WHEAT DEVELOPMENT FEATURES DEPENDING ON SOIL MOISTURE IN THE WESTERN LITHUANIA

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Abstract

Experiments were carried out at the Vėžaičiai Branch of Lithuanian Research Centre for Agriculture and Forestry. The aim of this study was to estimate the influence of soil moisture content on wheat root development and productivity features in acid soils of the Western Lithuania. The data of study accomplished under the conditions of the Western Lithuania climate in *Bathygleyic Distric Glossic Retisol* show that soil moisture content during the vegetation period had the significant impact on wheat development and better absorption of fertilisers. Under warmer and drier weather than usual, additional fertilisation with liquid fertilisers in more moist soil stimulated root mass increase. The grain yield of winter wheat grown in more moist soil was determined to be greater by 45.0%; additional fertilisation increased winter wheat grain yield by 11.0% more. The grain yield of spring wheat grown in more moist soil was determined to be greater by 95.0 %; additional fertilisation increased spring wheat grain yield by 5.8 and 13.1% more, respectively in dry and optimally moist soils.

Resumen

Los experimentos se llevaron a cabo en la sede de Vėžaičiai del Lithuanian Research Centre for Agriculture and Forestry. El objetivo de este estudio fue estimar la influencia del contenido de humedad del suelo sobre el desarrollo de las raíces del trigo y las características de productividad en suelos ácidos de Lituania occidental. Los datos del estudio realizado bajo las condiciones del clima de Lituania occidental en Batygleyic Distric Glossic Retisol muestran que el contenido de humedad del suelo durante el período de vegetación tuvo un impacto significativo en el desarrollo del trigo y una mejor absorción de fertilizantes. En un clima más cálido y seco de lo habitual, la fertilización adicional con fertilizantes líquidos en un suelo más húmedo estimuló el aumento de la masa de raíces. Se determinó que el rendimiento de grano del trigo de invierno cultivado en suelos más húmedos era superior en un 45,0%. Una fertilización adicional aumentó la producción de trigo de invierno en un 11,0% más. Se determinó que el rendimiento de grano del trigo de primavera cultivado en suelos más húmedos era mayor en un 95,0%. En este caso, la fertilización adicional aumentó el rendimiento de grano de trigo de primavera en un 5,8 y un 13,1% más, respectivamente, en suelos secos y óptimamente húmedos.

Key words: additional fertilisation, productivity, soil moisture, winter and spring wheat.

Introduction

Climate change is expected to seriously affect wheat (*Triticum aestivum* L.) production around the world in the future (Asseng et al. 2015). Wheat grain yield is predicted to decrease because of the global increase in air temperature (Sawada et al. 2019). Global wheat production is estimated to fall by 6% for each 1°C further temperature increase (Asseng et al. 2015). Plant capability to take water from deeper layers during the drought period depends on characteristics of the species. Literature indicates that plants with long roots better absorb water from the upper layers of the soil. It is also identified, that root presence in the certain layers does not necessarily reflects root activity. Root presence shows only the plant potential to reach different soil layers (Hoekstra et al. 2014).

It is very important, that moisture content in the upper layer of the soil would be sufficient just after the sowing and seeds could germinate gradually because undeveloped roots of the plants are not able to take the water from deeper layers (Kadžienė 2009). In dry soil, the roots wither and their functions become weaker. Lack of water in the soil can stimulate the root solidification; therefore the roots lose the ability to adjust to the soil pores with their diameter during the drought period (Lemcoff et al. 2006). Roots are an integral part of plants performing important functions in regulating growth of the whole plant. The primary function of the roots is absorption of water and other nutrients from the soil as well as the plant fixation (Gregory 2008). Roots are spread in depth up to 2 m; however the greatest mass of roots is in the arable layer in depth of 15-20 cm with more nutrients and better aeration conditions (Rimkus 2003).

