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SEASONAL CARBON EMISSIONS AND SEQUESTRATION IN AGROECOSYSTEMS OF ORGANIC CROPS IN CENTRAL LITHUANIA

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The growth rate of atmospheric carbon dioxide (CO_2) concentrations since industrialization in Anthropocene is characterized by large variability, mostly resulting from variability in CO_2 uptake by terrestrial ecosystems including agroecosystems. Various crops emit different rates of CO_2 into atmosphere. Investigations of seasonal carbon exchange in agroecosystems were carried out at the Training Farm of Agriculture Academy in 2014–2016. The aim was to investigate and compare carbon exchange rate of different crops of ecological farming. This study involved carbon exchange rate of agroecosystems including measurement of emitted and absorbed CO_2 fluxes by applying closed chamber method.

Plant (Ra) and soil respiration (Rs) varied between crops and during growth stages. However total respiration compose less than 30% of total carbon exchange in agroecosystems. Main drivers of mean plant and soil respiration were meteorological conditions, crop species, vegetation period and growth stage. Generally, respiration emissions were completely recovered by atmospheric carbon rates sequestered in crops gross primary production (GPP). Therefore the ecosystems biota was acting as atmospheric CO_2 sink. Photosynthetically assimilated mean CO_2 rates ranged between 10.148 µmol m-2 s-1 in vetch+oat mixture and 11.923 µmol m^{-2} s^{-1} in ley and exceeded mean respirational emissions by 72 %. The differences in photosynthetically assimilated CO_2 rates were significantly interacted and correlated with leaf area index (LAI) (r=0.4-0.8, p=0.01-0.04), specific leaf area (SLA) (r=0.3-0.8, p=0.01-0.03) and dry biomass (r=0.4-0.6, p=0.03-0.05). Between ecological crops, the highest mean net ecosystems production (NEP) was sequestered in biomass of ley and wheat and ranged between 9.931 and 9.199 µmol m^{-2} s^{-1}, respectively. These crops might be considered the most environmental sustainable between crops.

Key words: CO_2 fluxes, bio-parameters, environment, crops.

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INTRODUCTION

Croplands represent near 12% of the Earth's surface (Smith et al. 2007) and one third of the land surface in Europe (FAO 2003). Therefore agroecosystems plays a significant role in generation of anthropogenic emissions which accounts for 10–12% of total anthropogenic emissions of greenhouse gas (GHG) (Schlesinger & Bernhardt 2013). EU produces 9.78% of agricultural emissions, out of which 4.94% are emissions from the soil (EEA 2010). Agriculture produces near 21.4% of total emissions in Lithuania (LR 2012).

Photosynthesis process assimilates atmospheric CO_2 and creates a huge organic C pool in terrestrial vegetation, including crops biomass (Schlesinger &Bernhardt 2013), which is usually estimated by multiplying total plant biomass by a corresponding biomass C conversion factor, i.e., the C content (Thomas & Martin 2012, Zang et al. 2014). The most widely employed C content in plants is near 50% in the regional and global vegetation C stock estimations (Lambers et al. 2008, Johnson et al. 2007). Farming system, growth period duration and water content are the main factors that determine photosynthesis process, C fluxes in agroecosystems (Domingo et al. 2011), CO_2 fluxes and exchange in the system atmosphere-plant-soil (Aertsens et al. 2013). Strong correlation between CO_2 emission temperature and precipitation (r=0.7) was found during the summer season in organic and conventional agroecosystems (Baležentienė & Kusta, 2012). The conventional farming is aimed toward productivity for greater profits rather than to maintenance of sustainable environment. Thus, conventional farming has a significant negative impact on the long-term soil productivity and sustainability entire agroecosystem. Numerous studies revealed that control of yield, environment and carbon sequestration becomes possible if appropriate farming system, growing technology and crops have chosen (Janssens et al. 2003, Wood et al. 2000). Ecological point needs to be sustainably managed to reduce environmental impacts of agrothechnologies, while production quality, and profitability augmented (Huisingh et al. 2015). The relationship between the rates of carbon fluxes and bio-parameters of plants stands important for the evaluation of the possibility for the climate change mitigation and the development of sustainable agriculture. Evidence of the crop NEP would improve the understanding of the factors and mechanisms that influence carbon emissions and sequestration, and thus optimally regulate these processes reducing CO_2 emissions and predicting their changes (EC 2019).

