spikelet and increases the single kernel weight.

The precipitation changes did not affect the grain yield whereby in the plots with 25% reduced precipitation amount at normal precipitation frequency show high tillering compared to the plots with 25% reduced precipitation amount at 50% reduced precipitation frequency but no different has been shown to the other precipitation manipulation.

Results of this experiment indicate that warm conditions will benefit the spring wheat in high latitude regions, whereas in contempt of the reduction and altering of the precipitation spring wheat can maintain its performance.

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1. Introduction

Wheat (*Triticum aestivum* L.) is the most widely grown crop in the world. The area under wheat production amounts to more than 200 million ha (about 20% of the worldwide cultivated area) (Dixon et al., 2009), producing 656 million tons of grain (agrostats, 2010). After maize and rice wheat comes third in the production volume of food crops, however wheat is of even higher importance for human sustenance due to it s nutritive value. Wheat provides an excellent source of proteins, carbohydrates, fibers, minerals and certain vitamins. Together with maize and rice - wheat provides 75% of carbohydrates and 50% of proteins consumed by the world population (Bockus et al., 2010).

The world´s population is predicted to rise, thus the pressure on food production will increase. According to Rosegrant et. al. (2007) the demand for wheat will be about 813 million tons in 2020 cited by (Dixon et al., 2009). FAO forecasts the global wheat production to 651 million tons in 2010 (FAO, 2010); this implies a growth in the wheat supply of about 25% for the next ten years. In the past decades, the world wheat production has been doubled due to two substantial factors: 80% due to improved varieties and agronomic practices, and about 20% due to an increase of the production area (Khan& shewry, 2009). During the period 2004 – 2006 the world yield average for wheat amounted to about 2.9 t/ha (Dixon et al., 2009). Hanson et.al. (1982) predicted the absolute achievable wheat yield, based on genetic potential, to be 20 t/ha (Curtis, 2002). Between the currently attainable yield and the potential one a significant gap exists, which with more scientific effort and improved field management, can contribute to large extent to keep up with the growing demand for wheat.

Not only the population growth challenges the wheat production, furthermore the ongoing climate change presents a considerable threat to the efforts of assuring the production level in many areas around the world. According to the IPCC (Intergovernmental Panel on Climate Change, 2007) a linear warming trend over the last 50 years of 0.13°C per decade has been shown, this is nearly twice the rate occurred over the last 100 years. Furthermore, the best estimation of average temperature shows an increase of 1.8°C up to 4°C by the end of the 21 century (Dixon et al., 2009). In addition, the precipitation patterns are also affected by the climate change. Dore (2005) reported that the variance of precipitation is increasing, wet areas are becoming wetter, and dry and arid areas are becoming more so.

Thus an experiment was carried out in order to investigate the effects of changed temperature in the root zone and modified precipitation on the yield of spring wheat and yield components were measured, particularly key features such as kernel number and kernel weight were determined, as well as harvest index (HI) and thousand kernel weight (TKW) were quantified.

2. Hypothesis and objectives

Yield components and yield formation depend largely on the temperature and soil moisture availability. In the current experiment soil temperature was increased by 2.5°C and the amount and frequency of precipitation was modified to evaluate the response of the different plant organs playing an important role in the determination of yield components and ultimately the formation of yield of wheat. In Germany and in general in all high latitude regions temperature and particularly soil temperature is a major constraint in agricultural practice. In addition water shortage or excess at a definite plant stages cause restriction on yield.

The main focus of this work was to characterize the response of wheat to the different treatments and their influence on yield and yield components.

The main objectives of this work are:

- To investigate the effect of increased soil temperature on yield and yield components.
- To quantify the effect of the different precipitation changes on yield and yield components of wheat.

3. State of the art

3.1. Importance of wheat

Wheat (mainly bread wheat) is grown in more than 160 countries (70 countries on a substantial scale - more than 100,000 ha) and on 5 continents (Dixon et al., 2009). Wheat can be grown successfully between 30° and 60° north and 27° and 40° south, moreover wheat is grown from sea level to more than 3000 masl in altitude (Curtis, 2002). The high adaptability of wheat to many environments is attributed to the complexity of its genome; the genome of wheat is five times the size of human genome and much more complicated (Pennisi, 2008). In addition, wheat is growing in more areas than any other crops. The area planted to wheat exceeds that of maize or rice – the two competitors with wheat for food crops, that human diets relay on.

More than 20% of the wheat production enters the world market (Curtis, 2002). Wheat import to developing countries goes beyond the import of any other food crops (Dixon et al., 2009). According to CYMMIT (2005) 43% of the food imported to developing countries is wheat (Ortiz et al., 2008). According to Northoff & Kourous, (2010) in 2008/2009 139 million tons of wheat were sold in the world market, valuing about 3.5 billion dollars, where the price per tone was 250 US$ (FAO, 2010). The price has fallen after it reached the highest record with 480 US$ in March 2008. The actual price soared up again to 210 US$ (score 13 July 2010) after it was less than 200 US$ at the time between the end of 2009 to the beginning of 2010 (FAO, 2010). In contrast to the price fluctuation in the last years, wheat is going to increase its share in the global market, especially due to demand from the developing countries where wheat is the major food crop for their populations.

3.2. Classification of wheat

In wheat, scientists differentiate between bread wheat and durum wheat. Durum wheat accounts for only 5 % of global wheat production and it is growing and consumed mainly in North Africa and West Asia (Dixon et al., 2009). Additionally, according to cold requirement, wheat can be classified into winter, spring, as well as facultative type. The winter type requires a period of low temperature (vernalization: 0°C to 7°C for 30 to 60 days) to reach the double ridge stage (floral initiation), which induce the shift from the vegetative to the reproductive stage (Acevedo, Silva, & Silva, 2002), consequently the spikelet initiation phase starts (Rawson & Macpherson, 2000). This type endures the winter without frost damage; in addition it has been used by farmers to avoid the delay of sowing spring wheat in thawing fields (Khan & Shewry, 2009). The spring wheat is less tolerant to low temperatures (Acevedo, Silva & Silva, 2002). The differentiation between winter and spring type is not due to the sowing time, which is sometimes used confusingly. Particularly in some area with mild winters, farmers sow spring wheat in autumn to benefit most from the long growing period, and they refer to this wheat type as winter wheat. The difference between winter and spring wheat is due to the presence or absence of the vernalization response. Furthermore spring wheat can be a choice when the sowing of winter wheat is not possible, owing to bad weather in the fall (Börner et al., 2008). The facultative wheat can be sown either in winter or in spring time. Its requirement for vernalization is shorter and differs from variety to variety (Braun & Saulescu, 2002).

3.2.1 Spring wheat

The green revolution started with the development of improved spring wheat varieties then introduced to India, Pakistan and Turkey. On a global scale, the proportion of area that is sown with spring wheat exceeds that sown with winter/facultative wheat. In developing countries 70 to 75% of the wheat area is sown with spring varieties (Dixon et al., 2009, Sayre, 2002). Most of Australia’s wheat production is referred to spring varieties and in the USA and Canada sizeable areas are reserved to spring wheat (Sayre, 2002). Durum wheat, which accounts for roughly 5% of the global wheat production, is mostly produced from spring wheat types (Dixon et al., 2009). Spring wheat, mostly planted under irrigated conditions, implies high input and intensive management, which makes a failure in production very costly. The production of spring wheat under intensive management makes the system fragile to various biotic and abiotic stresses. Actually, the FAO statistic dose not separate accurately between winter and spring wheat, however Börner et al., (2008) suggested that spring wheat dominates in high latitude and under continental conditions but also in Mediterranean regions.

Although the most common type in the developed countries is winter wheat, the importance of spring wheat remains at a considerable level. In most of the wheat area of Western Europe, spring wheat serves as a countermeasure to deal with the risk of winterkills, which can affect the winter wheat in years with strong winter harshness (Börner et al., 2008). The preference for winter wheat is due to its 25% higher yield compared to that of spring wheat. Indeed, in unfavorable weather, when the sowing of winter wheat is not possible, farmers are forced to choose spring wheat. But since the yield loss will be compensated with the better protein content from spring wheat the monetary revenue will remain constant (Seile, 2007). In addition, the rotation between winter and spring crops offers many advantages, mainly with regard to soil fertility and management of weeds.

3.3. Yield of wheat

The achievable wheat yield differs from country to country; while under rain fed conditions yields of about 8 t/ha can be achieved in the United Kingdom, maximum yields are reduced to 2.6 t/ha in Canada and 0.9 t/ha in Kazakhstan. Under irrigated conditions, yields range between 2.6 t/ha in India and 6.5 t/ha on average in Egypt (Dixon et al., 2009). In the last decades, up to 50% of the yield increase has resulted from varietal improvement through breeding (Frederick et al., 1999, (Börner 2008). This success has been achieved through enhanced assimilate partitioning to reproductive growth during spike formation prior to anthesis, which resulted in higher kernel number per m^2 (Frederick & Bauer, 1999). Looking at the plant physiology the main components determining yield in wheat are: number of plants in m², spike per plants, spikelets per spike, grains per spikelets and single grain weight (Frederick and Bauer, 1999; Acevedo, Silvia & Silvia, 2002, Börner et al., 2008). The number of plants per m² depends on the sowing rate decided by the farmer. Unfavorable weather conditions and biotic stress can reduce the originally sown number of plants per m². The number of spikes/tiller depends on the genotype, on the wheat type (winter or spring), and growing conditions (Acevedo, Silvia & Silvia 2002, Rajala, 2009). Spikelets per spike and kernel per spike depends on the duration of the vegetative phase and the leaf area resulting from this period (Frederick & Bauer 1999; Acevedo, Sivia & Silvia 2002), and from favorable growth conditions (Elhami et al., 2007), and also from photoperiod and vernalization (Slafer & Rawson, 1994). Higher leaf area enables higher photosynthetic rate which together with sufficient nutrients supply result in high kernel number per spike (Frederick & Bauer, 1999, Fischer, 2007). Whereas some authors claim the single grain weight has little importance for the determination of wheat yield (Fischer, 2007, Acreche et al., 2008). Elhami et al., (2007) reported that under irrigated environments kernel weight does considerably contribute to the grain yield of wheat.

The duration of grain filling period is another important factor wheat yield ultimately depends on. The grain filling period is mainly affected by plant health and nutrient status, further the sink demand for assimilates plays an important role in the delay of the grain filling period, whereby adequate air temperature and soil conditions influence the nutrient uptake and thus positively affect the leaf senscene and root activity resulting in longer grain filling period (Frederick & Bauer, 1999)

3.3.1. Yield of wheat: potential and constrains

Potential yield is the function of light interception (LI), radiation-use efficiency (RUE) and harvest index

$$PY = LI * RUE * HI$$ (after Reynolds, 2009)

Whereby the harvest index is the partitioning of biomass - produced by LI and RUE - to yield. It has been improved since the initiation of the green revolution, mainly through the introduced dwarfing gene but also through further selection toward higher yield (Reynolds et al., 2009). Sayre et al. (1997) and Reynolds et al. 1999 reported that the harvest index stagnates since 1980 by 50%, although the theoretical HI was set to 62% as estimated by Austin, (1980) cited by (Reynolds et al., 2009). LI shows significant genetic variation and the selection towards higher LI is easy and has not been reported to be the obstacle to reaching higher yield in wheat. A suspect matter is RUE, hereto Reynolds et al. (2009) sugests that enhancement of the sink strength will result in higher RUE. In addition Acreche et al. (2008) concludes that further improvement of grain number per m² accompanied with enhancement of the RUE could result in higher yield in wheat. Since the HI is close to the maximum value, increasing the yield of wheat must be achieved through increasing the biomass (Slafer, Araus & Richards,1999).

Wheat shows high adaptability across environments porbably due to its genome size or the progress in its wider domestication. The wide adaptation comes with the cost of variable severities stressing wheat yield. Lodging of wheat is one of this constraints which can spoil up to 80% of the wheat yield (Reynolds et al., 2009). Biotic and abiotic stress are other problems accounting for up to 30% of wheat yield lost (Khan & Shewry, 2009).