Climatic conditions effect on the plants mostly comes through the changes in soil moisture content. During the active vegetation period, a part of precipitation drains away, the other part – evaporates. Soil moisture content strongly depends on the intensity of precipitation. The more rain falls, the less water soaks to the soil. Soil moisture content, when plants wither and can not revive even under the most favourable moisture conditions, is called withering humidity. It is not equal in soils of different texture. According to the data of the Lithuanian Research Centre for Agriculture and Forestry, the withering humidity in sandy loam soils is 2.0-3.2%, in light loam soils – 6.1-6.5% and in hard loam soils – 9.1-10.0% (Šimanskaitė 1985). The optimal loam soil moisture for the arable layer is 17-18% (Kadžienė 2009). The moisture content mostly varies in the depth of 0-5 cm, which is affected by the meteorological conditions: sparse precipitation moisten only the surface of the soil and the wind drains it faster than the deeper layers.

Understanding, how the phytomass of plant overground part and roots distributes under the changing environment conditions, is very important assessing plants growth and their reaction to sources of nutrients (Shipley and Meziane 2002). The Western region of Lithuania is strongly influenced by the maritime climate and is characterized as moderately warm and humid. In comparison with other regions, the amount of precipitation is the highest there. The soil is more podzolized and acid than in the other regions. It receives the highest rate precipitation, which has amounted to an average of 942 mm annually during the last 10 years. Bathygleyic Distric Glossic Retisol (RT) (WRB 2014) prevailing in the Western Lithuania are acid, low in organic matter and contain high level of toxic Al (Repsiene and Karcauskiene 2016, Volungevicius et al. 2018). Consequently, the aim of this study was to estimate the influence of soil moisture content on wheat root development and productivity features in acid soils of the Western Lithuania.

Materials and Methods

Experimental site. The experimental site was the Western Plateau of Žemaičiai Highland. The geographical location of the site is Latitude 55°697 N and Longitude 21°497 E. The soil was Bathygleyic Distric Glossic Retisol (RT) (WRB, 2014) with a texture of sandy loam. According to the content of clay particles, the soil profile is differentiated into alluvial and illuvial horizons whose diagnostic horizons: A (0–27 cm) – El (27–55 cm) – ElB (55–80 cm) – BtEl (80–105 cm) – BCg (105–120 cm) (Kryzevicius et al., 2019). The soil is typical of the region of the Western Lithuania, whose pH at the beginning of the trial was 5.2. The soil is moderate in mobile P_2O_5 content and high in mobile K_2O (139 ± 3.50 and 204 ± 4.0 mg kg^{-1} soil, respectively).

Experimental treatments and design. Due to naturally different soil moisture content conditions, experimental field was divided in two parts (I and II localisations). Application of NPK was done on the basis according to crop requirement for optimal yielding under natural environmental conditions of the Western Lithuania. The following experimental design was conducted: 1) winter wheat ($N_{118}P_{32}K_{32}$) (without additional fertilisation); 2) winter wheat with additional fertilisation ($N_{156}P_{47}K_{56}$); 3) spring wheat. ($N_{118}P_{32}K_{32}$) (without additional fertilisation); 4) spring wheat with additional fertilisation ($N_{156}P_{47}K_{56}$).

The crops were cultivated according to sustainable management practices using conventional tillage. Before sowing, the grains of winter wheat and spring barley were treated with Kinto (a.i. triticonazole + prochloraze) at a rate of 2 L t^{-1}. After the beginning of plant vegetation, Fertiactyl Starter 3 l ha^{-1} fertiliser ($N_{13}P_5K_8$, humic and fulvic acids) was applied for the additional fertilisation.

The experiment was established in four replications. The treatments were assigned randomly. The trial field area was 5.0 m × 20 m = 100 m^2.
The efficiency of additional fertilisers was studied during the cultivation of winter wheat (‘Ada’, seed rate 220 kg ha^{-1}) and spring wheat (‘Baldus’, seed rate 220 kg ha^{-1}).