The main objectives of this study were to assess the potential of atmospheric carbon assimilation and accumulation in biomass during growth period in organic farming agroecosystems of ley, winter wheat, vetch + oat mixture and barley + ley undercrop; to determine seasonal respiration fluxes and the rates of assimilated carbon. In order to explain carbon exchange, the photosynthesis parameters (crop density, leaf area index, productivity) were investigated at different plant' growth stages.

MATERIAL AND METHODS

Measurement object and location

Investigations of seasonal C exchange of organic farming ley (L), wheat (W), vetch + oat mixture and barley + ley undercrop (B) were carried out during growth period in 2014–2016 at the Training farm of Vytautas Magnus University (former Aleksandras Stulginskis University, 54°52' N, 23°49' E), Kaunas district (Table 1). The cropland soil types were *Hapli-Epihypogleyic Luvisol, LVg-p-w-ha*, or *Albi-Epihypogleyic Luvisol, LVg-p-w-ab*) (FAO 2015).

For evaluation of crop photosynthetic surface, the crop density (plant m^{-2}) and leaf surface area (LAI, m^2 m^{-2} was determined for the plots of 0.25 m^{-2} (0.5 m x 0.5 m) in six replications (Breda 2003). Fresh plant biomass (FM, g m^{-2}) and dry matter content (DM, g m^{-2}) were determined by the weighting method. Dry matter content was determined by drying plant samples (80°C thermostat (Tritec HANNOVER, Germany).

Table 1. Agroecosystem parameters

Farming type	Agroecosystem	Area, ha	Crop fertilising
Ecological	Ley	8.75	-
	Wheat	8.75	Manure, 36 t ha^{-1}
	Vetch + oat mixture	12.48	-
	Barley + ley undercrop	12.48	-

Carbon footprint investigation

Agroecosystems' seasonal C exchange was investigated applying static chamber method (Smith et al. 2013) using LCpro system (ADC Bioscientific LTD, UK). The rate of gross primary production (GPP, µmol m^{-2} s^{-1}) and respiration emissions of soil and autotrophs (Rs+a, µmol m^{-2} s^{-1}) were measured every 7–10 days with regard to environmental conditions and plant growth stages (BBCH-scale; Meier 2001). Carbon exchange of each agroecosystem was evaluated by net ecosystem production (NEP, µmol m^{-2} s^{-1}) which was calculated by the formula: NEP=GPP- Ra+s (Amthor 1989, Chapin et al. 2012).

Meteorological conditions. The vegetation period suitability for plant growth is expressed as a ratio of humidity and temperature, or hydrothermal coefficient (HTK).

2014 March HTK = 1.83 shows the extent moisture, and in April HTK = 0.78 - too dry conditions for plant growth, or 2 times drier than in March. May HTK = 2.03 June HTK = 1.13, July HTK = 0.82, August HTK = 2.02, September HTK = 1.98 (Fig. 1). October HTK = 1.61, or nearly optimal humidity, while November HTK = 4.15 indicates 3 times more moisture than in October.

2015 spring was excessively wet for plant growth, since March HTK = 3.2, April HTK = 2.2, May HTK = 1.22, but June was too dry with HTK = 0.41, July HTK = 1.34, and in August, there was no rain all with HTK = 0.11, September HTK = 1.32, October HTK = 1.96.

Summarizing, 2015 growing season was warmer but drier in comparison with 2014 and multi-annual averages. This is confirmed by the average hydrothermal coefficient (HTK), which was 1.81 in 2014 and 1.47 in 2015. Fluctuations and differences in weather conditions could affect not only autotrophs biometric parameters, but also photosynthesis and respiration processes.

