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Carbon Accumulation in Winter Wheat under Different Growing Intensity and Climate Change

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Abstract**—**World population growth drives food demand, promotes intensification of agriculture, development of new production technologies and varieties more suitable for regional nature conditions. Climate change can affect the length of growing period, biomass and carbon accumulation in winter wheat. The increasing mean air temperature resulting from climate change can reduce the length of growth period of cereals, and without adequate adjustments in growing technologies or varieties, can reduce biomass and carbon accumulation. Deeper understanding and effective measures for monitoring and management of cereal growth process are needed for adaptation to changing climate and technological conditions.

Keywords**—**carbon, climate change, modeling, winter wheat

I. INTRODUCTION

WORLD population growth drives food demand, promotes intensification of agriculture, development of new production technologies and varieties more suitable for regional nature conditions. Climate change driven by increasing atmospheric concentration of greenhouse gases in most parts of the northern middle and high latitudes results in increasing winter wetness and summer dryness [1]. Terrestrial ecosystems associate with land use and soil management play an important role in the global carbon budget [2]. The currant global terrestrial sink for carbon is estimated to hold 550–700 Pg of C in vegetation and 1200-1600 Pg in soil organic matter [3]. Land use and land use changes affect the exchange of greenhouse gases between terrestrial ecosystems and the atmosphere. Climate change has the potential to irreversibly damage the natural resource base on which agriculture depends, and in general adversely affects agricultural productivity.

Widely held opinion, that winter wheat will respond positively to these changes is subjected to a number of assumptions and raises complicated questions, such as optimization of inputs. Study of Reidsma et al. [4] suggests, that impacts of climate change and variability are largely dependent on farm characteristics, such as intensity, size, land use, which influence management and adaptation. A bulk of climate change studies focuses on crop yield, which is the result of many-non linear interactions between ranges of processes. Experiments performed under controlled conditions gave a solid insight into wheat responses to various factors; however, under field conditions the importance of interactions between elevated CO_2 and temperature, water and nitrogen stress is not fully understood, evidence from field experiments is limited and points in different directions [5].

Lithuania is situated in the intersection of two climate types – cool littoral and humid continental [6], and is affected by waves from north (Arctic) and from south (Mediterranean). The territory of Lithuania is divided into 10 regions, where annual amount of precipitation range from 500 to 900 mm [7]. The Lithuania midland, where concentrates most fertile soils, is in zone of rainfall excess and there crosses air masses from sea and continent. And it is difficult to predict how in future the climate change will affect the agriculture. Deeper understanding and effective measures for monitoring and management of cereal growth process are needed for adaptation to changing climate.

Aim of the study is to estimate carbon accumulation in winter wheat as affected by different growing intensity and likely climate change.

II MATERIALS AND METHODS

A. Description of site and Field Experiments

Field experiments with winter wheat (*Triticum aestivum L.*) were carried out in 2007-2009 at the Lithuanian Institute of Agriculture (since 2010 Institute of Agriculture of the Lithuanian Research Centre for Agriculture and Forestry) in Dotnuva, Kėdainiai, Lithuania on the basis of the long-term field experiment (55.22° N, 23.51° E) established in 1991 by A. Bučienė [8]. The experimental site, situated on the terrace of the Dotnuvele river, occupies 4.4 ha and contains 11 fields with separate drainage systems, covered with arable crop rotation or permanent grasses. The soil is characterised as light loam, *Endocalcari – Epihypogleyic Cambisol* (*CMg-p-w-can*), neutral, relatively rich in humus, medium in available potassium and phosphorus. The mean annual precipitation is 578 mm and the mean annual air temperature is 6.5 °C. Soil and climate conditions of the site are typical of Middle Lithuania lowland, a region with fertile soils and prevailing cereal production.