Biometrical analysis and yield component of wheat. At the time of assessment, 20 individual wheat plants were excavated from each treatment plot. The length (cm) of fresh plant parts and air-dried mass (g) of the roots and the aboveground part (shoots) were determined in BBCH 31-32 of winter wheat and in BBCH 39-40 spring wheat. The mass was determined by electronic scales.

Morphological characteristics, such as spike height, grain number per spike, and stem height, were determined from 10 productive stems of each plot at the mature stage. At harvest time, samples of 1 kg weight were taken from each plot to determine dry weights of the grain, their chemical composition and 1000-grain weight.

Grain yield was measured while harvesting 3 × 10 m plots. The grain yield, 1000-grain weight, and aboveground dry weight were corrected to t ha^{-1} (with 14.0% of moisture and 100% of cleanness). The content of protein of grain was measured as well.

Methods of analysis. Agrochemical characteristics of the soil were determined from the soil samples taken from 0-20 cm layer before establishing the experiment: soil pH_{KCl} was measured according to potentiometric method determined in 1M KCl (soil – solution ratio 1:2.5 (ISO 10390:2005), available P_2O_5 and K_2O – using Egner-Riehm-Domingo (A-L) method (LVP D-07:2012). Soil texture was determined according to the composition of three fractions: sand, silt and clay. Analysis was accomplished using Kaczynski method and modified according to FAO (ISO 11277:2009). Soil moisture content during the plant vegetation period was determined by weighting.

Grain protein content in dry matter was calculated by multiplying the corresponding total nitrogen (by Kjeldahl) content by a factor 5.7 (LST EN ISO 20483) using a semi-automated N analyser "Kjeltec system 1002".

Meteorological conditions. During the study period, the weather was dry and warmer than usual in the Western Lithuania. The amount of precipitation during the year reached 78.8% and during the plant vegetation period – 73.9% of the standard climate norm (SCN). During the study period in spring, the weather was dry. During the intensive plant growth, in May and June, it was dry and cool. In May, the precipitation was 36.9 mm (83% of the standard climate norm (SCN)) (Figure 1). Soil moisture in the depth of 0-10 cm was optimal at the end of May – early June (16.4–19.0%) (Figure 2), but the weather in the second and third decades of June was cool, 12.4–13.0 °C, slowing down the plant development and growth. The month of July was particularly dry, with only 33.8 mm or 38.0% of the SCN of precipitation. The moisture content of soil throughout the entire month from the second decade of July was close to the withering humidity of the plants, and at the end of July severe drought was recorded. The dry period lasted until August 11. The long-term lack of moisture during the intensive plant growth, meteorological conditions were unfavourable for the growth and development of wheat. Under the critical drought conditions, different soil texture of the experimental sites determined growth, development and maturation of plants.

Statistical analysis. Significance of the differences between the means was determined according to the Fisher's protected least significant difference (LSD) at 0.05 probability level. The data were processed using software *ANOVA* (Raudonius 2017).

Results and Discussion

Soil moisture content. Soil moisture content as the element of water balance is important analysing meteorological phenomenon locally and globally. The amount of precipitation and air temperature (amount of warmth) determine soil moisture content and plant growth conditions (Kudakas et al. 1998). Winter wheat in I localisation survived the soil moisture content stress for almost all plant vegetation period except for the second decade of May and the first half of June (Figure 1). In II localisation, there was a lack of moisture in the month of July and the first decade of August. Similar soil moisture content conditions were for the spring wheat to grow (Figure 2).

Winter wheat root development. Localisation sites of the experiment varied in soil moisture content conditions and depended on soil texture. During the study, soil moisture content in I localisation was lower than in II localisation, respectively: in the depth of 0-10 cm at the beginning of stem growth it was 17.0 and 18.3%, at the inflorescence – 20.8 and 23.1%, at the flowering stage (in the depth of 0-20 cm) – 13.5 and 20.3%.