All these constraints together with the effect of climate change will keep attainable wheat yield lacking far behind the potential yield geneticaly inherent in the wheat plant .Scientific efforts aiming to discover factors involved in resolving some of these constraints will contribute to reducing the yield gap in wheat. In the past, yield imporvement and stabilization was mainly done through genetic enhancement, but since the genetic increases are becoming dificult to achieve physiological and molecular approaches are becoming more important for scientists aiming at further improving wheat yield (Slafer, Araus & Richards, 1999).

3.3.2. Temperature affecting the yield of wheat

Temperature affects the growth of wheat from sowing until harvest. Changes in temperature during different phonological stages will have different effects on growth and development of wheat. Changed temperature at sowing time in late summer will either result in delayed crop establishment if it drop too low or in case temperatures increase, the emerging plants will show accelerated growth, resulting in higher vulnerability to cold stress occurring later during the winter. At any development stage temperature contributes to specific plant sensitivity, which also differs among genotypes and phenophase (Miralles & Slafer, 1999).

Wheat seed germinates at temperatures ranging from 12 – 25°C (Acevedo, Silvia & Silvia, 2002), depending mostly on wheat type (winter, spring or facultative).

Porter and Gawith, (1999) reviewed cardinal temperatures for the different growth stage of wheat including minimum, maximum and optimum temperatures for growth stage of wheat. Temperatures above 47.5°C or behind -17.2°C are beyond the tolerance limits for wheat plants. Slafer and Dawson, (1994) concluded that wheat responds to changes in temperature at all development stages. Entz and Fowler, (1988) reported that temperature sensitivity of wheat is lower at the vegetative phase than during the reproductive phase cited by (Porter & Gawith, 1999). The three most important stages affected by temperature, and directly influencing wheat yield are primordia initiation (leaf and spikelet initiation), anthesis, and grain filling stage. The range between minimum and maximum temperature for any of these stages lies at 20°C. The terminal spikelet phase, which occurs between the stage of primordia initiation (mainly spikelet initiation) and anthesis shows an optimal development at 10.6°C, whereby anthesis and grain filling stages are at 20.7° and 21° at their optimal development rate (Porter & Gawith,1999). Temperature influences the terminal spikelet; its initiation being delayed by a temperature increase from 10 to 19°c. But at 19°c the maximum spikelet number is found (Slafer & Rawson, 1994). Differently from anthesis, the temperature range for optimum fertilization has been ascertained at 18 – 24°C and assuming that other growth factors such as nutrient and moisture availability are adequate more than 80% of the florets will be fertilized resulting in high grain set (Subedi et al., 2000). Chilling (temperature less than 5°C) and high temperatures (above 30°C) are lethal to the pollen and will result in reduced fertilization rate; thus, the grain set will be reduced (Porter & Gawith, 1999). Pollen cells cannot produce heat shock proteins, which protect cells against heat damages, and this can explain the high sensitivity of pollen to heat stress (Stone, 1999)

High temperatures during the stage of grain filling result in reduced single grain weight, mainly because the grain filling period is reduced and also because the photosynthetic activity decreases, resulting in less assimilate accumulation in the single grain. The mobilization of vegetative (stem) reserves to kernel increases under heat stress, as compared to normal conditions where these reserves contributes less to the kernel weight (Dias & Lidon 2009). By contrast, most of the yield determinants are affected negatively by high temperature; tiller number (=ear per plant), spikelet per spike, and floret per spikelet, as well as the grain number per m^2 are reduced by elevated temperatures, therefore yield will consequently show a severe reduction (Stone, 1999).

In addition; associated with the climate change, the day/night temperature ratio will alter. Nighttime temperatures will decrease and the temperature difference between day – night will increase. (Lobell et al., 2005) reported that decreased night temperatures resulted in higher wheat yield in Mexico. another study has shown reductions in spring wheat yield due to increased nighttime temperature; with this reduction being mainly due to a decrease of photosynthesis, seed set and grain filling period (Prasad et al., 2008).

Plant response to root zone temperature

In general, due to increased root zone temperature germination of seed will speeded up, plant biomass increase, and root elongation and branching will be enhanced, whereas root zone temperatures below the optimum influence the water status by plant by reducing the stomatal conductance and photosynthesis (Füllner, 2007).

The effect of elevated root zone temperature on wheat has not been well investigated. A report from Nielsen and Humphries, (1966) suggest that root growth is more sensitive to temperature than the above-ground plant parts, cited by (Porter & Gawith, 1999). Tahir et al., (2008) studied the effect of high root and shoot temperature in environments where high temperatures are constraining wheat production. They found that elevated temperatures in the root zone negatively influence wheat growth; especially during the early growth stage high temperatures cause a decrease in xylem sap flow rate, dry weight, leaf area per plant and root / shot ratio. Furthermore elevated soil temperature affects the availability of soil nutrients (Füllner, 2007) and in environments where low temperature constrain wheat production, an increase in soil temperature may lead to higher growth rate and therefore positively influence wheat productivity. Patil et al., (2010) Showed in a study conducted in Foulum – Denmark, that soil warming enhances the vegetative growth of winter wheat but shortened the growing duration by about 12 days without reducing the grain yield.

In some environments higher temperatures will reduce the actual yield through influencing development stages determining yield formation, those regions are mostly located in developing countries, and at lower latitude, where heat stress during anthesis and at the grain filling phase results in shortening the grain filling phase, and therefore producing lower yield (Ortiz et al., 2008). At higher altitudes, low temperature limits yields, as well as wheat area expansion, therefore warmer conditions due to climate change may result in benefits for wheat production.

3.3.3. Precipitation affecting the yield of wheat

Plant growth and ultimately yield success depends to a large extent on the soil water availability (López-Urrea et al., 2009). Worldwide food production is rather limited by water access than by any other biotic or abiotic stress (Boyer & Westgate, 2004). In the next decades the demand for water will increase, mainly due to the growth of the world population and the effects of climate change (Tardieu, 2005). According to Falkenmark and Rockström, (2004) in 2050 more than 5600km^3 of water will be additionally required annually to keep up with the food demands of the rising world´s population, if no improvement of the water productivity occurred, cited by (Zwart et al., 2010). Mainly, plants responds to water deficit by reducing transpiration by two means; via reduced stomatal conductance in the short term or reduced leaf area in the longer term (Tardieu, 2005)

Boyer, (1982) studied the yield by environment relationship for the major six crops in the USA; maize, sorghum, wheat, barley, oat, and soybean and he found that the average yield was 18% off the global mean. This indicated that yield is limited by some constraints; thus Boyer, (1982) concluded that the soil water availability is the major contributor to the yield gap. Due to changes in rainfall amounts, the water use efficiency (WUE) is changing. Zhang and Oweis, 1999 reported that rainfall above

300 mm results in better WUE in comparison to rainfall of less than 300 mm, they worked with data from Mediterranean environment and they suggest that in water limited regions, irrigation should be applied at plant development stages which are more sensitive to water deficit aiming to enhance WUE.

Wheat is most susceptible to drought stress between jointing and heading. Westegate et al., (1996) reported that between booting and anthesis water deficit resulted in reduced floret set which they noted to be due to the decrease in shoot water status and increased accumulation of abscisic acid (ABA). However Dembinska et al., (1992) reported that ABA concentration is not the only factor reducing grain set in wheat cited by (Boyer & Wastegate, 2004). According to Rajala et al., (2009) water deficit prior to pollination reduces floret fertilization and grain set and results in reduced sink strength and thus a reduction in yield.

Many researchers have suggested that the reduced transpiration due to water shortage and thus the reduction of yield will be offset by the effect of the elevated CO_2 concentration in the atmosphere due to climate change. Schütz & Fangmeier, (2000) reported a 46 % increase of yield due to doubling of the atmospheric CO_2 concentration. They show that CO_2 enrichment increased the productivity of tillers more than that of the main stem, but no remarkable increase in single grain weight was noted. The soil water storage also may counteract the shortage and unfavorable distribution of precipitation; than Weather scenarios for the current century predict for the high latitudes regions an increase in winter rainfall and decrease of summer rainfall.

3.3.4. Constraints on wheat production in Germany due to climate change

In the 20th century, the average surface temperature in Germany has increased by 0.8°C (UBA, 2005). The precipitation is also changing worldwide; in the mid and high latitudes increased precipitation and increased heavy rainfall events have been reported in the last decades (Dore, 2005). Increased rainfall has occurred mainly in winter, and on the other hand drought events increased in summer (Christensen & Christensen, 2007). In Germany a reduced summer rainfall (30%) is predicted until 2100 whereas the winter rainfall will increase (30 %). In higher latitudes increased temperature and elevated CO_2 concentration (which counteract negative effects of water deficit) may lead to higher wheat yield. Lang, (1999) predicts positive impacts of climate change on German agriculture. However water excess in winter may lead to yield reduction and therefore reduce the gain resulting from temperature increase and CO_2 elevation. Dickin and Wright, (2007) reported that water logging has reduced the grain yield in winter wheat but they warned not to generalize this finding.

4. Materials and methods

The current experiment was a part of the project conducted by the Institute for Soil Science and Land Evaluation at the University of Hohenheim – Stuttgart (Poll, 2009). The project aims to investigate the soil organic carbon (SOC) turnover in arable land under manipulated climatic condition.

The project started 2007 including temperature and precipitation treatments. In the experimental plots soil heater and rain shelter were installed. Roofs on the rain shelter were only installed during summer to manipulate precipitation events that were expected to impact soil processes. In winter the soil is nearly water saturated and only the amount of precipitation was expected to influence soil processes like leaching, therefore no manipulation of precipitation events was conducted and the roof was removed. In this manner the experimental part of 2009 was conducted, which is the object of this thesis.

4.1. Experiment plan and design

The field experiment was established on arable field located on the research station for plant breeding Heidfeldhof (48°43´N, 9°13´E) with mean annual temperature of 8.5° and a mean annual precipitation of 685 mm. The soil is loess derived Luvisol with the soil texture silty loam (pH = 6.8 and organic carbon content = 10g/kg) (Poll 2009).

The experiment consisted of combinations of two temperature treatments and four precipitation manipulation treatments, and four replications.

TEMPERATURE:

- . ambient (AT)
- . elevated (ET) increase of the soil temperature up to 2,5°C in 4 cm depth.

PRECIPITATION:

- a: Ambient amount and temporal pattern of precipitation events (AMB).
- b: 25% decreased amount of precipitation and temporal pattern of precipitation events (25%_).

- c: Ambient amount of precipitation and decreased summer precipitation frequency by 50% (AMB→).
- d: 25% decreased amount of precipitation and decreased summer precipitation frequency by 50% (25%_→).

The target temperature increase at the 4 cm depth was set to 2.5 °C and summer rainfall was reduced by 25 % which are in the range of the expected increase of the mean annual temperature (2° - 3°C) as well as decrease of mean summer rainfall (20 – 30%) based on the scenarios of regional climate models for Germany.

Figure 1; Plot design with soil heating system and control thermometers (picture from Christian Poll)

The temperature manipulation was achieved with heating cables (thermocouple cable 611-7918, RS Components GmbH, Mörfelden-Walldorf, Germany) placed on the soil surface as the Figure 1 shows. To control and regulate the temperature thermometers were installed in the plots and connected to a controlling system, to ensure a constant temperature difference between both heated and unheated treatments. The heated and unheated plots which were located under rain shelter were 1x4m in the size, and here the four different precipitation manipulation treatments were conducted. The plots serving as roof control had also the same size and included only temperature treatments (ambient temperature with ambient precipitation and elevated temperature with ambient precipitation) and exclusion earthworm treatments, but this last treatment was not considered in the object of this thesis.

The roofs consisted of light and UV transparent greenhouse film (dm-folien GmbH, Reutlingen, Germany) it was fixed to shelter installed 2m above the surface and covered an area of 27,3m^2 and has open sides to allow free air movement. The roofs were installed about two months after sowing on 28.05.2009. Natural precipitation was gathered from the roof with gutters into storage tanks near the plots and the collected water was used to watering the plots of precipitation manipulation treatments. The different water amount for the precipitation manipulation treatments was applied with watering can.

The spatial arrangement of the experimental plots is shown in Figure 2.