RESULTS AND DISCUSSION

C exchange and plant growth are closely related with meteorological conditions during growth period and soil chemical properties. Average air temperatures seasonally ranged depending on the season and month. It was found strong positive correlation (r_a=0.6 and r_s=0.8; p=0.02, respectively) between plant and soil respiration (R_a and R_s) and air temperature in OF agroecosystems (Fig. 1,2). During vegetation period mean soil respiration varied between 0.236 and 2.065 µmol m^{-2} s^{-1} since the smallest values obtained in early spring and late autumn when soil moisture surplus in (and in spring) determined unfavourable anaerobic conditions for soil biota, and thus decreased soil respiration Rs in our temperate climate. However, summer precipitation deficiency also reduced soil respiration R_s rates even though air temperature increased. Mean plant respiration (R_a) varied from 0.354 in March to 1.704 µmol m^{-2} s^{-1} in June (Fig. 2). Plants respiration increased in conjunction with their growth intensity up to flowering stage and decreased at plant maturity stage. Plant respiration subject to LAI values (Fig. 3).

These plant and soil respiration emissions (Ra+ Rs) ranged between 2.519 and 3.517 µmol $m^{-2}s^{-1}$ however composed insignificant part in total carbon exchange. Moreover, respirational emissions were completely compensated by the

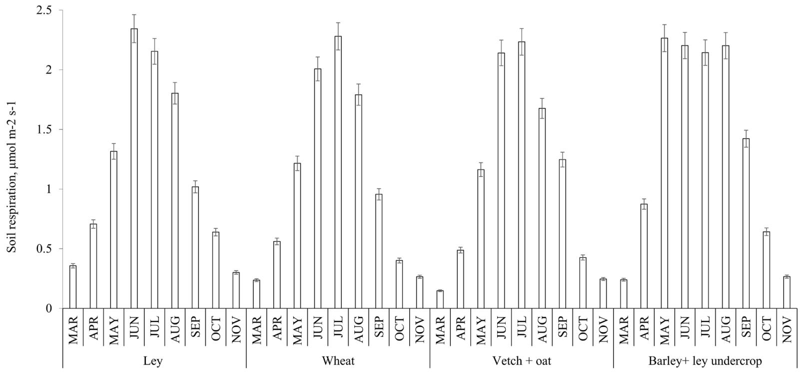

Fig. 1. Soil respiration (Rs) in organic crops, 2014-2016 (mean±SE).

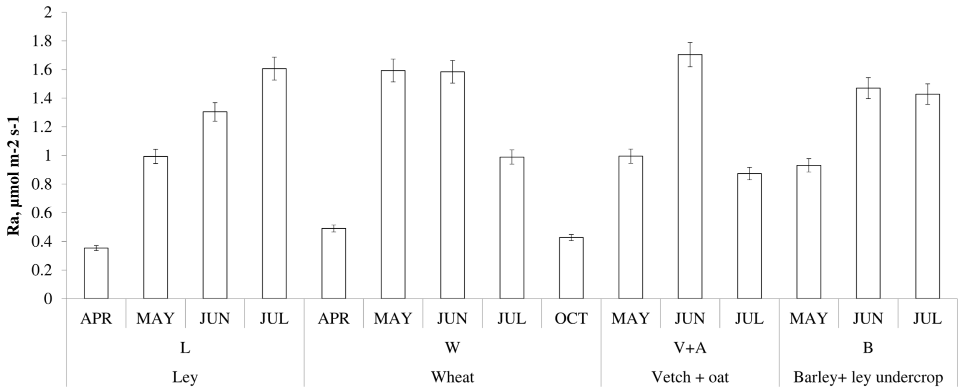

Fig. 2. Plant respiration (Ra) in organic agroecosystems, 2014-2016 (mean±SE).

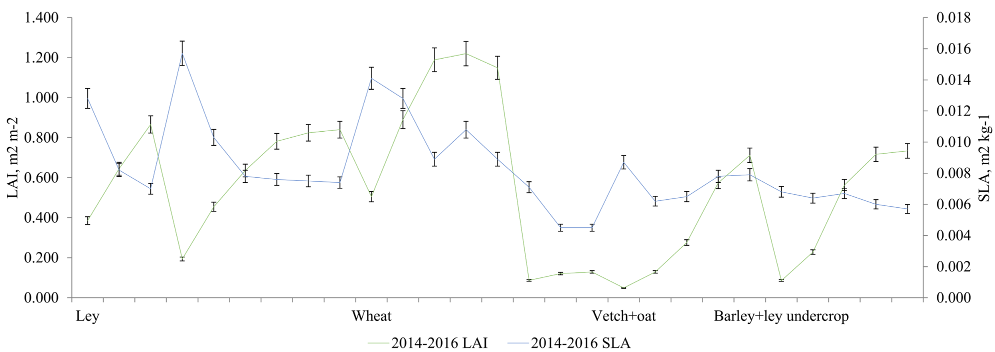

Fig. 3. LAI and SLA in crops agroecosystems (mean±SE).