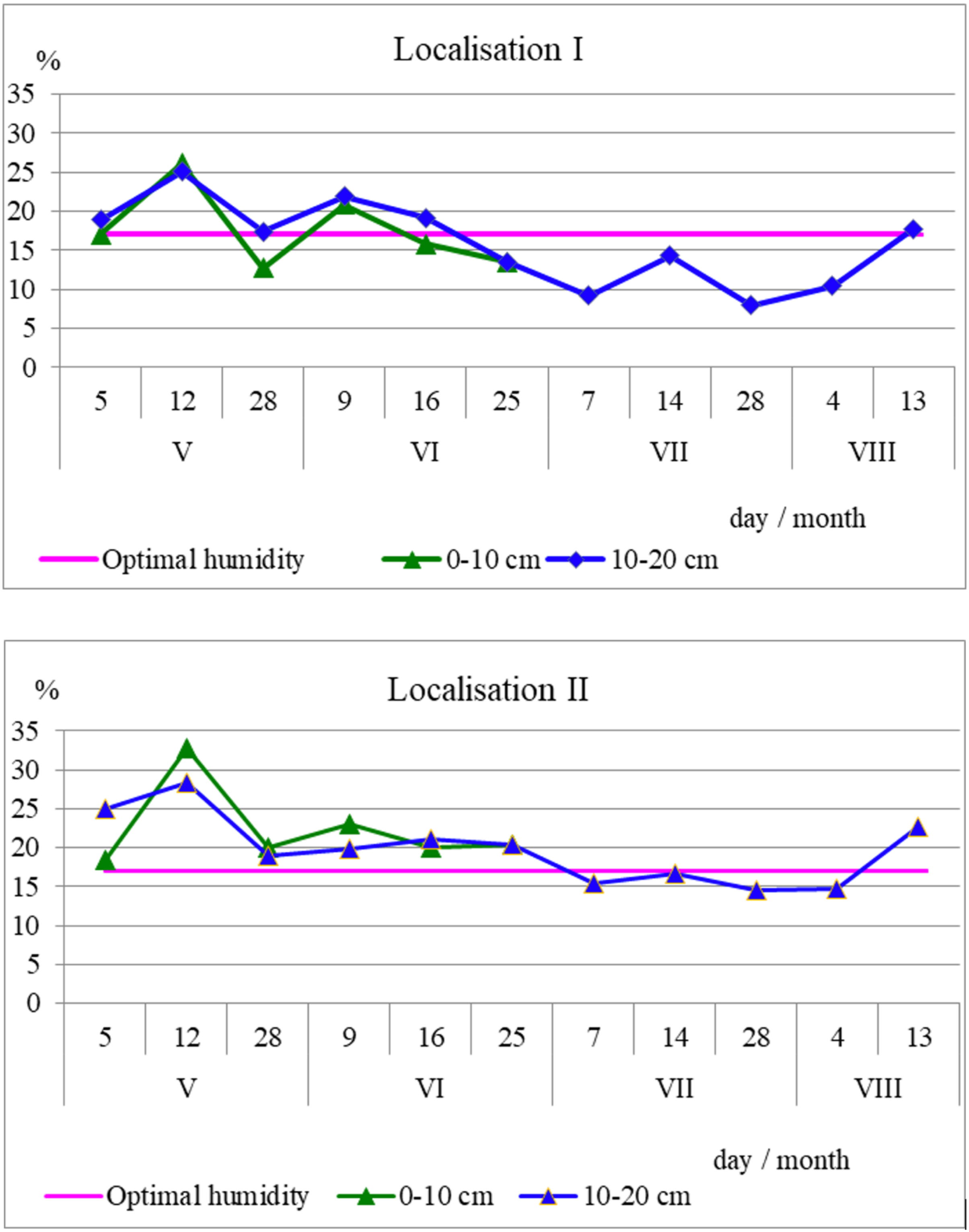