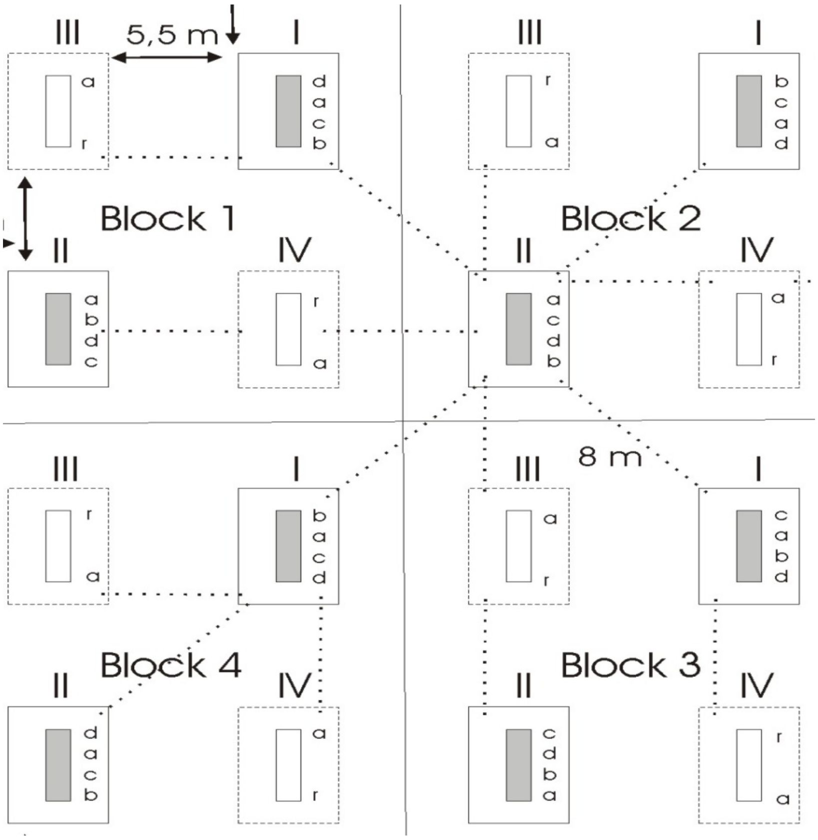

Figure 2: the spatial arrangement of the experimental plots, roofed plots appear grey shaded and the white one are the unroofed plots, plots with the roman numbers I and III are the heated plots and the plots with II and IV are the unheated plots. The letter a, b , c, and d represent the four precipitation treatments (provided by Christian Poll)

4.2. Field experiment and management.

The cultivar was spring wheat (*Triticum aestivum* L. CV Triso). Triso is classified as elite quality wheat; according to Bundessortenamt, (2010)-Germany E-quality means high in minimum requirement for quality like falling number, crude protein, flour yield and others. Triso has a high protein content and robust grain yield and can also perform well as facultative wheat. It is registered since 1996; can be sown in a wide range of environments and still has a good distribution among farmer´s in Germany (DSV, 2010).

Figure3: the view of the experimental plots before the installation of the roof
(picture from Christian Poll)

Figure 4: and the view after the installation of the roof
(picture from Christian Poll)

During the cropping period the average temperature was about 15.6°C (7.4°C min and 24°C max). Temperature was measured by the meteorological station of the Mini-FACE project belonging to the Institute for Landscape and Plant Ecology, University of Hohenheim. The precipitation amount which was recorded during the cropping period was 438mm. the precipitation measurement was taken from the meteorological station of the German weather service (www.dvd.de) located in the Stuttgart airport not far from the research station. The course of the precipitation and temperature are shown in Figure 5 below.

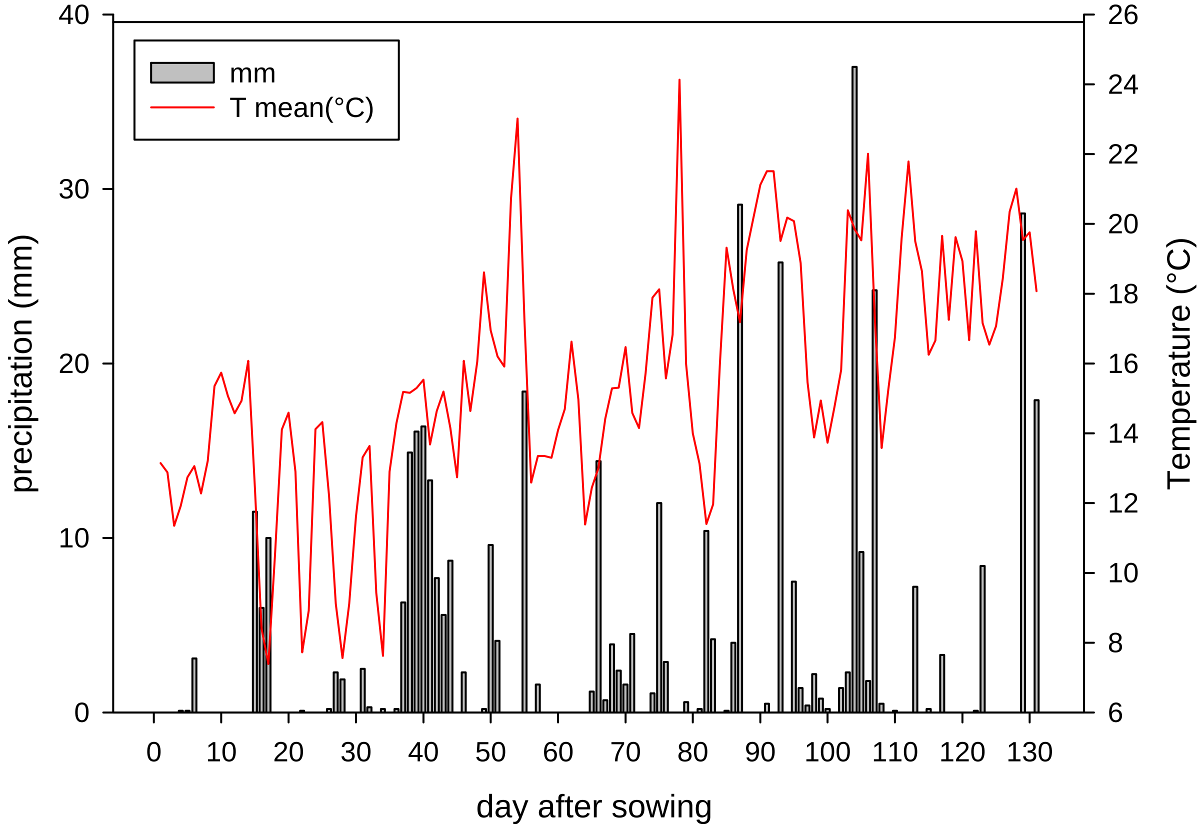

Figure 5: Daily records of temperature (°C) recorded by the meteorological station of the Mini FACE near the experimental field and precipitation (mm) taken from the meteorological station of the Stuttgart airport from 2nd April till 10 August 2009. Meteorological data was provided by (Högy 2009)

Sowing was conducted on 2nd of April 2009. Each subplot was divided in 9 rows sown with a seeding rate aiming to establish 450 plants per m². To ensure the establishment of 450 plants per m² two grains were sown to each hole and thinned out to 450 plants per m² on 12./13.05.2009.

Fertilizer application was carried out twice on 29 .04.2009 with kalkammonsalpeter, 50 kgN/ha and 16.06.2009 with kalkammonsalpeter, 26 kgN/ ha. The available soil nutrients were not measured.

Pest management was conducted twice:

- Herbicide application (Ralon super and Ariane C) on 07.05. 2009,
- Fungicide (Opus Top 21) on 08.07.2009

Figure 6: During harvesting the core of the plot was split into two parts, one part was investigated in the current thesis

All management steps such as ploughing, fertilizer application were performed by hand.

Harvesting of the above ground plant biomass was done on 11and12.08.2009. The harvest was carried out by hand with plants being cut closely above the soil surface

4.3. Measurement and data collection

The sampled area was 50x25cm from the core of the plots of each treatment. Measurement on plants was carried out in several steps. During harvest the number of plant per m² was evaluated at the same time the separation between main stem and tiller was done and then stored in separate paper bags of adequate size.

The measurement of the length of the different plant parts was done with a yardstick. The length of stem, peduncle and ear was recorded, after that the biomass was separated in straw and ear which than was dried to constant weight in an oven with 75°C for 48 hours and afterwards the dry weight was determined using a kern balance with 0.1g readout (www.kern-sohn.com).

The next step aimed to determining the components of the grain yield incrementally and this has been done separately for main stems and tillers respectively. A subsample of 20% from the evaluated 50x25cm area was analyzed in detail. The following yield components at spike level were determined:

- Ear length with an without awn
- Basal spikelet: is the spikelet not bearing grain at the initial of the spike
- Spikelet bearing grain
- Sterile floret: are the florets which had been initiated but not further developed to set a grain (unfertilized or aborted floret)
- Ear weight
- Grain number per spike
- Shrunken grain number and weight
- Total grain weight per spike

The total grain yield was determined after threshing the rest of the plants so that the total grain yield was recorded not only from the 20% subsample.

Furthermore, to understand the climate effect on the yield the single grain weight for each spike from the 20% subsample was determined separately. Kernel by kernel was weighted using a PRECISA balance. To enable faster and preciser gathering of the single kernel weight the balance was linked to the program Balint 5.00 (Precisa Instrumenst AG, Moosmattstr. 32 – 8953 Dietikon/Switzerland). Afterwards the thousand kernel weight (TKW) was calculated from the single kernel weight measurement.

4.5. Statistics

Data were analyzed with the SAS (version 9.2) program. The experiment was arranged as a randomized block design with four repetitions for each treatment. To investigate the difference between the treatments an ANOVA with Tukey test at $p<0.05$ was applied.

5. Results

5.1. Effects of increased soil temperature

The heating cables placed on the soil surface had the objective to increase the root zone temperature by 2.5°C at 4 cm depth. During the study the thermometers of the controlling systems of the heating application have recorded an average of 1.77 °C increase in unroofed plots and 2.18 °C increase in the roofed plots. This means that the aspired 2.5°C increase of soil temperature was not completely reached and the roof have supported the increase of the soil temperature. To evaluate the effects of the soil temperature elevation only the data coming from the roofed plots were analyzed.

5.1.1. Temperature and phenological stages

The growing period, from sowing until the physiological maturity lasted in this experiment 131 days from 2nd of April until 10th of August, this is quite usual for spring wheat. Since evaluation of the different phenological phases (emergence, tillering, booting, heading, anthesis, and grain filling) was not conducted, which would have been useful to interpret the effects of the different treatments on the different plant growing phases, only a comparison with the information about the examined variety provided by the breeding company and data from other research work (Dias & Lidon, 2009) had helped to somehow overcome this restriction.

According to the information of the breeding company the variety Triso need until seedlings emergence about 11 to 13 days, this would had happened in the second week of April where the main temperature was about 13 °C. Temperature mentioned here was measured outside the experimental plots therefore this temperature level will be not the same that has occurred in the heated plots. The second important phenological phase for the yield determination is the spikelet initiation phase which would have happened at end of April or beginning of May where temperatures on average has reached 14 °C. In Addition to this spring wheat needs to reach the heading stage between 60 and 75 days. So in this experiment this would have happened in the first two weeks of June, where the main temperature was at 16 °C.

After the plants completed the stage of heading anthesis began, this would have occurred at middle of June with average temperatures of 16 °C, afterwards the grain filling phase started. Grain filling phase would have happened from middle of June until August at this time temperatures varied between 16 and 20 °C. The course of the temperature during the growing period is shown in Figure 7. The temperature fluctuation (difference between minimal and maximal temperature) was higher in April and May compared to June, July and August.

