

**PRODUCTIVITY OF WINTER WHEAT AND MAIZE AS AFFECTED BY WEATHER
CONDITIONS AND NITROGEN NUTRITION**

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Abstract

The field experiments with winter wheat were conducted at the Lithuanian Research Centre of Agriculture and Forestry in 2007 – 2009, and whit maize in 2010 – 2012. In field experiments winter wheat and maize leaf area, biomass and grain yield was measured with a view to interconnect fertilization with nitrogen as well as water availability status. Our study suggest that under Lithuanian climate conditions water availability plays an important role in the formation of grain yield; however, nitrogen nutrition is a major limiting factor of concern, specially under law input management.

Key words: leaf area, photosynthetic potential, grain yield, water stress, model DSSAT.

INTRODUCTION

Winter wheat (*Triticum aestivum* L.) is C3 cereal plant, one of the major crops in Lithuania and in the world. Maize (*Zea Mays* L.), C4 plant, is one of dominating crops in the World. The total area under winter wheat in Lithuania in 2011 was 275 thousand hectares and under maize for silage and green fodder was 21 thousand hectares and for grain 9.6 thousand hectares (Statistical yearbook...2012). In 2011, winter wheat grain yield amounted to 3.32 t ha⁻¹ on average. Maize was introduced to Lithuania in 1950 as silage crop; however, nowadays a number of short season varieties for grain production suitable for Lithuania climate conditions are available in the market. The further increases in ambient temperature accelerate the rate of plant development, allowing maize to complete its phenological stages in shorter periods of time and to consider growing of medium season varieties in Lithuania. The yield of maize biomass for silage and green fodder was 33.0 t ha⁻¹ in 2011. There was an increase of area of maize for grain 6 times from 2005 and the grain yield of maize increased too – from 3.08 t ha⁻¹ in 2005 to 7.48 t ha⁻¹ in 2011. Experiments in climate chambers conducted with barley, pea, red clover, timothy, tomato, radish and soybean showed that a number of factors related to climate change can have significant impact on crop productivity (Juknys et al., 2011).

The reasons of low realisation of yield crop potential are not always clear and lack of objective criteria complicates decisions regarding management intensity. Water and nitrogen are the main factors **conditioning** utilisation of crop yield potential (Nangia et al. 2008; Pala, et al. 2007). Nitrogen nutrition is especially important yield formation factor in the northern temperate climate zone, where excess of moisture supply is typical and crops rarely suffer from shortage of moisture. However, in Lithuania climate change causes more frequent invasions of tropical air masses which results in increasing probability of dry spells and incidence of crop water shortage stress. Drought stress caused by soil and atmospheric water deficiency is one of the most significant environmental factors affecting plant growth and productivity worldwide. The reactions of the plants to water stress differ significantly at various organizational levels depending upon intensity and duration of stress as well as plant species and its stage of development (Chaves et al., 2003). C3 and C4 plants have evolved in different climates and consequently differ from each other structurally and functionally as well as for

their climatic requirements (Nayyar, 2003), C3 plants are believed to have a temperate origin, C4 plants have evolved in tropical and arid environments (Ward et al., 1999). C4 plants are reported to be better adapted to water stress and have superior water use efficiency than C3 plants (Vitkauskaitė, Venskaitytė, 2011).

Crop simulation models, intensively elaborated during the last decades, turned into handy tools for estimating likely effects of interactions of climate, soil and management on yield and its development, simulation of processes in the system atmosphere – plant – soil (Naud et al., 2008). Different models have been developed for a variety of purposes in agriculture (Brisson, et al., 2004; van Ittersum et al., 2003). The DSSAT model has been widely used in the world for simulation of yield and parameters of main plant growth processes (Eitzinger et al., 2003). The model relatively well simulated grain yield in the countries under temperate climate zone of the Central Europe – Czech Republic, Hungary (Trnka et al., 2006a; Holden, Brereton, 2006). The results of model yield simulation performance in the northern regions are controversial. The model simulated the yield with lower accuracy under condition of North-Germany (Langensiepen et al., 2008). There is limited experience in Lithuania of application of models in agronomic research, and modelling in studies of agroecosystems' productivity has been applied only fragmentary (Ivanauskaite et al., 2012). The model DSSAT v4.0.2.0 was used for spring barley and winter wheat yield and water stress simulation under middle Lithuania climatic conditions (Povilaitis et al., 2008; Lazauskas et al., 2012).