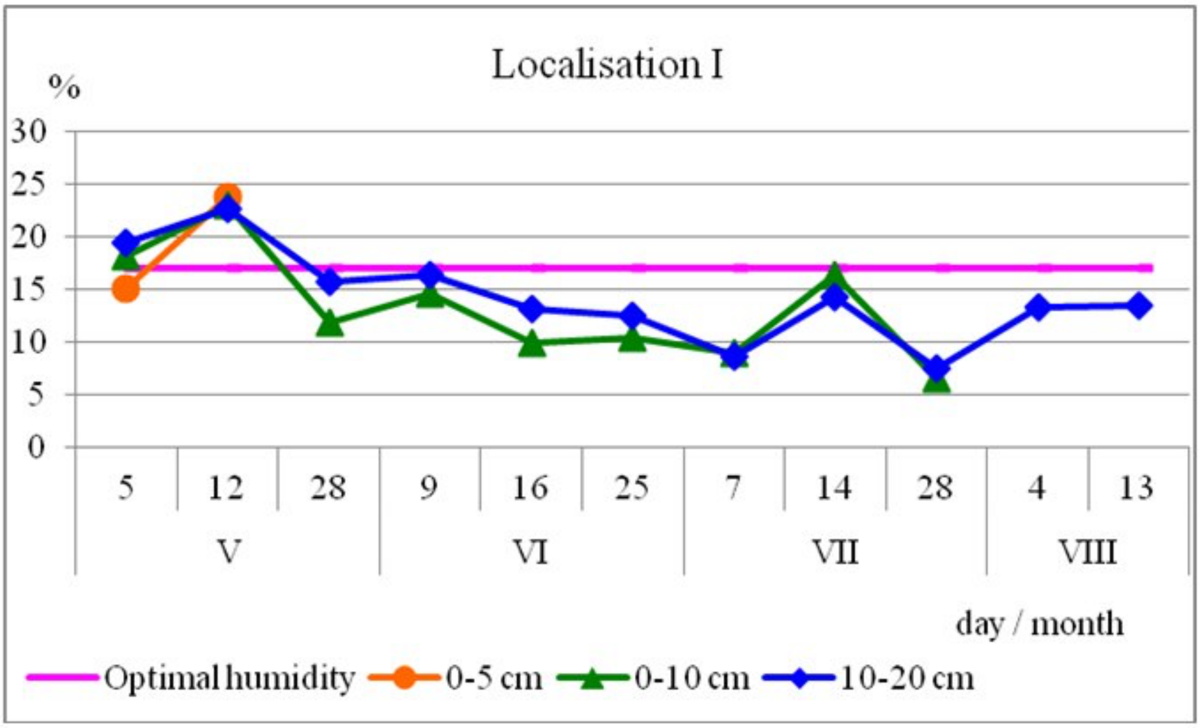