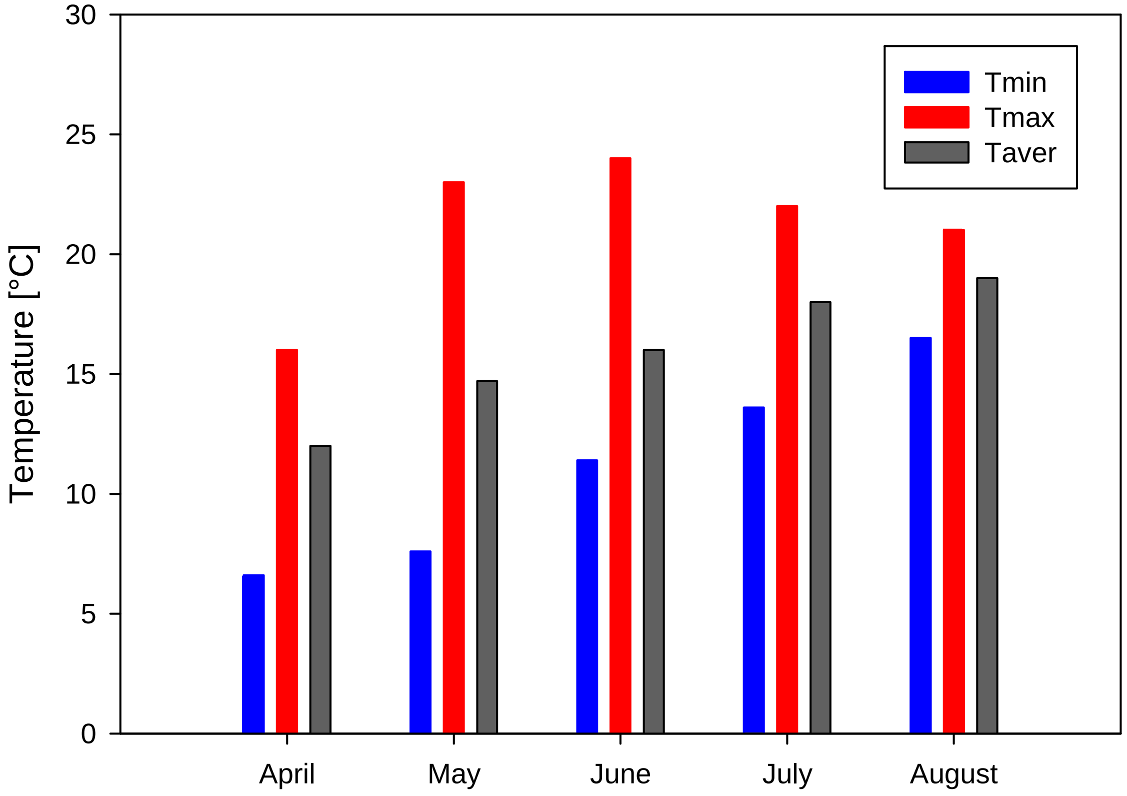

Figure 7: the course of temperatures (Tmin: minimal temperature, Tmax: maximal Temperature Taver: average temperature) between April and august measured near the experimental field

5.1.2. Effects of increased soil temperature on plant height and ear length

The increase of soil temperature affected the plant growth stronger than the roof treatments. As shown in the table 1. Stem length was significantly ($p<0.01$) increased by 2.6 cm on average with higher soil temperature compared to ambient soil temperature. Increased soil temperature also resulted in significantly longer peduncles (0.8 cm on average between the treatments; p<0.05). Again the ear length responded significantly to increased soil temperature, compared to the ambient soil temperature the length of ear increased by 0.85 cm on average with higher soil temperature (p<0.001).

Table 1: the average of the stem, peduncle and ear length in cm. Means in one row followed be the same letter are not significantly different at p<0.05.

	AMB*	AMB*+T	25%_*	25%_*+T	AMB->*	AMB->*+T	25%_->*	25%_->*+T
stem length/cm	51.1 ± 2.0a	56.4 ± 0.7b	50.2 ± 1.6a	52.5 ± 2.7b	51.8 ± 2.3a	54.0 ± 1.3b	51.1 ± 1.4a	53.6 ± 1.5b
peduncle length/cm	19.3 ± 0.8a	19.8 ± 0.6b	18.8 ± 0.7a	19.8 ± 0.6b	18.6 ± 0.7a	19.7 ± 0.9b	19.7 ± 0.9a	19.9 ± 0.9b
ear length/cm	6.1 ± 0.4a	7.1 ± 0.2b	5.9 ± 0.1a	6.7 ± 0.3b	5.9 ± 0.3a	7.0 ± 0.4b	6.1 ± 0.2a	6.7 ± 0.3b

Note: AMB: ambient precipitation and ambient temperature, T: indicates the elevation of soil temperature; *: indicates the presence of the rain shelter (roof); 25%_: indicate the reduction of precipitation amount at 25%, and→: indicate the reduction of the precipitation frequency at 50%.

5.1.3. Effects of increased soil temperature on yield components

Table 2: Average straw and grain weight [g/m²]. the TKW [g] and the HI. Means in one row followed by the same letter are not significantly different at p<0.05.

	AMB*	AMB *+T	25%_*	25%_* +T	AMB-->*	AMB-->* +T	25%_-->*	25%_-->* +T
straw weight[g]	794 ± 49	902 ± 72	837 ± 43	853 ± 70	753 ± 69	822 ± 25	704 ± 58	816 ± 51
grain weight[g]	640 ± 56a	860 ± 72b	640 ± 20a	776 ± 61b	562 ± 68a	800 ± 12b	550 ± 54a	771 ± 40b
HI	0.44a	0.49b	0.43a	0.48b	0.42a	0.49b	0.44a	0.49b
TKW[g]	41 ± 1a	43 ± 0.6b	41 ± 0.4a	43 ± 0.6b	41 ± 1a	43 ± 1b	42 ± 0.7a	44 ± 0.3b

Note: AMB: ambient precipitation and ambient temperature, T: indicates the elevation of soil temperature; *: indicates the presence of the rain shelter (roof); 25%_: indicate the reduction of precipitation amount at 25%, and→: indicate the reduction of the precipitation frequency at 50%.

In the table 2 the effect of the temperature on the yield components is shown. The number of ears per m² was not changed in all of the treatments. The soil temperature did not influence the straw weight. Neither in the heated plots nor in the plots with ambient soil temperatures, was the straw weight significantly different.

The grain weight was significantly (p<0.001) increased by 34 % on average with increased soil temperature compared to ambient soil temperature. Though the harvest index was affected by temperature, plots with increased soil temperature reaches a HI by 0.49, this was significantly (p<0.001) higher than that reached by the plots with ambient soil temperature (HI was on average 0.44). Furthermore the TKW of the plants in plots of the increased soil temperature treatments was significantly increased by 5% on average compared to the treatments with ambient soil temperature (on average TKW reached 43.5 g with increased soil temperature compared to 41.4 g for ambient soil temperature).

5.1.4. Effects of increased soil temperature on ear components

The effect of the temperature on the ear components is shown in the table 3. At the ear level most of the components was affected by increase of the soil temperature.

Table 3: average of the ear components measured from a 20% subsample. Means in one row followed by the same letter are not significantly different at p<0.05.

	AMB*	AMB *+T	25%_*	25%_*+T	AMB-->*	AMB–>*+T	25%_-->*	25%_–>*+T
spikelet bearing grain	12.2 ± 0.8a	14.2 ± 0.7b	11.7 ± 0.3a	13.9 ± 0.8b	11.2 ± 1a	14.4 ± 0.5b	11.3 ± 0.5a	13.7 ± 0.5b
basal spikelet	4.6 ± 0.3a	3.9 ± 0.4b	5 ± 0.36a	3.75 ± 0.2b	5.6 ± 0.5a	3.7 ± 0.4b	5.1 ± 0.4a	3.75 ± 0.3b
ear weight/g	1.02 ± 0.1a	1.4 ± 0.2b	1.05 ± 0.04a	1.45 ± 0.1b	1 ± 0.1a	1.48 ± 0.1b	1.05 ± 0.1a	1.4 ± 0.1b
sterile floret	14.8 ± 0.8a	17.7 ± 1.3b	13.7 ± 0.28a	17.4 ± 1.1b	13.3 ± 1.3a	17.7 ± 0.7b	13.5 ± 0.8a	16.5 ± 1.2b
grain number / ear	22 ± 2a	25.7 ± 2.5b	20.1 ± 0.6a	26.7 ± 1.6b	18.9 ± 2.1a	27.1 ± 1.6b	20.1 ± 1.7a	25.8 ± 1b
shrunken grain / ear	0.47 ± 0.1	0.8 ± 0.2	0.37 ± 0.16	0.22 ± 0.1	0.18 ± 0.1	0.2 ± 0.1	0.33 ± 0.2	0.23 ± 0.1
grain weight / ear	0.95 ± 0.1a	1.18 ± 0.1b	0.86 ± 0.03a	1.17 ± 0.1b	0.81 ± 0.1a	1.2 ± 0.1b	0.82 ± 0.1a	1.12 ± 0.1b

Note: AMB: ambient precipitation and ambient temperature, T: indicates the elevation of soil temperature; *: indicates the presence of the rain shelter (roof); 25%_: indicate the reduction of precipitation amount at 25%, and →: indicate the reduction of the precipitation frequency at 50%.

In average with higher soil temperature a significantly (p<0.001) increase of the number of spikelet-bearing grains by 22% was observed. On the contrary with higher soil temperature the number of basal spikelets declines significantly (0.001) by 27%. In average only 3.7 basal spikelets were found by plants in plots with increased soil temperature compared to 5.1 basal spikelets by plants in plots with ambient soil temperature. Basal spikelet is that spikelet which does not bear grain and found at the initial of the spike. In addition the ear of the plants found in the heated plots was significantly ($p<0.001$) heavier than that found in plots with ambient soil temperature. In heated plots the ear weight increased by 3.3% on average.

In the plots with increased soil temperature the number of sterile florets per ear was significantly ($p<0.001$) increased by 25% on average compared to the ambient soil temperature (17.3 sterile florets in heated plots, and 13.8 sterile florets in unheated plots). The number of grains per ear was also significantly ($p<0.001$) different. With increased soil temperature the number of grains per ear increased by 30% on average compared to the ambient soil temperature (on average there were 26.3 grains per ear in heated plots, and 20.2 grains per ear in unheated plots). On the contrary, the number of shrunken grains per ear did not significantly vary between the heated and unheated plots.

5.1.5. The difference between main stems and tillers in their response to increased soil temperature

Main stems and tillers response differently to increased soil temperature. The stem length as well as peduncle length show on general significant difference due to temperature. But looking at both separately shows that no difference can be noticed. In fact the ear length has shown only by the tillers to differ significant with increased soil temperature. The length of the ears of the main stems did not reveal any difference.

For the yield components; the grain weight was significantly increased due to increased soil temperature. Looking at the grain weight for main stems and tillers separately shows that neither the grain weight of the main stems nor that of the tillers was significantly different. The harvest index in the main stems as well as in the tillers revealed the same significant increase due to increased soil temperature. The TKW neither for the main stems nor for the tillers was increased due to increased soil temperature, although in general a significant increase of the TKW has been shown due to the heating of the soil.

At the ear components level there were also difference between main stems and tillers. Where, on general the spikelet-bearing grains was increased due to soil heating, this difference has been not confirmed at the main stems or tillers level. Actually, the number of basal spikelets has been significantly decreased due to increased soil temperature and this decrease was ratified also at the main stems and tillers level respectively. Similarly was shown by the ear weight which was increased due to soil heating and this increase was also verified for the main stems and tillers respectively.

The number of sterile florets, the number of grains per ear and the grain weight per ear was increased due to increased soil temperature; this was at the same significance for both main stems and tillers.

5.2. Effects of the changes in the precipitation patterns.

Changing the precipitation patterns affected only the number of tillers and the number of the shrunken kernels per ear, other collected parameters did not show any difference. In average, in all treatments, less than one shrunken kernel per ear was observed. Reduced precipitation amounts and decreased precipitation frequency decrease the number of shrunken kernels. With ambient precipitation on average 0.62 shrunken kernel per ear was evaluated, this was significantly higher compared to the number of shrunken kernels in the three treatments of manipulation of the precipitation patterns (25%_, AMB→, and 25%_→), where 0.29, 0.19 and 0.27 shrunken kernel per ear were observed respectively.