plant photosynthesis when atmosphere CO_2 has been absorbed and assimilated. Short-living vetch+oat mixture and barley+ley undercrop exhibited the maximal Ra+ Rs of 3.037 µmol $m^{-2}s^{-1}$ and 3.517 µmol $m^{-2}s^{-1}$ respectively if compared to minimal respiration in ley and wheat agroecosystems. These results correspond to previous findings that more intensive agrotechnologies applied in rotational systems with short-living crops increased negative impact on environment (Goglio et al. 2018).

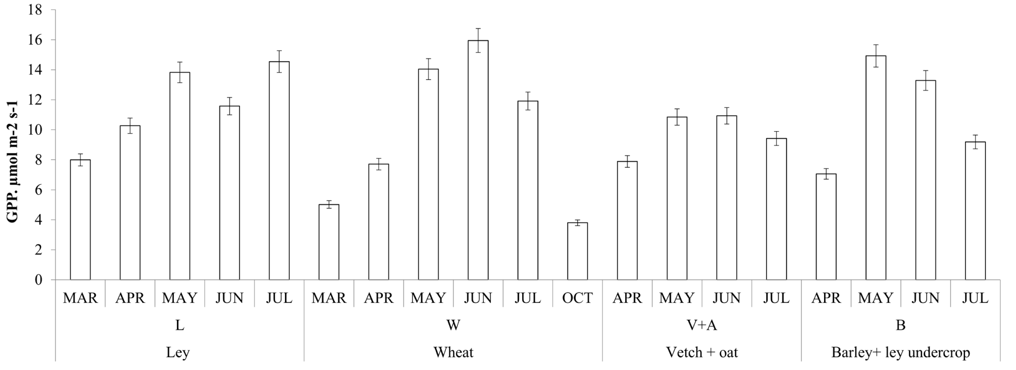

Fig. 4. Atmospheric CO_2 sequestration in crops GPP (mean±SE).

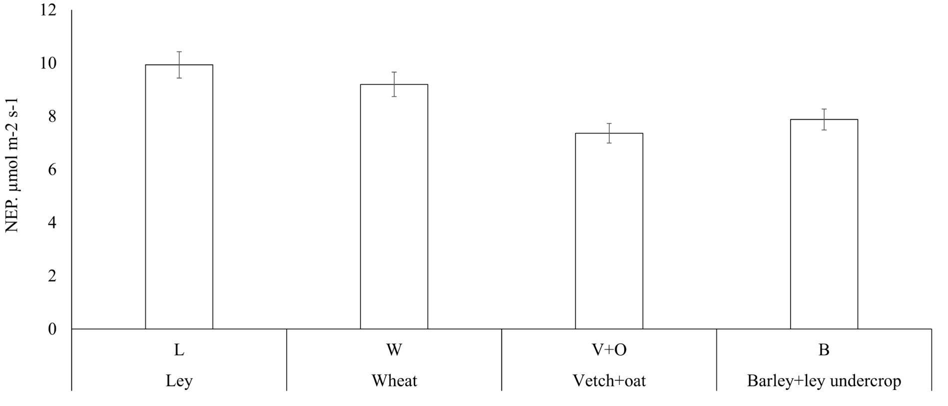

Fig. 5. Net ecosystem production (NEP) in organic agroecosystems (mean±SE).