Figure 1. Soil moisture content during the winter wheat vegetation period in different localizations.



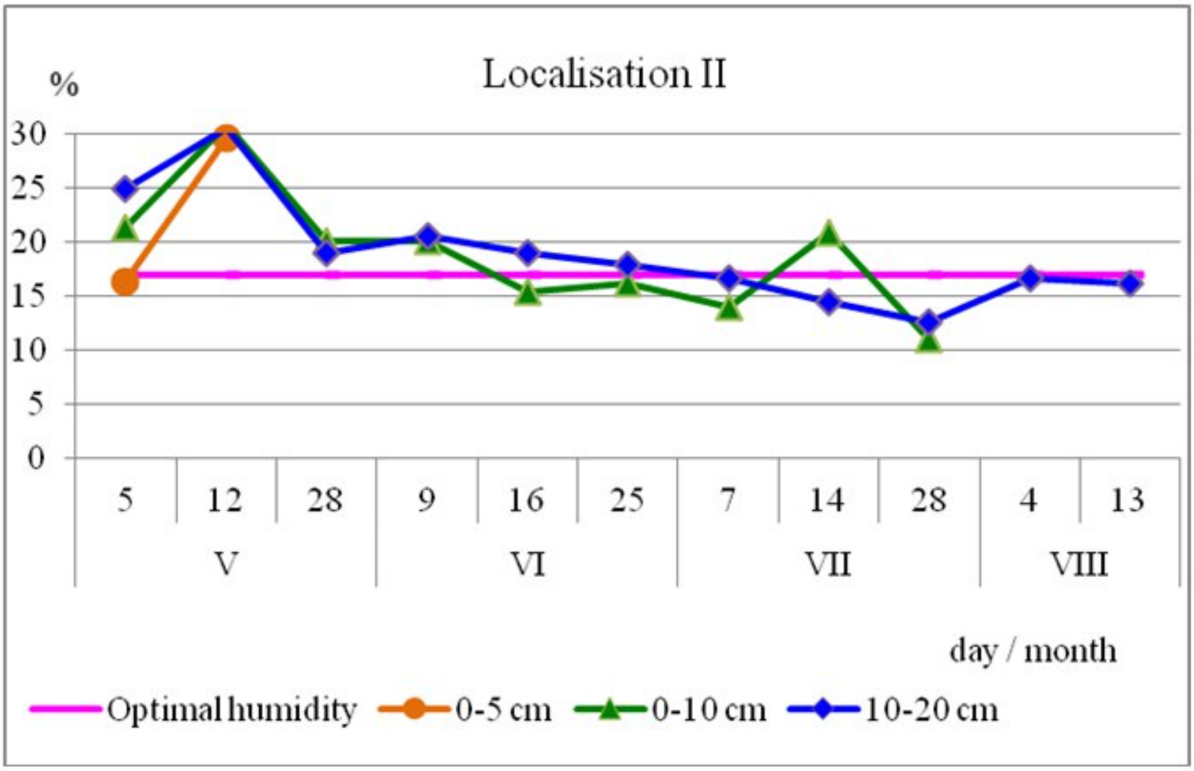
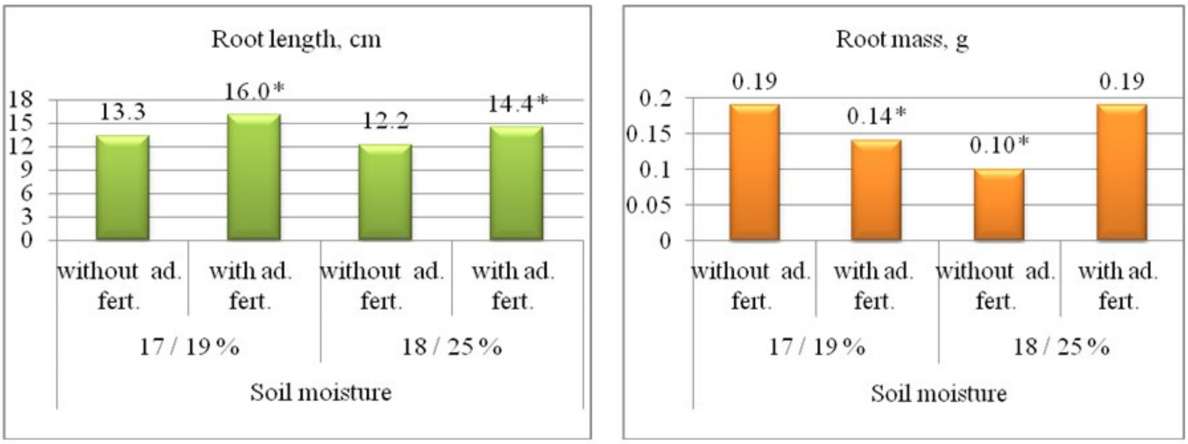


Figure 2. Soil moisture content during the spring wheat vegetation period in different localizations.

Comparing different localisation variants without the additional fertilisation, it can be seen that in soil with the average moisture of 17-19 % during the vegetation period, the roots of winter wheat were slightly longer and their mass was 1.9 times greater (Figure 3). In soils of different moisture content, additional fertilisation with liquid fertilisers stimulated root elongation, and in more moist soil – mass increase.