The tiller numbers per plant differentiated also due to the changes in the precipitation patterns. In the treatment with 25% less precipitation amount the number of tillers was significantly higher compared to that measured by the treatment with 25% less precipitation amount at 50% less precipitation frequency. The number of tillers by the treatment with ambient precipitation amount and by the treatment with ambient precipitation amount at 50% less precipitation frequency shows no difference compared to the first two treatments (figure 2).

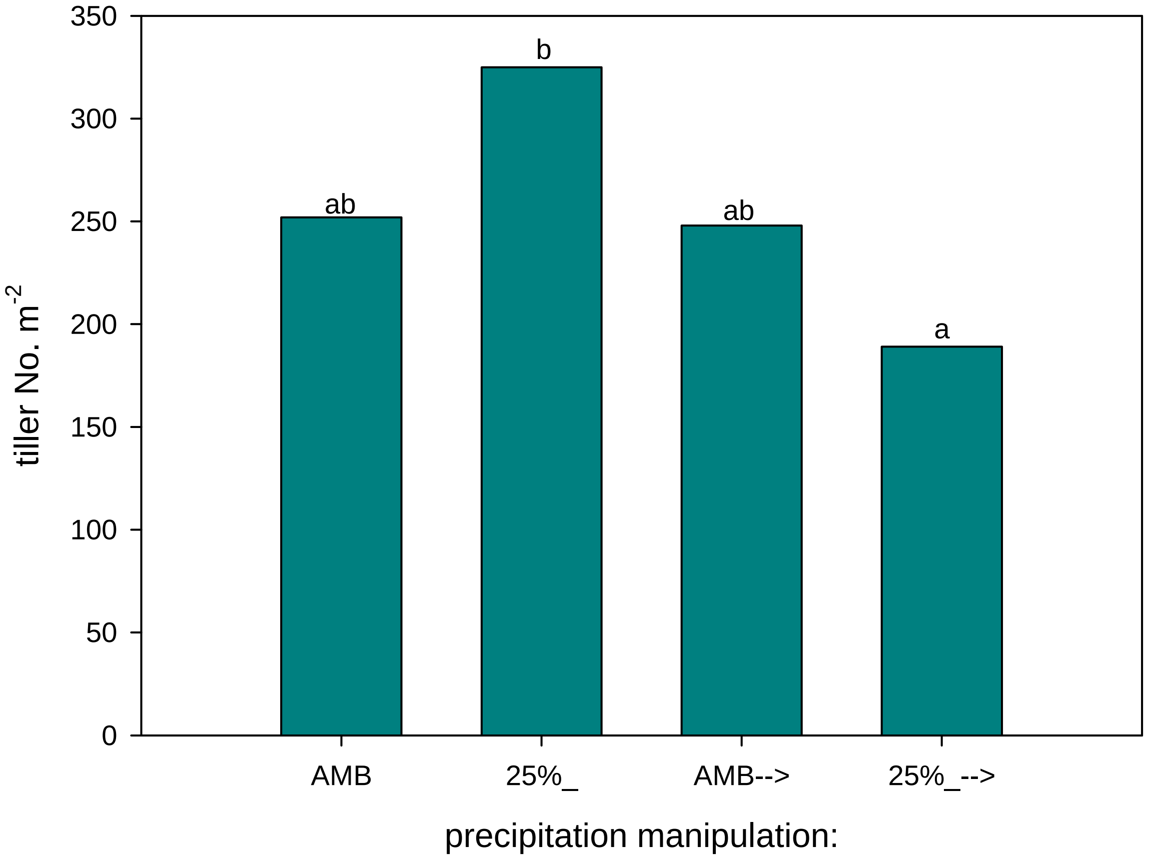

Figure 8: precipitation manipulation treatments and their effects on the number of tillers [m²]. Means sharing the same letter are not significantly different, p<0.05.

AMB: ambient precipitation, 25%_: reduction of precipitation amount at 25%, and -->: reduction of the precipitation frequency at 50%.

5.3. Effects of roof

5.3.1. Effects of roof on the plant height and ear length

Table 4: the average of the stem, peduncle and ear length in cm. Means in one row followed by the same letter are not significantly different at p<0.05.

	AMB	AMB + T	AMB*	AMB *+ T
stem length/cm	49.7 ± 1.6a	49.3 ± 3a	51.05 ± 1.95b	56.35 ± 0.65b
peduncle length/cm	17.65 ± 0.5a	18.55 ± 1.2a	19.3 ± 0.75b	19.75 ± 0.6b
ear length/cm	6.06 ± 0.2a	6.32 ± 0.3a	6.12 ± 0.35b	7.05 ± 0.18b

Note: AMB: ambient precipitation and ambient temperature, T: indicates the elevation of soil temperature; *: indicates the presence of the rain shelter (roof).

The average length of the different plant parts are shown in table 4. Roof has influenced the plant high and ear length notably. Stem length of the plants standing under roof show significantly (p<0.001) taller growth than stem length that found by the plants in plots without rain shelter. Plants of the variant AMB* and plants of the variant **AMB+T*** of the roof treatment show in average 51.05 and 56.35 cm stem length respectively compared to the control treatments **AMB** and **AMB+T** with average 49.7 and 49.3 cm length respectively. Peduncle (the stalk of the inflorescence of the wheat plant) was under rain shelter significantly (p<0.01) taller in comparison treatments without rain shelter. Under roof the average peduncle length of **AMB*** and **AMB+T*** was 19.3 and 19.75 respectively. Under roof also the average of ear length was significantly (p<0.05) higher than those of the treatments without rain shelter. The average ear length of **AMB*** and **AMB+T*** reaches 6.12 and 7.05 respectively compared to 6.05 and 6.32 of the control treatments AMB and AMB+T.

5.3.2. Effects of roof on the yield components

Analysis of variance shown in table 5 indicates that harvest-index as well as TKW was affected by the roof treatments. However the straw and grain weight was not influenced by the roof.

Table 5: Average straw and grain weight [g/m^2]. The TKW [g] and the HI. all the parameters was compiled from 50x25 cm plot area. Means in one row followed by the same letter are not significantly different at $p<0,05$.

	AMB	AMB + T	AMB*	AMB *+ T
straw weight/g	848 ± 24	794 ± 49	816 ± 80	902 ± 72
grain weight/g	616 ± 18	640 ± 56	709 ± 85	860 ± 72
HI	0.42a	0.46a	0.44b	0.49b
TKW/g	40.7 ± 0.4a	41 ± 0.3a	41.4 ± 1b	43.4 ± 0.6b

Note: AMB: ambient precipitation and ambient temperature, T: indicates the elevation of soil temperature; *: indicates the presence of the rain shelter (roof).

The straw weight ranges from 99.3 g at **AMB*** to 112.8 g at **AMB*+T** whereby it reaches 106 g and 102 g at **AMB** and **AMB+T** respectively without having statistical difference between the roof treatments and the control.

For the grain weight also statistical analysis did not show any difference between the control and the roof treatments.

The HI ranges between 0.42 for AMB and 0.46 for **AMB+T** this was significantly ($p< 0.05$) lower than the HI for plants of the roof treatment which ranges between 0.44 by **AMB*** and 0.46 for **AMB*+T**. In both roof treatments with and without increase of soil temperature the TKW shows statistically significant ($p<0.01$) higher value than by the treatments without roof. It reaches 41.4 and 43.4 g respectively. In the treatments without rain shelter, this was 40.7 and 41 g for ambient temperature and increased temperature respectively.

5.3.3. Effects of roof on the ear components

To evaluate the ear components a subsample of 20% of the plants grown in the 50x25 cm plot area was sampled. This analysis includes most of the ear components shown in the table 6 below.

Table 6: average of the ear components measured from a 20% subsample. Means in one row followed by the same letter are not significantly different at p<0.05.

	AMB			AMB + T			AMB*			AMB *+ T		
spiklet bearing grain	10.85	±	0.5a	12.1	±	0.65a	12.2	±	0.75b	14.17	±	0.73b
Basal spiklet nb	5.27	±	0.25a	4.23	±	0.37a	4.6	±	0.32b	3.9	±	0.37b
ear weight/g	1.15	±	0.05	1.15	±	0.07	1.02	±	0.11	1.4	±	0.17
sterile floret / ear	14.45	±	0.66a	14.4	±	0.83a	14.75	±	0.79b	17.7	±	1.25b
grain nb / ear	22.8	±	0.9	23.3	±	1.25	22	±	1.95	25.65	±	2.45
grain weight / ear g	0.9	±	0.04a	0.95	±	0.06a	0.95	±	0.09b	1.18	±	0.09b

Note: AMB: ambient precipitation and ambient temperature, T: indicates the elevation of soil temperature; *: indicates the presence of the rain shelter (roof).

The number of spikelet-bearing grains in the treatments without rain shelter was significant ($p < 0.05$) lower than in the roof treatment. Plants standing beneath the rain shelter have shown more spikelet-beset with grains than those of the plots without roof. Furthermore the number of spikelet-bearing grain responses significantly ($p<0.05$) to the interaction between roof and temperature. On the contrary the number of basal spikelets lies significantly ($p<0.05$) higher by treatments without roof than in the roof treatments. The basal spikelet is the initial spikelet on the ear which did not further developed into spikelet-bearing grains; even more no floret was being recognized which could have been set early in the development stage. The number of sterile florets was also significantly ($p<0.05$) affected by the roof treatment. Under rain shelter: Plots with elevated soil temperature show more sterile florets than plots with ambient soil temperature. The same was noticed for the grain weight per ear, we could observe significantly heavier ear for plant standing under rain shelter in comparison to those of the control treatments; under rain shelter grain weight per ear was higher in plots with increased soil temperature compared to plots with ambient soil temperature.

The ear weight as well as the grain number per ear did not show any difference due to the roof treatment.

5.3.4. The difference between main stems and tillers in their response to roof.

All of the measurements, which were conducted to the main stems and tillers, were done separately. This enabled the evaluation of the different effect of the treatments on the main stems and tillers respectively.

The effect of the roof on the stem length was stronger to the tillers ($p<0.01$) than to the main stems ($p<0.5$). For the roof treatment the peduncle length of the main stems was significantly affected, on the contrary to that of the tillers which was not influenced due to the presence of the roof. On general roof increase the ear length significantly ($p<0.05$) but looking at the ear length for the main stems and tillers separately shows no difference between roof treatments and control.

For the yield components only the HI and TKW show significant difference between roof treatments and control. This difference was mainly at the main stems level whereas at the tillers level the HI and TKW were for roof treatments and treatments without roof not significantly different.

Looking for the ear components separately for main stems and tillers we could notice that number of spikelet-bearing grains and number of basal spikelets were not different for roof treatments and treatments without rain shelter, although on general they have shown significant difference. The number of sterile florets shows also in general significant difference and this difference has been shown only by the tillers. In contrary to the grain weight per ears has been noticed to be significantly different only by the main stems.