Our study utilized part of the long-term experiment representing winter wheat cultivar 'Ada' grown under two

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levels of input intensity: a) moderate (conventional), and b) low (organic). Each treatment was replicated twice in space - experimental plot (replication) occupied approximately 786 m^2 (32.2 m long, and 24.4 wide) and contained 6 sub-plots (44 m^2 – 20 m long, 2.2 m wide). Wheat under conventional system was applied with the fertilizers at a rate of $N_{110}P_{90}K_{140}$ calculated for target 6 – 7 t ha^{-1} yield, applied with herbicide, fungicide and insecticide. Under organic system the crop was managed following the rules of organic agriculture without application of industrial N fertilizers and plant protection products. Winter wheat was sown at a density of 400 kernels per m^2 in the middle of September and harvested at the end of July or beginning of August.

Plants for biomass measurements, biomass chemical analysis and leaf area were sampled six times per growing season. The samples were collected from each sub-plot, from an area of 0.13 m^2 (0.5 m long two adjacent crop rows). All leaves, with green surface more than 50%, were detached, scanned and leaf area was measured with a computer program 'WinFolia pro v2004a'.

B. Meteorological conditions

Lithuania is situated in the intersection of two climate types – cool littoral and humid continental [8], and is affected by waves from north (Arctic) and from south (Mediterranean). For this reason, the weather conditions in specific year can markedly diverge from climatic norm. During our study, the average air temperatures were 7.9ºC, 8.5ºC and 7.2ºC respectively in 2007, 2008 and 2009, and were much higher than the local average (6.5ºC) of 1961-1990. The accumulated precipitation was respectively 668 mm, 573 mm and 736 mm – similar to or much higher than local average (578 mm). Thus the weather conditions were similar to those, which we can expect in the nearest decades due to the climate change.

Statistical analysis of leaf area duration and carbon yield was performed using ANOVA completely randomized design, and interdependence of individual characteristics was assessed using linear correlation and regression (Clewer and Scarisbrick, 2001).

C. Modelling and climate change scenarios

Simulation of winter wheat leaf area and grown duration was performed with a computer model DSSAT v4.0.2.0. The weather data (daily maximum and minimum air temperature, precipitation) was obtained from Dotnuva and solar radiation from Kaunas weather stations. Soil input data were derived from the Valinava experimental site soil profiles and data on crop management represented actual operations performed in field. Genetic coefficients of the winter wheat were chosen from the model's data base, representing Western Europe type.

The majority of the published scenarios of the expected climate change provide similar trends in global temperature, CO_2 and precipitation [10], [1], [11]. Based on this material, two scenarios for simulating winter wheat performance were elaborated: the 1st scenario – air temperature higher by 2ºC and CO_2 ambient 375 ppm, the 2nd scenario – air temperature higher by 2ºC and CO_2 increased up to 485 ppm. Meteorological data of winter wheat growing seasons 2006-2007, 2007-2008 and 2008-2009 in Dotnuva, were used as a baseline for simulations.

III RESULTS AND DISCUSSION

A. Leaf area index and carbon accumulation

Leaf area index (LAI) was significantly influenced by input level (fig. 1). The largest values of LAI and differences between treatments were found at winter wheat growth stage BBCH 31 – 34. Nitrogen concentration in plant biomass at the beginning of intensive growth period, the criterion which is often used as an indicator of plant N nutrition status, in all cases was well below optimum values necessary for unlimited plant growth.