Lithuania lays in the zone of interaction of the cool littoral and humid continental air masses (Maracchi G. et al. 2005) and this situation suggests higher variation in cereal yield formation and yield potential realisation level. The aim of this article is to explore the aspects of productivity formation of maize and winter wheat, grown under different fertilization intensity on an *Endocalcari-Epihypogleyic Cambisol* in the northern latitudes of temperate climate and to assess the suitability of DSSAT v4.0.2.0 model for the simulation of water stress simulation.

MATERIAL AND METHODS

Experimental site. The field experiments with winter wheat were carried out at the Institute of Agriculture, LRCAF, Kėdainiai distr., in Valinava long-term experiment (55.22° N, 23.51° E) in 2007 – 2009. This experiment was established in 1991 by A. Bučienė (Bučienė et al., 2007). The experimental site is situated on the terrace of the Dotnuvė River and occupies 4.4 ha. The prevailing soil is light loam, Endocalcari – Epihypogleyic Cambisol (CMg-p-w-can), carbonates are at 40 – 60 cm depth. Soil pH – 7.2, Content of total N – 0.18 %; available phosphorus (P_2O_5) – 151 mg kg⁻¹, available potassium (K_2O) – 119 mg kg⁻¹.

Description of field experiments. Winter wheat (*Triticum aestivum* L.) 'Ada' was grown in a crop rotation typical of Middle Lithuania: spring barley intercropped with red clover, red clover, winter wheat and spring rape. Crops were grown under different levels of intensity: a) conventional, and b) organic. Agroecosystems were repeated twice in space, each occupied approximately 786 m² (32.2 m long, and 24.4 wide) and contained 6 sub-plots (44 m² – 20 m long, 2.2 m wide).

Winter wheat in conventional agroecosystem were applied with herbicides, fungicides and insecticides and in organic system were grown without application of industrial fertilisers and plant protection measures. In conventional system, winter wheat was fertilised with $N_{110}P_{90}K_{140}$ for a target yield of 6 – 7 t ha⁻¹ yield. Winter wheat was sown in the middle of September at a density of 400 kernels m⁻². Herbicides were applied once, fungicides and insecticides once or twice, depending on pest incidence. Winter wheat was harvested at full maturity separately from each sub-plot with a grain harvester 'Wintersteiger'. Grain yield was adjusted to 14% moisture level and recalculated to t ha⁻¹.

Maize 'Ixxes' (FAO 190) was grown under three levels of nitrogen – N_0 , N_{90} and N_{180} . Maize was sown in the beginning of May, at the density 10 plants m^{-2} . The harvested yield of biomass was in middle of September. For an average of grain yield calculation were took five ears from each plot. There is presented grain's yield average of tree years.

Leaf area and biomass measurements. Samples of winter wheat were taken biweekly, six times per growing season. Samples were collected from 3 sub-plots of each agroecosystem, from an area of 0.13 m^2 (two adjacent crop rows 0.5 m long). The maize leaf area was measured 5 times during the vegetation period. Samples were taken from 1 m length row (0.75 m^2 area) of each experimental plot. All leaves, with green surface more than 50%, were detached from the selected plants, scanned and leaf area was measured with a computer program 'WinFolia pro v2004 a'. Then plants were dried and biomass was assessed. Photosynthetic potential (leaf area duration) was calculated using the equation of Power et al. (1967). All leaf area and biomass results are presented per square meter.