5.4. Single kernel weight analysis

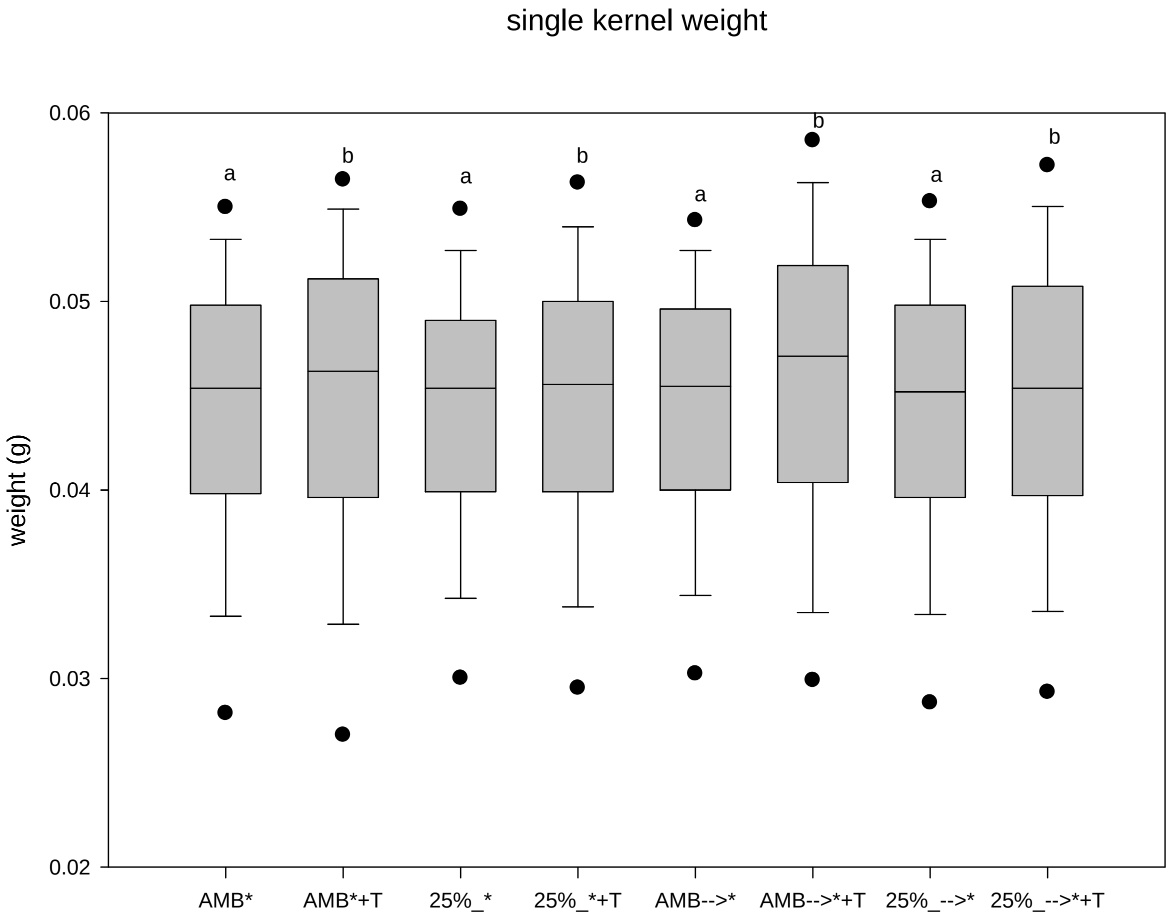

Figure 9: single kernel weight analysis

Note: AMB: ambient precipitation and ambient temperature, T: indicates the elevation of soil temperature; *: indicates the presence of the rain shelter (roof); 25%_: indicate the reduction of precipitation amount at 25%, and →: indicate the reduction of the precipitation frequency at 50%.

In general the weight of the single kernel is one of the determinants of the yield by wheat; therefore the single kernel weight analysis could provide more detailed information on the yield structure. In the current analysis mostly the temperature had affected the weight of the single kernel but also like in figure 9 indicates reduction of precipitation amounts by 25% resulted in less heavy kernel for both the heated and unheated plots compared to the other treatments. Nevertheless, due to the ANOVA test, the effect of the precipitation on the single kernel weight was not significantly different between all treatments. On the contrary to the statistical test shows for the temperature a significant differentiation impact on the single kernel weight.

For the ANOVA test curried out for the single kernel weight analysis we used the mean, the minimal, and the maximal weight of the kernel. In heated plots the mean and the maximal weight of the kernel were increased significantly compared to that measured by the plants of the plots with ambient soil temperature. On average, in the heated plots the mean weight of the single kernel increased by 5 %compared to the ambient soil temperature. The maximal kernel weight with increased soil temperature reached on average an increase by 7 % compared to the ambient soil temperature (0.06 g with increased soil temperature, and 0.056 g with ambient soil temperature). For the minimal weight of the kernel no significant difference was observed, this maybe because of the including of the shrunken kernel in the measurement.

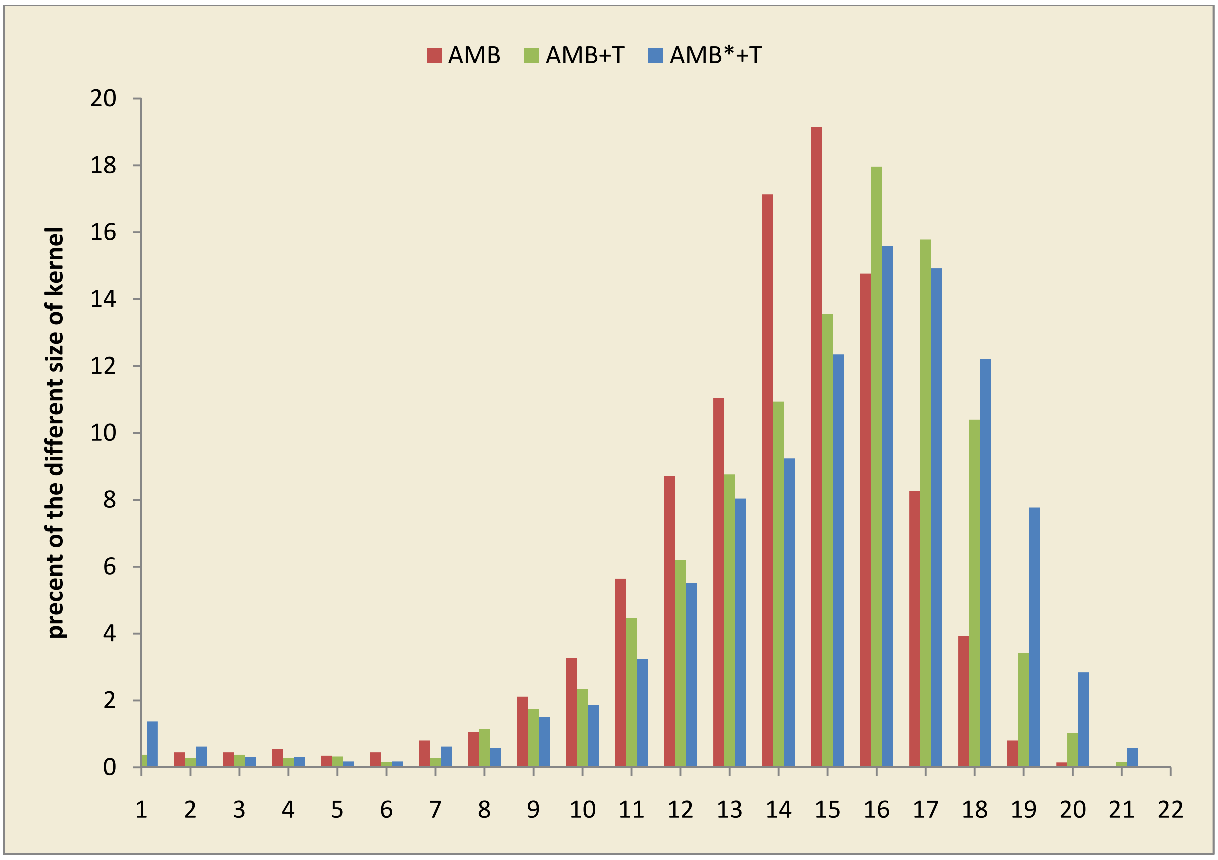

Figure 10: the distribution of the kernel size; 22 size classes were defined, 1st class is for the kernel with weight between 0.003 to 0.006 g, 2nd class for the kernel with weight between 0.006-0.009 g and further so on till the 22nd class for the kernel with weight between 0.063 to 0.066 g.

In Figure 10 the distribution of the kernel size is shown, and indicates that due to increased soil temperature the proportion of heavier kernel with more than 0.045 g (off class 16^{t}) was higher compared to the ambient soil temperature. In addition this trend was boosted in the presence of roof. This trend was also maintained despite the different precipitation manipulation treatments. (Appendix 11)

When analyzing separately the single kernel weight of the main stems and the tillers a significant difference due to increased soil temperature and precipitation manipulation is also found.

In the main stems the minimal kernel weight was not influenced by the treatments either due to the temperature elevation or due to the manipulation of the precipitation. On the contrary the mean weight of the kernel and the maximal weight were influenced. Due to increased soil temperature the main weight of the kernel was increased significantly by 2.3% compared the ambient soil temperature. Again with increased soil temperature the maximal weight of the kernel was increased significantly by 5% compared to the ambient soil temperature.

In the tillers elevation of the soil temperature also has affected the kernel weight. In average the mean weight of the kernel were increased in about 8 %. In the heated plots the mean weight was 0.041g, whereby in the plots with ambient soil temperature on average the mean weight of the kernel reached only 0.038 g. Meanwhile the maximal and the minimal weight of the kernel by the tiller did not show any different due to temperature elevation.

5.5. Yield anaylsis

5.5.1. Main stem and tiller contribution to the yield

The yield of wheat is the composition of the yield of the main stems and that of the tillers (figure 10). In general, the total grain yield was higher in the treatments with increased soil temperature as compared to treatments with ambient soil temperature. The contribution of the main stems and tillers to the total grain yield was but differently variable. While in the control treatment the attribution of the tiller to the yield was in about 17.6%, with soil temperature elevation at ambient precipitation amount and frequency tillers have attribute only 15.4% to their total grain yield and this was less compared to the control treatment.

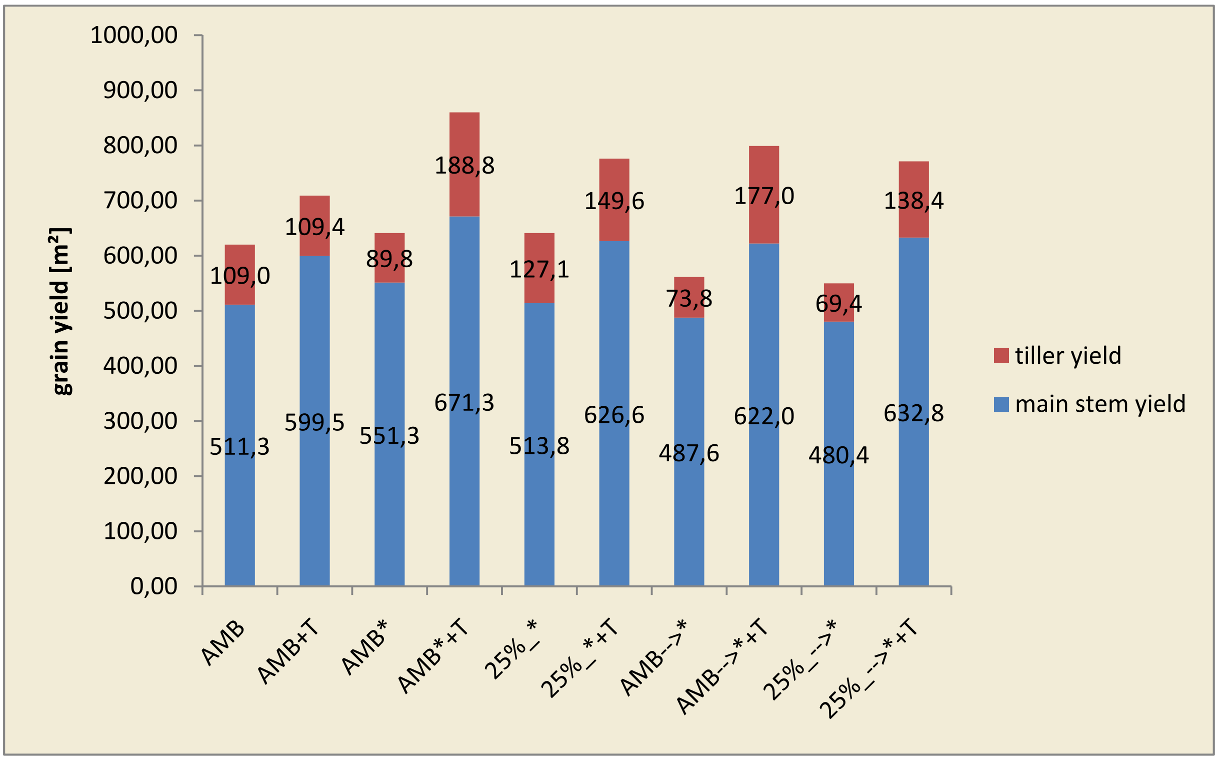

Figure 11: the measured grain yield [g/m²] consisting from the yield of main stem and the yield of tiller

Note: AMB: ambient precipitation and ambient temperature, T: indicates the elevation of soil temperature; *: indicates the presence of the rain shelter (roof); 25%_: indicate the reduction of precipitation amount at 25%, and →: indicate the reduction of the precipitation frequency at 50%.