Leaf area formation (LAI) and growth occurred during plant intensive growth stages until flowering stage. The plant growth and their bio-parameters also varied seasonally in dependence on meteorological and agrotechnical conditions. LAI is the main structure involved in photosynthesis process when plants assimilated and sequestered CO_2 in GPP (Fig. 4). The maximal mean LAI of 0.625 m^2 m^{-2} and 0.661 m^2 m^{-2} was recorded for ley and wheat, respectively. nonetheless, the minimal LAI of 0.348 m^2 m^{-2} and 0.466 m^2 m^{-2} was documented for vetch+oat mixture and barley+ley undercrop due to their small habitat and short vegetation period. Specific leaf area (SLA) is another important trait regulating and controlling plant functions such as carbon assimilation and carbon allocation (Smith et al. 2007). SLA increased together with plant maturity from 0.005 to 0.016 m^2 kg^{-1} since LAI decreased due to withering of bottom leaf.

LAI and SLA determined the photosynthetic surface and volume of assimilated CO_2 (GPP and NEP) in agroecosystems.

Significantly strong correlation between temperature and GPP ($r=0.7$, $p=0.001$) confirmed that seasonal temperature fluctuations resulted the average seasonal GPP alteration in agroecosystems. Seasonal changes in the rates of assimilated CO_2 (GPP) can be attributed to seasonal variation of LAI and biomass at different growth stages. This was confirmed by strong correlation between GPP and LAI ($r = 0.8$) in assessed agroecosystems. Maximal mean GPP rate of 11.9 µmol $m^{-2}s^{-1}$ was recorded in ley and minimal of 10.1 $m^{-2}s^{-1}$ – in vetch+oat mixture due to different bio-parameters and growth period.

Net ecosystem production (NEP) shows the CO_2 content of assimilated and converted to biomass. NEP was different in agroecosystems depending on plant species and longevity of growth period (Fig. 5). NEP varied correspondingly to environmental conditions and bio-parameters, particularly to LAI (r=0.8), during the growth period. The mean NEP values responded to seasonal climate. The highest NEP was found in the ley and wheat agroecosystems and mean value rated 9.936 µmol $m^{-2}s^{-1}$ and 9.199 µmol $m^{-2}s^{-1}$ respectively. These crops sank and assimilated the highest amount of atmospheric CO_2, which was accumulated in the biomass. Therefore, they may significantly contribute to increase in sustainability of agriculture due to decrease in CO_2 concentration in the atmosphere and consequent climate change mitigation. This result obtained due to their the longest vegetation period between assessed crops and correspond to other findings (Smith et al., 2013). Subsequently the minimal NEP was of short vegetation crops, i.e. vetch+oat mixture and barley+ley undercrop.

The total amount of carbon sink by plants (NEP) exceeded total respiration rate several times, thus agroecosystems significantly reduced atmospheric CO2 concentration.

CONCLUSION

Mean soil respiration advanced plant respiration by 18%. Total respiration CO_2 emissions were higher in short-living vetch+oat mixture and barley+ley undercrop that in ley and winter wheat agroecosystems. Alteration of respiration CO_2 emissions strongly depended on meteorological conditions, i.e. air temperature (r_s=0.6 and r_a=0.8). Precipitation exhibited negative correlation to soil (r_s=-0.6) and plant respiration (r_a=-0.7).

Differences of CO_2 exchange throughout photosynthesis and respiration among investigated agroecosystems strongly correlated with the leaf area index (r = 0.8). The investigated agroecosystems sequestered greater rates of atmospheric CO_2 than they emitted during respiration. Crop's LAI, determined photosynthetic surface and rates of assimilated CO_2 (GPP and NEP) in assessed agroecosystems. Among the agroecosystems analysed, ley and wheat exhibited the highest CO_2 assimilation capacity. Therefore, they may significantly contribute to increase in sustainability of agriculture due to decrease in CO_2 concentration in the atmosphere and consequent climate change mitigation. The results also revealed, that optimal choice of plant species alongside with correction of their area in rotation systems may reduce CO_2 emissions and their impact on the environment and climate change.

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REFERENCES

Aertsens J., de Nocker L., Gobin A. 2013. Valuing the carbon sequestration potential for European agriculture. *Land Use Policy*, 31: 584–594 doi:10.1016/j.landusepol.2012.09.003.

Amthor J. S. 1989. Respiration and crop productivity. New York : Springer-Verlag, pp. 215.