Soil moisture measurements. Soil moisture sensors 'Watermark' were installed in the soil in winter wheat and maize at the 20 cm, 40 cm and 60 cm depths. The technical characteristics of the soil moisture sensors 'Watermark' allow measurements of soil moisture in the range from 0 to 200 Centibars (kPa). The measurements are reliable at soil temperature $> +16^{\circ}C$.

Modelling. In this study the computer model DSSAT v4.0.2.0 was used to simulate winter wheat and maize water stress. The required weather data input set was obtained from the Dotnuva meteorological station (daily maximum and minimum air temperature, precipitation). The solar radiation data for the model's DSSAT v4.0.2.0 input was calculated using 'AgroMetShell 1.57' model from the sunshine hours. Soil input data were derived from the field experimental site descriptions.

Statistical analysis of biomass yield, leaf area duration was performed using ANOVA for randomized block design (Clever and Scarisbrick, 2001).

RESULTS AND DISCUSSION

Winter wheat. Leaf are index measurements showed formation of leaf area index in all years of the study followed similar pattern, with the higher values measured under conventional agroecosystem and much lower under organic (Figure 1). The largest differences between agroecosystems were measured when winter wheat reached stage BBCH 31 – 34 – leaf area index under conventional growing peaked on average at 4.5 $m^2 m^{-2}$, while under organic only at 2.5 $m^2 m^{-2}$. During the later stages of development leaf area index and differences between growing systems gradually decreased. The plant protection measures and applied nitrogen fertilisers helped to preserve healthy leaves longer in the conventional agriculture systems. The reason of leaf area decrease is not only diseases but also shortage of water, nitrogen, and other nutrients (Salvagiotti, Miralles, 2008; Dagdelen et al., 2006).

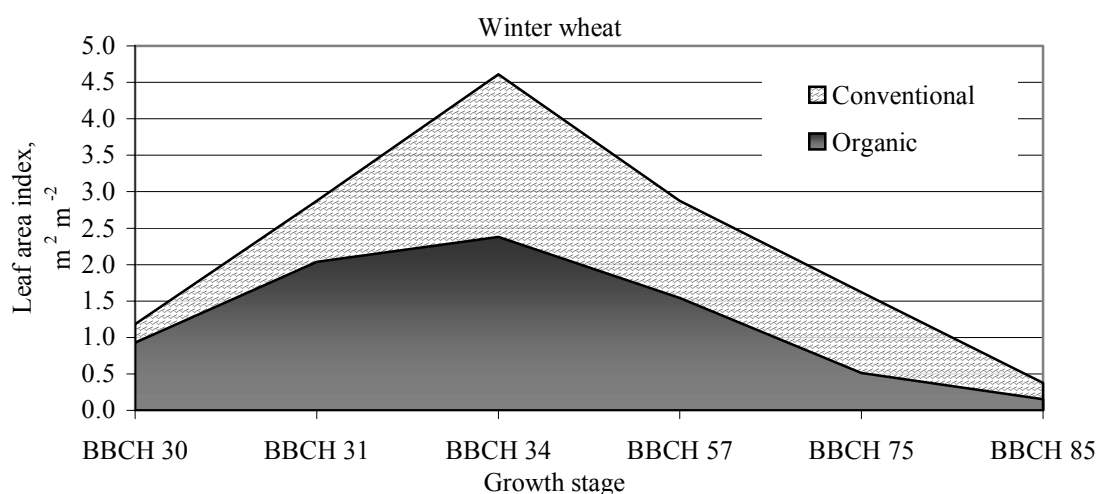


Figure 1. Development of leaf area index of winter wheat under different growing intensity, average of 2007- 2009, Dotnuva