Moreover, in the treatment which includes rain shelter tillers attribution to the total grain yield was compared to the control treatment higher with increased soil temperature and lower with ambient soil temperature, whereby in the treatments with 25% reduction of precipitation amounts the contribution of the tillers to the total yield was for both temperature treatments similar but still higher compared to the control treatment. A Table which show the percental attribution of the yield of main stems and yield of tillers to the total grain yield is shown in the appendix 1

5.5.1. Potential yield

Furthermore, in general the composition of the yield is the result of the plants per m², ears per plant, spikelets per ear, kernels per spikelet and single kernel weight. In the current experiment we had determined the number of ears per m², the number of the spikelet-bearing grains, the number of the basal spikelets, the number of sterile florets. The number of grains (filled grain) and the single kernel weight, this components help to calculate the potential yield with the following formula:

Potential yield = ear per m² * spikelet per ear * potential grain per spikelet * grain per potential grain * single kernel weight

Hereby the number of spikelets per ear is the addition of the number of spikelet-bearing grains and the number of basal spikelets. The potential grain per spikelet results from the number of grains per ear plus the number of sterile florets. The number of grains per potential grain is the number of grains per ear, but calculated with the consideration of the number of sterile florets (unfertilized or aborted floret).

In Table 7 the potential yield for the control as well as all of the treatments is listed. Separation between main stems and tillers was also done to obtain deeper understanding on the yield formation and to be able to extract the share of the main stems as well as of the tillers on the yield formation.

For the main stems; in all of the treatments the number of spikelets per ear increased in average by 16 % compared to the control. In all of the treatments the number of potential grains per spikelet was lower compared to the control. The number of grains per potential grain was with increased soil temperature similar with that of the control and lower by the variants with ambient soil temperature. The single kernel weight was in all treatments on average by 7.5% heavier compared to the control, thereafter as a result, the main stems shows by the variants with increased soil temperature higher potential yield compared to the potential yield of the main stems of the control.

Differently from the main stems the number of tillers varied and in all of the treatments the number of tillers was lower than that of the control, only by the variant with ambient soil temperature at 25% reduction of precipitation amounts the numbers of tillers exceed that of the control. The number of spikelets per ear increased by 3% with increased soil temperature and rain shelter, and with ambient soil temperature and rain shelter decreased by 8%, also a decrease by 8% was observed by the variant **AMB+T**. Compared to the control, the number of potential grains per spikelet increase with increased soil temperature and decrease with ambient soil temperature. The number of grains per potential grain was in all of treatments lower than that of the control, exceptionally, the variant **25%_→** shows no difference compared to the control. In addition in all of the treatments on average a slight enhancement of the single kernel weight by 9 % was observed.

Table 7: potantial yield as the composition of the number of ears per m^2, the number of spikelets per ear, the number of potential grains per spikelet, the number of filled grains per potential grain and the single kernel weight.

	AMB	AMB+T	AMB*	AMB*+T	25%_*	25%_*+T	AMB-->*	AMB-->*+T	25%_->*	25%_-->*+T
main stems (MS)										
ears no.m^{-2}	450	450	450	450	450	450	450	450	450	450
Spikelets/ear	15.53	17.2	18.1	18.3	18.1	18.5	18.2	18.6	17.9	18
pot. grains/spikelet	2.97	2.75	2.68	2.70	2.52	2.86	2.30	2.81	2.42	2.78
grains/pot. grain	0.63	0.64	0.62	0.63	0.61	0.63	0.61	0.63	0.60	0.63
SKW	0.041	0.044	0.044	0.0443	0.044	0.0443	0.0441	0.0457	0.0438	0.0446
MS yield [g/m^2]	534.5	595.2	588.6	624.0	546.5	665.8	502.1	674.5	512.5	632.2
tillers (T)										
ears no.m^{-2}	336	226	210	294	382	268	252	244	140	238
Spikelets/ear	16.7	15.45	15.5	17.84	15.3	16.8	15.4	17.54	14.8	16.8
pot. grains/spikelet	1.69	1.82	1.61	2.09	1.42	2.10	1.47	2.14	1.61	2.05
grains/pot. grain	0.59	0.58	0.56	0.54	0.57	0.57	0.55	0.57	0.59	0.58
SKW	0.04	0.043	0.043	0.0439	0.043	0.0437	0.0434	0.045	0.0429	0.0439
T yield [g/m^2]	223.9	159.0	126.4	258.1	203.4	234.2	136.7	235.5	84.7	209.0
GY total [g/m^2]	758.4	754.2	715.0	882.1	749.9	900.1	638.8	910.1	597.1	841.2
yield gap [%]		-0.5	-5.7	16.3	-1.1	18.7	-15.8	20.0	-21.3	10.9

Note: AMB: ambient precipitation and ambient temperature, T: indicates the elevation of soil temperature; *: indicates the presence of the rain shelter (roof); 25%_: indicate the reduction of precipitation amount at 25%, and →: indicate the reduction of the precipitation frequency at 50%.

The potential yield analysis shows that the potential yield of the main stems only in the treatments **AMB→** (50% reduction of the precipitation frequency and ambient soil temperature) and **25%_** → (25% reduction of precipitation amounts, 50% reduction of precipitation frequency and ambient soil temperature) were lower than that of the control (AMB). Moreover in all the treatments with ambient soil temperature the potential yield of the tillers was the factor constraining the potential total yield.

The potential yield of the variant **AMB+T** was in general lower compared to the control (AMB), although the potential yield of their main stems was higher because of more spikelet per ear and higher single kernel weight, but the potential yield of the tillers was considerably lower mainly because of less tillers and also less spikelet per ear.

At this manner all the different variants can be compared. (Appendix 2-10)

Interestingly, is to look at the variant **25%_** (25% reduction of precipitation with ambient soil temperature) where 13.7% more tillers per m^2 was observed compared to the control. This variant had slight higher potential yield of main stems than that of the control but the tillers although increased by 13.7%, they has less spikelets per ear, less potential grains per spikelet and less grains per potential spikelet. In the variant **25%_+T** (25% reduction of precipitation with increased soil temperature) the main stems were able to produce more grain than that of the control because of more spikelets per ear and higher SKW, although the potential grains per spikelet decreased by 3.7% compared to the control. And in the tillers were also able to produce more grain than that of the control because of mainly increased potential grains / spikelet ad increased SKW by 9.5%, and although the number of tillers was decreased by 20 % compared to the control.

6. Discussion

The ongoing global warming will influences the agriculture in different ways. While current reports about events related to climate change are an essential subject matter in the world media, research publications about the global warming exceed any other scientific topics. The climate change is a valuta with many frames; rising temperature (soil and air temperature), changes in the precipitation patterns, elevated $CO_{2,}$ and alteration of the properties of the season, all this are imbedded in the growing concerns around the climate change. Effect of the single factor player in the global warming is more or less good investigated. The concern is more due to the unpredicted interactions between the different actors. Temperature elevation will influence the yield of the crops negatively in regions already facing high temperature whereby in regions with cooler temperature warming condition will benefit the agricultural production. Precipitation amount and changes in precipitation patterns is also a stronger player in the plant development and attribute directly to the yield success or failure. In the current experiment, data was ascertained only from the plant biomass after has been harvested, no measurement was done during the vegetative phase and the evaluation of the plant phenological stages simultaneously with the different treatments application were also not done.

To ease the realization of the treatments a rain shelter was installed. Thus effects related to the rain shelter have been shown in the statistical analysis. Most of the plant parameter has responded to the rain shelter and it influences mainly the plant growth positively. Under rain shelter plants react with higher growth (stem, peduncle and ear length). And although the biomass (straw and grain weight) did not differ significantly despite the HI and the TKW were significantly different. The ear components analysis's shows also an effect of the rain shelter. The number of spikelet-bearing grains increases, and on the contrary the number of basal spikelets decrease. In addition the number of sterile florets decrease and also the weight of the grains per ears increase. This gives evidence that rain shelter has benefit the yield of wheat, and even at the different yield stage. During the experiment only the soil temperature in all of the plots was measured but no evaluation of the air temperature has been conducted and no measurement of the photosynthetically active radiation (PAR) and of the wind speed was done. What has exactly influenced the plant growth beneath the rain shelter probably their effect of increasing the air temperature. Results from other studies show that installation of a rain shelter influences the wind speed, the soil temperature and the daytime air temperature. In the current experiment the soil temperature of the plots located under the rain shelter shows higher value compared to that plots without rain shelter, although in all of the plots, where soil heating was conducted, the same heating cables and management was used but observations showed that under rain shelter soil temperature reached 2.18°C which was higher compared to that of plots without rain shelter where soil temperature reaches only 1.77°C. This difference in soil temperature is likely due to the rain shelter this will agree with the result found by Svejcar, Angell & Miller, (1999) they reported that under rain shelter an increased soil temperature and reduction of the wind speed was observed. Also he found that the PAR was reduced. Whitford et al. (1995) found an elevation of the daytime air temperature at 3 to 5°C due to rain shelter effect. Apparently the rain shelter in general affects the temperatures and this lead to enhanced plant growth, which in turn leads to enhancement at the different components-determining yield.

6.1. Yield Composition and the Contribution of the yield-determining components

As broadly known, the yield of wheat is the composite of the plants per m^2, spikes per plant, spikelets per spike, grains per spikelets, and single kernel weight (Rajala et al., 2009); thus, in the current experiment we have evaluated the different yield-determining components to be able to determine at which level soil warming and/or changes of precipitation patterns had influenced the yield of wheat. Reduction of precipitation amount and changes of the precipitation patterns did not influenced any of the yield-determining components. In this experiment due to increased soil temperature most of the yield-determining components at the ear level (that means: spikelets per spike, grains per spike, and single kernel weight) were positively influenced, but the number of plants per m^2, and number of spikes per plant was not influenced. Patil et al., (2010) found that soil warming reduce the number of ears per m^2, but the grain yield remains unchangeable due to increased single kernel weight. In this experiment may be due to high planting density (450 plants per m^2) no effect on the number of ears per m² was resulted and the warmer conditions have supported the growth of all the established ears in this experiment. Different from Patil et al. (2010) where they established only 150 plants per m² and due to soil warming plant tillering was reduced and thus the number of ear per m² declines. It seems that at low planting density the soil warming influences negatively the tillering activity of wheat plant and to counterbalance the reduction of tillers the only effective way to maintain the grain yield is by increasing the single grain weight. And may be a high planting density is advantageously to counterbalance the warmer conditions in the future but may be also to benefit from the warmer conditions in northern countries.

At the high planting density less tiller are developed and thus their contribution to the grain yield is lower, this can be approved in the current experiment, where in all of treatments the contribution of the main stems was in average about 83% for the total grain yield. (Appendix 1)

In the most of the experiments which dealt with temperature scientists was aiming to investigate the response of the plant to increased temperature in environments already negatively affected by high temperature and they showed reduction in plant productivity due to heat stress (Dias & Lidon, 2009, Elhami et al., 2007).

Royo et al., (2007) reported that increase of grain yield per area had resulted from increased number of plants per m², the number of spikes per plant and the number of grains per spike cited by (Alvaro et al., 2008). In this experiment the contribution of the number of grains per m² and the single grain weight to the wheat yield was shown. The number of grains per ear and the single kernel weight has been increased due to soil warming. Sayre et al. concluded that the yield progress of the Mexican wheat cultivars was associated with greater grain number cited by Fisher, (2007). Increase of the single kernel weight due to soil warming was also shown by Patil et al. (2010). In addition, reported by Elhami et al., (2007) that thousand kernel weight contributes under irrigated environments to the grain yield of wheat. It seems that in affordable growing condition wheat plant can produce even biger kernel.