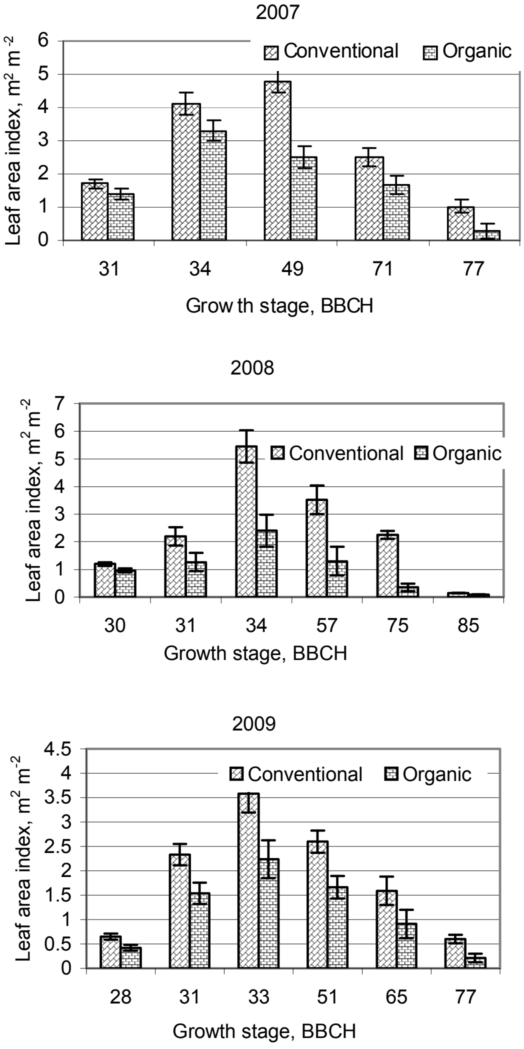

Fig.1 Leaf area index of winter wheat grown under different intensity, Dotnuva, 2007-2009

The amount of carbon accumulation in biomass of winter wheat depends from input intensity too. The highest amount of carbon was accumulated in moderate system (fig. 2-4). The amount of carbon increased during the vegetation season and maximum value ranged from 689 g m^{-2} in 2007, till 1039 g m^{-2} in 2008 in moderate system, and from 576 g m^{-2} in 2009 by 737 g m^{-2} in 2008 in organic system. Brakas and Aune [12] in nineteen land use types estimated that aboveground C stock varied from 2.9 to 234 Mg ha^{-1}, and the highest stock was observed in forest, however the accumulation in wood is relative slow, of the order of 5 Mg C ha^{-1} year^{-1}.

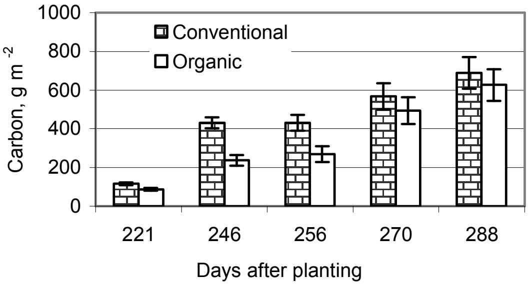

Fig. 2 Carbon accumulation in biomass of winter wheat in 2007, Dotnuva

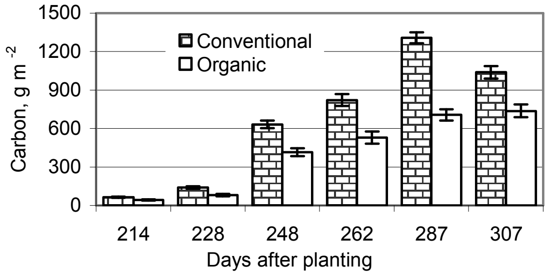

Fig. 3 Carbon accumulation in biomass of winter wheat in 2008, Dotnuva

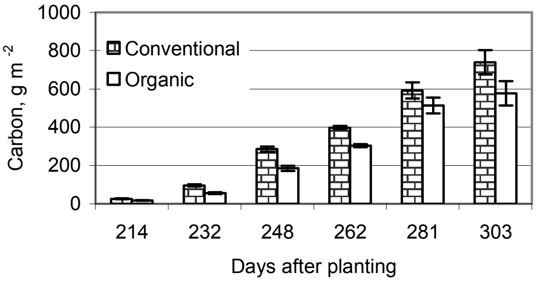

Fig. 4 Carbon accumulation in biomass of winter wheat in 2009, Dotnuva

The concentration of carbon in biomass of winter wheat was increasing from 42% in beginning of vegetation by 57% under moderate system, and from 43 by 56% in winter wheat growth under organic management in our field experiment. Wang et al. [13] estimated that total C in winter crops was significantly influenced by the soil type. Also total carbon and nitrogen as well as biomass production of winter cover crops were significantly influenced by crop species and growth temperatures. When water is non-limiting, both carbon and nitrogen capture and use are closely linked with one another through the development of leaf area and the pattern of intercepted radiation [14]. Wang et al. [13] noted that in general, biomass C accumulation was greater in the winter than in the summer crops.