Three years' data of photosynthetic potential and grain yield were subjected to combined analyses of variance (Table 1). For photosynthetic potential the effect of management was significant, whereas there was no effect of the year or interaction between year and management on this parameter. For photosynthetic potential, only effect of management was significant and this result was in a good agreement with data of leaf area index. Photosynthetic potential of winter wheat under conventional growing was on average by $79 \text{ m}^2 \text{ m}^{-2}$ higher than that under organic growing. There was very strong correlation between photosynthetic potential and grain yield ($r = 0.95$; $p < 0.01$). The same trend was indicated in literature (Zhang et al. 2006). Combined analyses of variance showed significant effect of management, year and interaction between year and management on grain yield. The variation in grain yield and effect of management on this parameter across years is apparent and reflects climatic fluctuations. In 2008, differences between crop management systems were much higher than in 2007 or 2009.

Maize. Leaf area measurements showed that nitrogen nutrition was highly important factor in formation of maize canopy: leaf area index was respectively 3.5 and $4.5 \text{ m}^2 \text{ m}^{-2}$ in plots applied with N_{90} and N_{180} . Without N fertilization maize leaf area was lower by 32 - 43%, and below $3 \text{ m}^2 \text{ m}^{-2}$. The weather conditions had evident effect on maize crop performance. The vegetation period of maize in 2010 was the warmest and driest, with the average air temperature by 3°C above climatic norm. Average air temperature in 2011 and 2012 was also higher than climatic norm: respectively by 2°C and 0.7°C . The difference of maize leaf index treated and untreated with nitrogen fertilizers was the lowest in 2012. The highest difference of photosynthetic potential of maize in untreated treatment (N_0) was in 2010 and 2011, respectively $75 \text{ m}^2 \text{ m}^{-2}$ and $148 \text{ m}^2 \text{ m}^{-2}$. Difference of photosynthetic potential between plots applied with N_{90} and N_{180} was 28% in 2010, however, below 10% in 2011 and 2012. The photosynthetic potential significantly correlated with maize grain yield ($r = 0.65$; $p < 0.05$). The highest maize grain yield, on average 7.98 t ha^{-1} , was produced in plots applied with N_{180} , more than double higher than that produced in untreated with nitrogen plots - 4.28 t ha^{-1} .

Water stress simulation. During the study period, temporary water shortage occurred several times per season. Water stress simulated by the DSSAT v4.0.2.0 model correlated relatively well with actual

readings of soil moisture sensors. The correlation coefficient of three years data in winter wheat was 0.80, $p < 0.05$, and in maize - $r = 0.80$, $p < 0.05$.

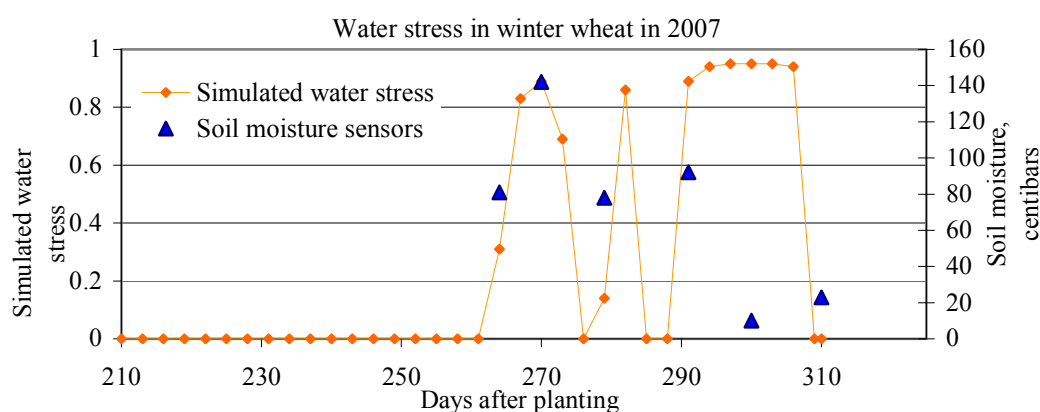
The most droughty year for winter wheat was 2008 (1 fig.). The two short and one longer periods of drought stresses were simulated by model DSSAT v4.0.2.0 in winter wheat in 2007. Shortest simulated water stress was in 2009, with corresponding moisture sensors readings above 100 centibars. It was a short period, thus it is not very likely, that negative effect for the winter wheat yield was significant. According models simulations and soil moisture sensors readings water shortage started in May or later, thus winter wheat could pass some of the most critical stages of development before water shortage occurs. However the grain yield level was influenced not only by management intensity and water availability, but, also by the interaction between these two factors (Table 1).