Baležentienė L., Kusta A. 2012. Reducing greenhouse gas emissions in grassland ecosystems of the Central Lithuania: multi-criteria evaluation on a Basis of the ARAS Method. *The Sci. World J.,* 3:1–11. doi:10.1100/2012/908384.

Breda N.J.J. 2003. Ground-based measurements of leaf area index: A review of methods, instruments and current controversies. *J. Exp. Bot.,* 54: 2403-2417.

Chapin III, F. S., Matson, P. A., Vitousek, P. 2012. Principles of Terrestrial Ecosystem Ecology. 2nd Ed.; Springer: New York, NY, USA, pp. 546.

Domingo F., P. Serrano-Ortiz, A. Were, L. Villagarcía, M. García, D.A. Ramírez 2011. Carbon and water exchange in semiarid ecosystems in SE Spain. *J. Arid Environ.,* 75 (12): 1271–1281. doi:10.1016/j.jaridenv.2011.06.018.

EC. 2019. Future of the common agricultural policy (CAP), https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en#documents.

EEA. 2010. The European environment – state and outlook 2010: synthesis. European Environment Agency, Copenhagen, Pp. 228.

FAO. 2003. FAO statistical databases. Food and Agriculture Organization of the United Nations, Rome, http://faostat.fao.org

FAO. 2015.World reference base for soil resources 2014, Update 2015. Food and Agriculture Organization of the United Nations, Rome, 2015. http://www.fao.org/

Goglio P., Smith W. N., Worth D. E.,. Grant B. B, Burgess P. 2018. Development of Crop. LCA, an adaptable screening life cycle assessment tool for agricultural systems: A Canadian scenario assessment. J*ournal of Cleaner Production*, 172: 3770-3780.

Huisingh D., Zhang Z., Moore J.C., Qiao Q., Li Q. 2015. Recent advances in carbon emissions reduction: policies, technologies, monitoring, assessment and modeling. *Journal of Cleaner Production, Carbon Emissions Reduction: policies, Technologies, Monitoring. Assess*. Model. 103, 1e12. http://dx.doi.org/10.1016/j.jclepro.2015.04.098

Janssens I.A., A. Freibauer P. Ciais P. Smith G.J. Nabuurs G. Folberth et al. 2003. Europe's terrestrial biosphere absorbs 7 to 12% of European anthropogenic CO_2 emissions. *Science*, 300: 1538–1542. doi : 10.1126/science.1093592.

Johnson J. M. F., Barbour N. W., Weyers S. L. 2007. Chemical composition of crop biomass impacts its decomposition, Soil Science *Society of America Journal*, 71:155–162.

Lambers H., F.S. Chapin III, T.L. Pons. 2008. Plant Physiological Ecology. 2nd edition. Springer, New York.

LR, 2012. National policy of climate change management. LR Ministry of Environment, Vilnius, 80, http://www.am.lt

Schlesinger W.H., Bernhardt E.S. 2013. Biogeochemistry: an analysis of global change. 3rd ed. Academic Press Elsevier, New York.

Smith P., Martino D., Ciais Z., Gwary D., Janzen H., Kumar P. et al. 2007. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. *Agriculture, Ecosystems, Environment*, 118: 6–28, doi: 10.1016/j.agee.2006.06.006

Smith W.N., Grant B.B., Desjardins R.L., Kroebel R., Li C., Qian B., Worth D.E., McConkey B.G., Drury C.F. 2013. Assessing the effects of climate change on crop production and GHG emissions in Canada. *Agriculture, Ecosystems, Environment*, 179: 139-150. http://dx.doi.org/10.1016/j.agee.2013.08.015.

Thomas S. C., Martin A. R. 2012. Carbon content of tree tissues: A synthesis. *Forests*, 3: 332–352.

Wood S., K. Sebastian, S.J. Scherr. 2000. Pilot analysis of global ecosystems. International Food Policy Research Institute and World Resources Institute, Washington, 125.

Zhang J., Wang X., Wang J., and Wang W. 2014. Carbon and Nitrogen Contents in Typical Plants and Soil Profiles in Yanqi Basin of Northwest China. *Journal of Integrative Agriculture*, 13(3): 648-656. Doi:10.1016/S2095-3119(13) 60723-6.

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