B. Climate change effects on leaf area index and growth duration

The efficiency of C sequestration by various vegetations differs largely as influenced by differences in their physiological characteristics, growth rates, biomass accumulation rates, etc., and by many environmental factors [13]. One of these factors is 'green-house gases' (GHG) and it is now universally accepted that increased atmospheric concentration of GHG are the main cause of the ongoing climate change [15]. In results of Moriondo et al. [16] simulation of winter wheat under climate change in Southern Europe showed that vegetation period of winter wheat was considerably shortened – up to 50 days. In Northern areas of Europe indicated, that climate change may have positive effects through increases in productivity and range of species grown [17].

In our previous study, the DSSAT v4.0.2.0 model was tested against the grain yield data of the experiments with winter wheat 'Širvinta 1' and showed relatively good performance judging from both the correlation level (R^2 = 0.81) and 1:1 line view [18]. Simulation of LAI with DSSAT model according to previously described climate change scenarios showed, that major effect of climate change on winter wheat LAI development can be expected in relation to increasing air temperature - shift of LAI maximum to earlier dates in spring and earlier leaf senescence in summer. If the temperature increases by +2°C, the shift of LAI maximum by 20-23 days can be expected. If the temperature increases by +2°C and increase CO_2 emission up to 485 ppm, the LAI maximum increase by 2% more. In both cases, the model simulated similar LAI maximum: approximately 3 m^2 m^{-2} under low and 5 m^2 m^{-2} under moderate input management.

The increasing air temperature can shorten period of growth. An increase in average air temperature by 1 °C can reduce growth period of cereals by approximately 5 days, and an increase by 2 °C can result in shorter growth period by 11 days in winter wheat. This shorten can reduce an accumulation of biomass and carbon amount in biomass too. However plant use CO_2 as an input in the photosynthesis process, so increasing CO_2 levels might spur plant growth and yields. However, yield declines stemming from warmer temperatures therefore may be offset by CO_2-fertilization [19]. A faster rate of canopy development and a longer growing cycle give cereals a major advantage to accumulate more biomass [20]. It is suggested that use of longer cycle crops for a summer crop to lengthen the time for biomass accumulation in a warmer climate [21], but the increasing risk of drought can negatively effect biomass accumulation [18], [22]. On the other hand shorter growth period and earlier harvest of winter wheat provides some management alternatives – e.g. possibility to increase share of winter crops in crop rotation.

In our study no extreme events were envisioned and currently applied crop growing technologies were used, including dates of sowing, varieties, etc. For this reason results of simulations can be treated as very preliminary estimations of possible effects on LAI and carbon accumulation caused by changing climate. The increasing mean air temperature resulting from climate change can reduce the length of growth period of cereals, and without any adjustments in growing technologies or varieties, can reduce biomass and carbon accumulation.

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REFERENCES

[1] IPCC (2007). Intergovernmental Panel on Climate Change Woking Group II. Climate Change 2007: The Physical Science Basis. Solomon S., Qin D., et al. (eds).

[2] R. Lal (2004). Soil Carbon Sequestration to Mitigate Climate Change. Geoderma, Vol. 123, p.1-22.

[3] K. Paustian, O. Andre, H.H. Janzen, R. Lal, P. Smith, H. Tiessen, M. Van Noordwijk and P.L. Woomer. (1997). Agricultural Soils as a Sink to Mitigate CO2 Emissions. Soil Use and Management, Vol 13, p. 230-244.

[4] P. Reidsma, F. Ewert, A. O. Lansink, and R. Leemans. (2010). Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses. European Journal of Agronomy, Vol. 32, p. 91-102.

[5] A.J. Challinor, F. Ewert, S. Arnold, E. Simelton and E. Fraser (2009). Crops and climate change: progress, trends, and challenges in simulating impacts and informing adaptation. Journal of Experimental Botany, Vol. 60, p. 2775–2789.