Table 1. The results of ANOVA of photosynthetic potential and grain yield of winter wheat grown under different intensity.

Agro ecosystem	Photosynthetic potential, $\text{m}^2 \text{m}^{-2}$			Grain yield, t ha^{-1}		
	2007	2008	2009	2007	2008	2009
Conventional	196	257	191	6,27	8,15	6,86
Organic	132	83	111	4,79	3,95	5,05

Analyses of variance		
F value		
Source of variance	Photosynthetic potential	Grain yield
Year	1.47	51.03**
Agro ecosystem	15.25**	316.99**
Interaction	1.53	34.81**

Significant: ** - $p < 0.01$



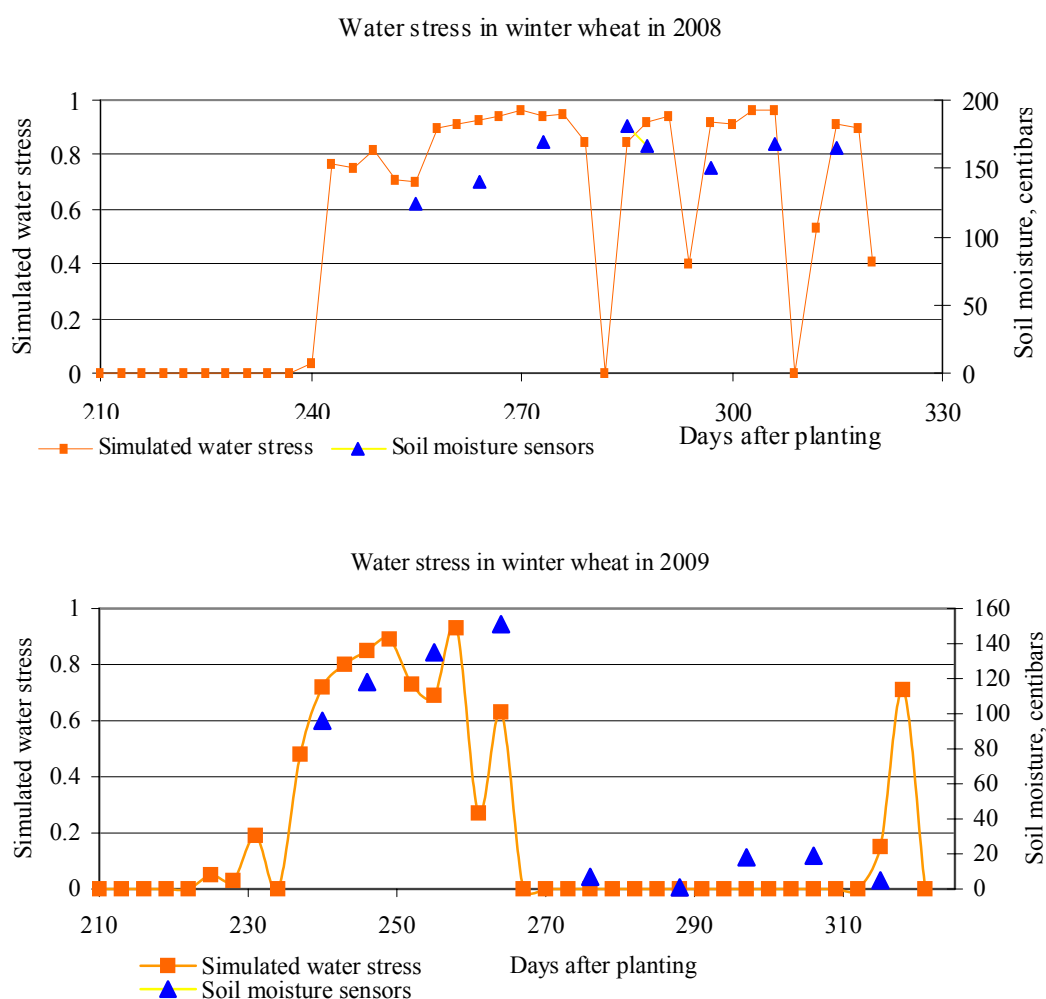


Figure 2. Model's DSSAT v4.0.2.0 simulated water stress and soil moisture sensors in the winter wheat in 2007 – 2009.

The highest drought stress in maize was in 2010 (Fig. 3). The results of model DSSAT v4.0.2.0 simulation showed, that water shortage started two month after planting. As a C4 plant, maize is a considerably more water-efficient crop than C3 plants. Maize is most sensitive to drought at the time of silk emergence, when the flowers are ready for pollination (Meza et al., 2008). For the simulation, we used a short season maize variety. Modelling results indicated, that in 2010 the most intensive water shortage occurred, when maize was at the silking stage. In 2011 shortage of water occurred twice, but outside critical stages and lasted only a week. According to the results of simulation the most favourable growth period for short season maize was in 2012. Within a range between 10 and 35 °C, increases in ambient temperature accelerate the rate of development, allowing maize to complete its phenological stages in shorten periods of time (Meza et al., 2008). Typical response of this crop under climate change conditions are acceleration of the rate of development and reduction of biomass (Meza et al., 2008). Tubiello et al. (2000) reported that higher temperatures accelerated plant phenology and reduced dry matter accumulation. They found that the maize growing cycle was shortened by two weeks compared to the baseline climate.