/ average soil moisture data in the depth of 0-10 cm / 10-20 cm, *, **, significant at P < 0.05, P < 0.01 respectively

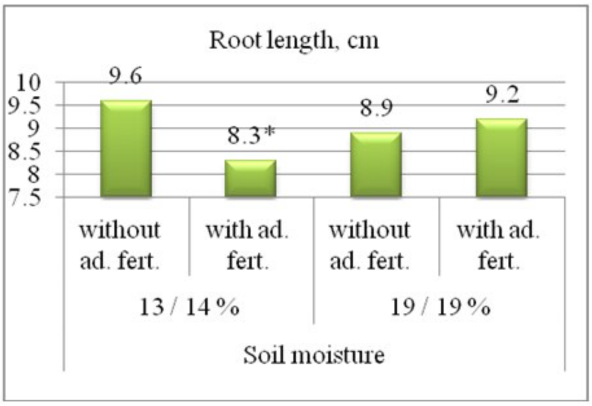
Figure 3. Winter wheat (BBCH 31-32) root length and mass.

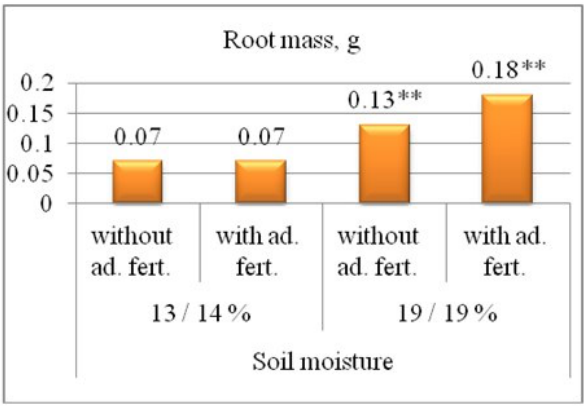
Additionally fertilised winter wheat developed longer roots, but the overground part of the plant was shorter compared to wheat without the additional fertilisation, respectively: in I localisation the wheat roots were longer by 20.3% and in II localisation – by 18.0%, while the overground part of the plant was shorter by 6.1 and 14.2% (Figure 3).

The root length shows great development plasticity emergent due to the soil profile heterogeneity determined by water accessibility and plant variety (Klimek-Kopyra et al. 2015). It is known that water is natural solvent and an environment, in which the metabolism of organisms takes place; water is also important for keeping turgor (liquid pressure to the cell wall) in plant matter.

Spring wheat root development. The greatest amount of moisture for spring wheat is necessary during the stages of tillering, stem elongation and booting. The lack of moisture at the stage of wheat booting results in weakly developed spikes (Šiuliauskas 2015). During the investigation period, the soil moisture content in I localisation was lower than in II localisation, respectively: during the sowing time soil moisture in the depth of 0-10 cm was 16.6 and 18.8%, at the tillering stage – 14.6 and 20.0% and during the stem growth and at the beginning of booting of the last leaf – 9.9 and 15.4%.

Comparing different localisation variants without the additional fertilisation, it can be seen that in the extremely dry soil the roots of spring wheat were longer by 7.3% and their mass was lower (Figure 4). Additional fertilisation with liquid fertiliser in more moist soil, where the optimal soil moisture content persisted until the beginning of the spring wheat booting, the root length and air-dry root mass were determined to be greater than fertilising usually, respectively: 3.4% and 37.8%.





/ average soil moisture data in the depth of 0-10 cm / 10-20 cm, *, **, significant at P < 0.05, P < 0.01 respectively

Figure 4. Spring wheat (BBCH 39-40) root length and mass.

Contrasting data of the plant overground part, root length and mass in dry soil can be explained by the optimal soil moisture content for spring wheat germination, however there was a lack of moisture at the stages of tillering, stem elongation and booting. Plants experienced strong stress by the climatic factors. *Yield and yield components***.** Under the different moisture regime, not only the wheat root mass and length varied but also the indicators of spike productivity and quality. In regard to winter wheat grown under more favourable moisture conditions (II localisation), the length of spike was determined to be greater by 5.5%, the length of stem – greater by 10.7%, the quantity of undeveloped grain – lower by 25.2% and 1000-grain weight – greater by 7.4% compared to dry soil (Table 1).