[6] G. Maracchi, O. Sirotenko, M. Bindi (2005). Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. Climatic Change. Vol. 70, p. 117-135.

[7] Lietuvos TSR atlasas. Maskva. 1981. (In Lithuanian).

[8] Bučienė A., Antanaitis Š., Mašauskienė A., Šimanskaitė D. 2007. Nitrogen and Phosphorus Losses with Drainage Runoff and Field Balance as a Result of Crop Management. Communications in Soil Science and Plant Analysis. Vol. 38, p. 2177 – 2195.

[9] A.G. Clever and D.H. Scarisbrick, (2001). Practical Statistics and Experimental Design for Plant and Crop Science, Wiley, New York . 332 p.

[10] J.E. Olesen, M. Bindi (2002). Consequences of climate changes for European agricultural productivity, land use and policy. European Journal of Agronomy. Vol. 16, p. 239–262.

[11] R. H. Patil, M. Lægdsmand, J.E. Olesen, J.R. Porttwer (2010). Effect of soil warming and rainfall patterns on soil N cycling in northern Europe. Agriculture, Ecosystems and Environment. Vol. 139, p.195–205.

[12] S. G. Brakas, J. B. Aune (2011). Biomass and Carbon Accumulation in Land Use Systems of Claveria, the Philippines. Carbon sequestration potential of Agroforestry systems. Vol. 8, p. 163-175.

[13] Q. Wang, Y. Li, A. Alva (2010). Growing Cover Crops to Improve Biomass Accumulation and Carbon Sequestration: A Phytotron Study. Journal of Environmental Protection, Vol. 1, p. 73-84.

[14] G. Lemaire, E. van Oosterom, J. Sheehy, M.H. Jeuffroy, A. Massignam, L. Rossato (2007). Is crop nitrogen demand more closely related to dry matter accumulation or leaf area expansion during vegetative growth? Field Crop Research, Vol. 100, p. 91–106.

[15] P. Forster, V. Ramaswamy, Artaxo P, Berntsen T, Betts R, Fahey DW, Haywood J, Lean J, Lowe DC,Myhre G, Nganga J, Prinn R, Raga G, SchulzM, Van Dorland R (2007) Changes in atmosphericconstituents and in radiative forcing. In: Solomon S, Qin D, Manning M, Chen Z, MarquisM, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

[16] M. Moriondo, C. Giannakopoulos, M. Bindi (2011). Climate change impact assessment: the role of climate extremes in crop yield simulation. Climate Change, Vol. 104, p. 676-701.

[17] J. Alcamo, J.M. Moreno, B. Nováky, M. Bindi, R. Corobov, Devoy RJN, Giannakopoulos C, Martine, J.E. Olesen, A. Shvidenko (2007). Europe. Climate change 2007: impacts, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 541–580

[18] V. Povilaitis, S. Lazauskas (2010). Winter wheat productivity in relation to water availability and growing intensity. Žemdirbystė=Agriculture Vol. 97, p. 59–68.

[19] W. Schlenker, M. J. Roberts (2009). Nonliner temprrature effects indicate severe damage to U.S. crop yield under climate change. PNAS, Vol. 106, p. 15594-15598.

[20] F. Giunta, G. Pruneddu, R. Motzo (2009). Radiation interception and biomass and nitrogen accumulation in different ceral and grain legume species. Field Crop Research, Vol. 110, p. 76-84.

[21] C. Giannakopoulos, P. Le Sager, M. Bindi, M. Moriondo, E. Kostopoulou, C.M. Goodess (2009). Climatic changes and associated impacts in the Mediterranean resulting from global warming. Global Planet Change 68:209–224

[22] G. Šabajievienė, S. Sakalauskienė, S. Lazauskas, P. Duchovskis, A. Urbonavičiutė, G. Samuolienė, R. Ulinskaitė, J. Sakalauskaitė, A. Brazaitytė, V. Povilaitis (2008). The effect of ambient air temperature and substrate moisture on the physiological parameters of spring barley. Žemdirbystė=Agriculture, vol. 95, No. 4, p. 71-80 (in Lithuanian).