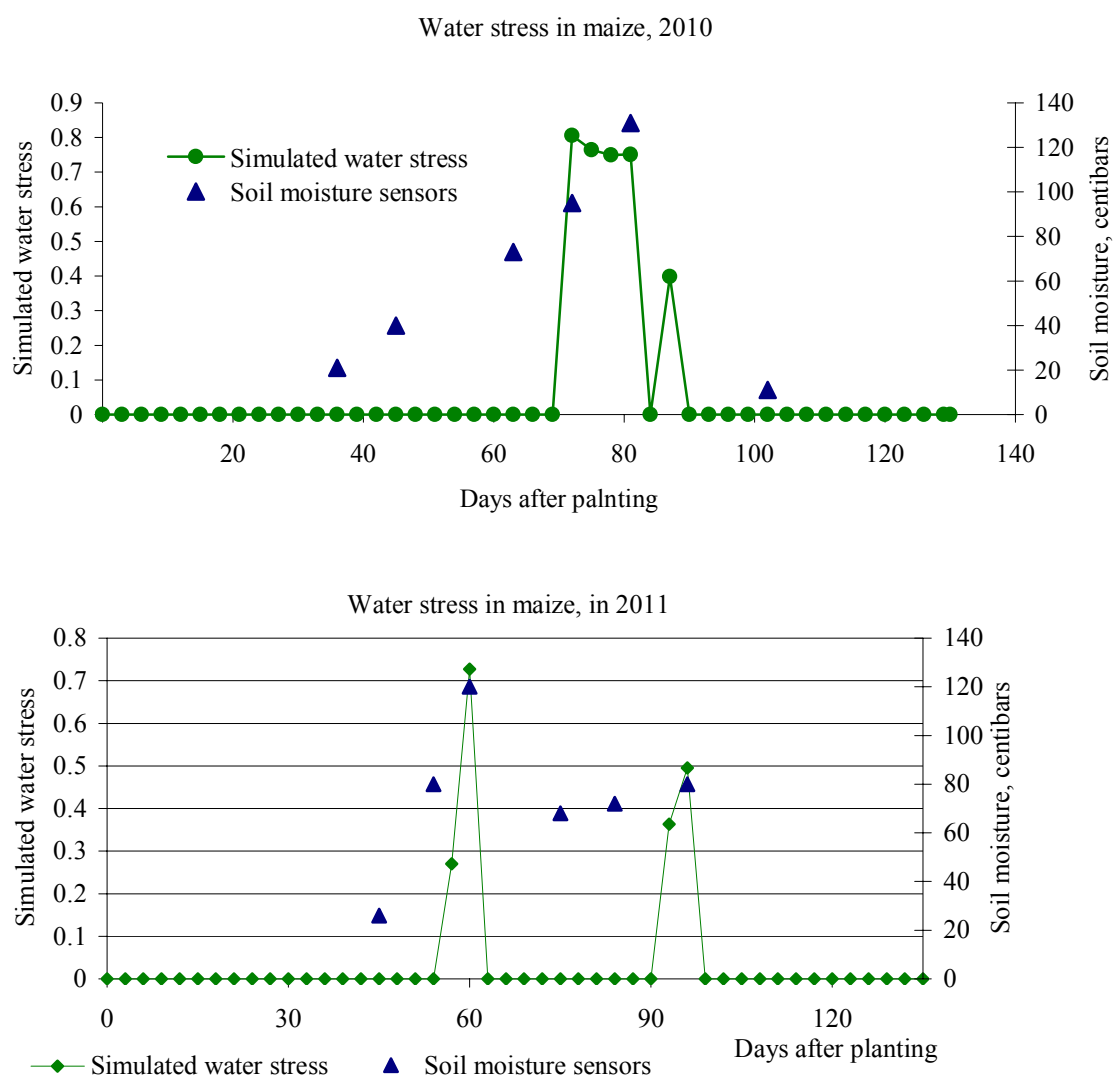


Figure 3. Model's DSSAT v4.0.2.0 simulated water stress and soil moisture sensors in maize in 2010 and in 2011.

Simulation by the DSSAT v4.0.2.0 model showed, that winter wheat for transpiration under conventional management used by 20 – 32% more water than under organic management. However, under organic management, more water was used for evaporation. These suggestions are in agreement with results of our other studies (Feizienė et al., 2008). The model calculations of transpiration in maize showed similar results as for winter wheat: in fertilized with nitrogen plots maize for transpiration used by 3 – 31% more water, than in control plots. The maize canopy covers the soil longer in the second part of summer (in August) and the beginning of autumn than winter wheat and reduce loses of water due to evaporations processes. But this process depends on air temperature in autumn, particularly in September. September air temperature in 2010 – 2012 was higher by +0.1 – +1.9°C than climate norm. Due to climate change increasing length of warm season in autumn suggest

considering of growing more productive maize of longer vegetation, however, management, especially nitrogen should be investigated in more detail.

CONCLUSIONS

Maize and winter wheat responded positively to application of nitrogen fertilizers. The difference in leaf area index between control and applied with nitrogen plots was 32 – 43 % in maize and up to 50 – 55 % in winter wheat. The grain yield of winter wheat was higher by 26 - 52 % and more than 52 % of maize in conventional system (fertilized by nitrogen) compare with organic (without nitrogen). Relatively good correlation ($r = 0.80$, $p < 0.05$ for maize and 0.80 , $p < 0.05$ for winter wheat) was found between water stress index simulated with model DSSAT and indicated soil water availability by soil moisture sensors 'Watermark'.

Simulation showed that winter wheat applied with nitrogen fertilizers used for transpiration by 20 – 32% and maize by 3 – 31% more water than crops in control plots without application of fertilizers.

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