Winter wheat grain yield in more moist soil was greater by 45% compared to the soil with lower than the optimal moisture content (17%). Additional fertilisation increased winter wheat grain yield by 11.0%. The amount of protein, being one of the major indicators for wheat quality (Finney et al. 1987), varied from 10.8 to 12.4%. A little winter wheat grains' protein value from I localisation shows that plants lacked of nitrogen; soil moisture was not sufficient for a better absorption of fertilisers. Parida et al. (2007) indicate, that soil moisture regime has the decisive impact for plants development processes.

Table 1. Soil moisture content impact on productivity indicators of winter and spring wheat.

Yield components	Winter wheat		Spring wheat	
	Localisation			
	I	II	I	II
	Soil moisture, %			
	17 / 19 [a]	18 / 25	13 / 14	19 / 19
Spike length, cm	7.27±0.13	7.67±0.19	6.6±0.20	7.2±0.12
Stem length, cm	70.3±1.48	77.8±1.65	72.9±1.81	82.8±1.89
Grain number in spike, unit	32±0.97	30±0.82	34±1.15	37±1.23
Undeveloped grains, unit	1.07±0,03	0.80±0,05	2.33±0,09	1.27±0,07
1000-grain weight (14 % moisture), g.	41.8±0.59	44.9±0.52	31.7±0.41	37.2±0.48
Grain quality. Protein %	10.83±1.00	12.43±0.56	12.94±0.62	12.60±0.82
Grain yield supplement depending on soil moisture, %	100	145	100	195
Grain yield supplement depending on additional fertilization, %	100	111	106	113

[a] – average soil moisture data in the depth of 0-10 cm / 10-20 cm.

In regard to spring wheat grown under more favourable moisture conditions (II localisation), the length of spike was determined to be greater by 9.1%, the length of stem – greater by 13.6 %, the quantity of undeveloped grain – lower by 45.5% and 1000-grain weight – greater by 17.4% compared to dry soil (Table 1).

Spring wheat grain yield in more moist soil was greater by 95.0% compared to dry soil. Additional fertilisation increased winter wheat grain yield by 13.0%.

Literature indicates that only under sufficient moisture content conditions in the atmosphere and soil, plants do photosynthesis at most intensity (Parida et al. 2007). Soil moisture content is one of the most important environmental factors determining plant productivity. The observation of soil moisture content is essential in determining watering regime, assessing plants water needs, reasoning the efficiency of used water, following water motion patterns in the soil, analysing models of water absorption in roots, doing plant pathological observations, exploring carbon distribution in the soil and plant matter, studying different soil tillage, ecological questions and problems, changes in ecosystems, etc.

Conclusions

The data of study accomplished under the conditions of the Western Lithuania climate in Bathygleyic Distric Glossic Retisol show that soil moisture content during the vegetation period had the significant impact on plant development and better absorption of fertilisers.

Additional fertilisation used in the beginning of plant vegetation stimulated root development during the period of active growth of winter wheat. The roots were averagely longer by 18.8 % and their dry matter mass was greater by 14.3% compared to wheat without the additional fertilisation. The grain yield of winter wheat grown in more moist soil was determined to be greater by 45.0%; additional fertilisation increased winter wheat grain yield by 11.0% more.

The roots dry matter mass of additionally fertilised spring wheat was averagely greater by 25.5% compared to wheat without the additional fertilisation. Spring wheat formed averagely 13.9% more of stems, 14.5% more of productive stems, 17.7% less of undeveloped grain in spike than in wheat without the additional fertilisation. The grain yield of spring wheat grown in more moist soil was determined to be greater by 95.0%; additional fertilisation increased spring wheat grain yield by 5.8 and 13.1% more, respectively: in dry and optimally moist soils.

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