6.2. Phenological phases and yield composition influenced by temperature

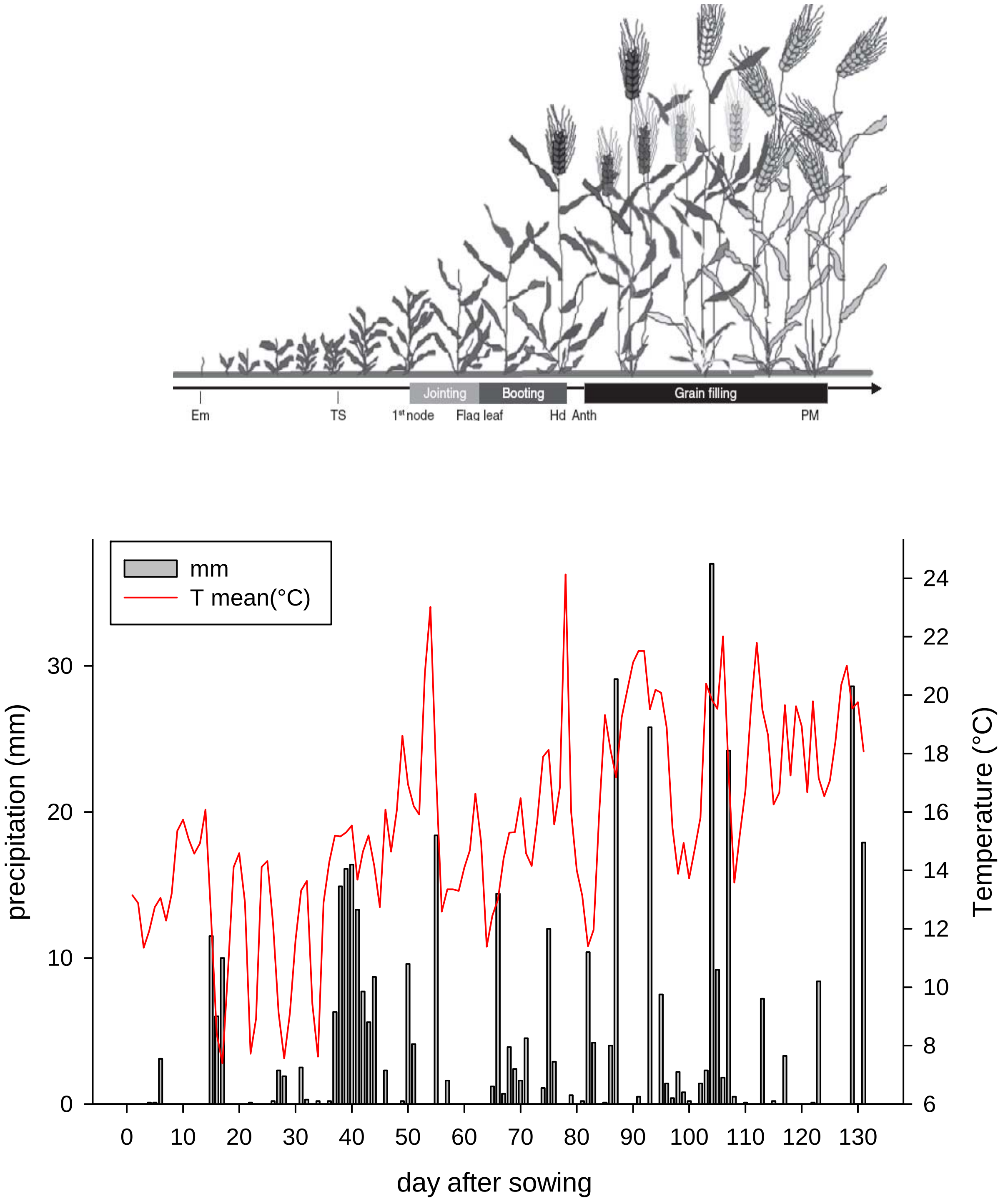

Figure 12: the course of the temperatures and precipitation during the growing period and a schema illustrating the development stages of the wheat adopted from Dias & Lidon, (2009)

The course of the weather during the growing period shows in general a low temperature. In the first two weeks after sowing the average temperature ascertained near the experimental field was about 13°C. The breeder of the variety Triso estimates 10 to 13 days as the time needed to seedling emerges. According to Porter & Gawith, (1999) the optimal temperature for the phenological phase “sowing to emergence” is identified by 22 °C, this temperature is higher than that occurred at the field of this experimental so it can be assumed that the increase of soil temperature had benefits the plant growth at this phase. Also Narciso et al. (1992) had estimated the optimal temperature at about 15 – 25 °C for the phenological phase “sowing to emergence” in the south European countries where mainly spring wheat is planted, this also verifies the assumption made before.

The number of primordia is determined in the period between seedling emergence and terminal spikelet. Since the increased of soil temperature in this experiment had increased significantly the number of spikelet (mainly the number of spikelet which bears grain) in about 2.5 spikelets we could assume that at the period of the development of the primordia a temperature of 14 °C was restricting this process and increased soil temperature had enhanced the setting of more spikelet. This conform to the result of Rawson et al. (1970) where he found that increased temperature does increase the number of spikelets. And also Slafer and Rawson (1994) conclude from their result that temperature has at least little impact on the development of the primordia. The result found in our experiment disagree with that found by Rahmen and Wilson (1978), they concluded that temperatures do not increase the number of spikelet. But they used in their experiment temperatures ranging from 16 to 30 °C which are quiet higher than that recorded during our experiment, where the temperature at this time reached in average 14 °C.

The assumption about heading occurrence which we expect to had happened around the first two weeks of June confirmed with data from Sachsen – Germany, where in three years field trial Triso had reach the stage of heading between 9 to 13 of June (Beese 2000)

Around anthesis the temperature reached in average 16 °C, after Russell and Wilson, (1994) temperatures between 18 and 24°C are identified to be optimal for a successful anthesis. Since in the current experiment the soil temperature was 2.18°C higher than that of the unheated area, the grain yield, and harvest index showed in general significant difference due to temperature manipulation and especially the number of grains per ear, which is the best indicator for successfully anthesis, and which was also significantly higher compared to that of the unheated plots; it can be assumed that around anthesis increase of the temperature impacts positively the grain set and therefore results in higher yield. Our result is comparable with that found by Patil et al. (2010), where soil warming enhanced wheat crop development at significant level. In their experiment they showed that soil warming enhances mainly the green leaf area index and at early stages the above ground biomass. In contrary they found that the number ears per m² were reduced due to soil warming and the enhanced grain yield was mainly due to increased thousand kernel weight. In this experiment the thousand kernel weight was also significantly enhanced due to soil warming but no difference in regard to the number of ears per m² was observed.

During the grain filling phase temperature ranges between 16 and 20°C, Porter and Gawith, (1999) identified the optimal temperature for the grain filling phase at 19.3 to 22.1°C. After tacking in consideration the increase of soil temperature in the current experiment, the optimal required temperature for the grain filling phase would have occurred and therefore it can be assumed to be the reason for the yield enhancement. According to Moragues et al., (2006) and Royo et al., (2006) the contribution of single kernel weight to the total yield increase in adequate growth conditions cited by (Alvaro et al., 2008)

The potential yield analysis shows the parameters which had influenced the yield formation. In general, in this experiment the yield improvement due to increased soil temperature and rain shelter (which shows also an effect in increasing the temperature) was mainly because of increased number of spikelets per ear and increased SKW by the main stems. But by the tillers only due to increased soil temperature an increased number of spikelets per ear, number of potential grains per spikelet and increased SKW had resulted in increased yield. The spikelet initiation starts shortly after the plants emerge, and last until the stage of jointing (booting), at this time during this experiment the outside temperature ranges between 8 to 14 °C. Increased soil temperature in this stage may have enhanced the development of spikelets due to enhanced vegetative growth for both tillers and main stems. But maybe tillers have higher sensitiveness to temperatures during the spilekets initiation and the optimal temperature range for tillers during the spikelets initiation is narrower than that of the main stems. This can explain why by the tillers only in plots with soil warming and roof had greater number of spikelets per ear. This also is maybe the reason for more potential grains per spikelets. The higher sensitiveness of the tillers due to abiotic stress has been also shown by Schütze and Fangmeier, (2001).

The increased SKW can be due to the enhanced grain filling phase but also due to longer duration of the grain filling phase, Patil et al., (2010) reported that soil warming even shorten the duration of the grain filling phase. So is more likely that better source-sink relationship during this experiment has enhanced the SKW.

6.3. Yield and temperature in Germany

The yield of many spring wheat varieties in southern Germany – Bayern was investigated and the variety Triso was included in this screening. On average of three years the yield of Triso reaches 5960 kg/ha (Nickl, Hartl, & Wiesinger, 2008), this is comparable with the yield reached in the control plot in the current experiment where the grain yield weighted about 6160 kg/ha. But the number of ears per m² of the control plot in this experiment has reached 786, this extend that of the screening experiment which attained only 702 ears per m². On the contrary, in our experiment the number of grains per ear with 22.8 was lower compared to that of the screening which reaches 28 grains per ear. It seems that the number of ears per m² compensates the lower number of grains per ear, which in turn generates a grain yield which is comparable with that of the screening trial. After comparing the yield of the control plot with the normally attainable yield in the region we can assume that the yield enhancement shown in this experiment due to soil temperature elevation can be predicted for the next time and the coming warming condition due to climate change will benefits the crop productivity. This finding disagrees with that found by (Patil et al., 2010), who found that soil warming enhances the plant biomass during the vegetative phase and shortened the crop duration without increasing the grain yield. He concludes that soil warming has maintained the same grain yield despite shortened crop duration. After Börner et al, (2008) in high montains, northern country and regions with conntinental climates temperature is the most limiting factors for wheat production, therefore the enhancing of the wheat yield due to the soil warming is as a matter of course. Tacking into account the finding of Slafer and Dawson, 1994 where he revealed that wheat responses at all development stage to temperature change and also as reported by Entz and Fowler, (1988) that the response of wheat on temperature during the reproductive phase is more decisive cited by (Porter & Gawith, 1999). This can support the statement that soil warming and warmer condition in general are beneficial for regions where agricultural production is limited by low temperatures during the crop cycle.

6.4. Precipitation

Most of the yield-determining components show no significant difference between all of the precipitation manipulation treatments. Only the number of the shrunken kernels was reduced by the 25% reduction of precipitation. But in general the number of shrunken kernel was less than one per ear, therefore the number of the shrunken kernels could not influenced the grain yield at a considerable level.

The number of tillers was increased due to less precipitation amount (25% lower) whereby no difference has been shown between the other precipitation treatments. Since, despite the difference of number of tiller due to less precipitation no difference in all the yield-determining components have been shown, this may be due to the fact that the amount of precipitation occurred in the growth period was enough to support the plant development and even reduction of the precipitation did not negatively affected yield. This result conforms to the finding of Patil et al. (2010) where he shows that rainfall pattern as expected for the future in Denmark did not influenced the yield of winter wheat. He gave for this result three possible reasons:

- The increased amount of precipitation occurred in winter percolates in the deeper soil layer and did not cause waterlogging that could affect the plant development
- The mild Danish winter conditions may have supported the plant to develop a good root system which could have had access to the water stored in the deeper soil layer, or

- The rainfall reduction was too small to make a significant effect on the plant development.

Since we had spring wheat and the waterlogging cannot have occurred during its growing period. But maybe the increased rainfall amount during winter which could has been stored in deeper soil layer, was available for the plants to support their growth.

7. Conclusion and Outlook

At the research station for plant breeding “Heidfeldhof” the imposed soil temperature increase in the current experiment had influenced the yield-determining components, which in turn leads to a high grain yield

The enhanced grain yield was shown to be supported simultaneously from main stems and tillers. Increased soil temperature and increased the air temperature (due to roof) had benefit the plants in the early growth period and during the grain filling phase and had resulted in higher total grain yield.

Rainfall changes in this experiment had no effect on the yield despite their influence on the number of tillers per m².

To confirm the results of this study some issues do require more clarification:

- More detailed studies concerning the effect of different soil on the increased temperature and changes in precipitation. Mainly the effect of the soil capacity on water holding which also affects the soil temperature.

- More detailed studies in the effect of the planting density and the response of the plants (main stems and tillers) on the yield and yield formation.

Under future warmer climates the benefit for the wheat production in high latitudes could help to counterbalance the constraints of wheat productivity in other regions. To take advantages of this situation more researches are needed to gain more understanding on the processes behind the response of the plants to warmer winter.

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