EREM 72/4

Journal of Environmental Research, Engineering and Management
Vol. 72 / No. 4 / 2016
pp. 45-49
DOI 10.5755/j01.erem.72.4.16631

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Received 2016/10 | Accepted after revision 2016/12

http://dx.doi.org/10.5755/j01.erem.72.4.16631

Short-term Effects of Elevated Temperature and CO_2 on Carbon Sequestration in Winter Wheat and Summer Rape

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In order to study organic carbon (C) sequestration in different plant parts of different crop species, a closed growth chamber experiment was performed with winter wheat (*Triticum aestivum* L.) and summer rape (*Brassica napus* L.) in a controlled environment at ambient [21°C/400 ppm] and elevated [25°C/800 ppm] temperature and CO_2 conditions. Measurements of organic carbon sequestration were carried out at a 28-day period after the treatment. Carbon content was measured with Shimadzu TOC solid sample module SSM-5000A. The results showed that under elevated temperature and CO_2 conditions both species of crop sequestrated the biggest amount of organic carbon in stems (575 mg g^{-1} in wheat and 545 mg g^{-1} in rape). Under conditions of [25°C/800 ppm], the amount of organic carbon in leaves of rape increased by 6.9% ($p < 0.05$) as compared with the ambient climate conditions. There were no significant differences ($p > 0.05$) between [21°C/400 ppm] and [25°C/800 ppm] in the amount of sequestrated organic carbon in stems and roots of rape. Conversely, roots of wheat under conditions of [25°C/800 ppm] sequestrated a significantly bigger amount of carbon (6%, $p < 0.05$) as compared with the conditions of [21°C/400 ppm], while in the above-ground parts of wheat, there were no significant differences ($p > 0.05$) between ambient and elevated temperature and CO_2 conditions. Our results suggest that under future elevated temperature and CO_2 conditions, both investigated crop species will sequester more carbon in their biomass but in a different manner.

Keywords: carbon sequestration, closed chamber experiment, summer rape, winter wheat.

Introduction

Climate change seems to be one of the biggest ecological problems at this time. Terrestrial ecosystems may provide a positive feedback in climate change; therefore, it is important to investigate all its possibilities. The ability of agricultural land to sequester carbon is one of the opportunities to mitigate climate change, which depends on such factors as soil type, type of crop or management practices. How single plants or whole ecosystems will respond to changes in climate (temperature, water availability and atmospheric CO_2 concentration) is still a matter of intense research (Studer, 2014). Biomass production, as a final result of photosynthesis, reveals the amount of carbon stored in response to new environmental conditions (Kimball et al., 2002).

Biomass partitioning between canopy and root is an important parameter for estimating the balance of photosynthesis and respiration and, therefore, the modelling of regional and global carbon cycles (Luyssaert et al., 2007). Major biogeochemical fluxes of all elements occur through plant roots, and the roots of agricultural crops have a significant role to play in soil sustainability, carbon sequestration, and reducing emissions of greenhouse gasses (White et al., 2013). Also root biomass makes a greater contribution to soil C sequestration than above-ground residues (Johnson, 2006).

Winter wheat and summer rape are one of the main crops in Lithuanian agriculture; therefore, it is important to analyse which crops can sequester a bigger amount of organic carbon. In order to investigate organic carbon sequestration in different plant parts of different crop species, a closed growth chamber experiment was performed with winter wheat (*Triticum aestivum* L.) and summer rape (*Brassica napus* L.) in a controlled environment at ambient [21ºC/400 ppm] and elevated [25ºC/800 ppm] temperature and CO_2 conditions.

Methods

The experiment was conducted at Vytautas Magnus University in 2015. Elevated CO_2 and temperature (day/night temperature of 25/18ºC and 800 ppm of CO_2) treatment was applied when the seedlings reached BBCH growth stage 12 (Meier, 2001) and lasted 4 weeks. Until that, all plants were grown in a control chamber under conditions of current climate, i.e., average day/night temperature of 21/14°C and 400 ppm of CO_2. The following stable conditions were maintained in both chambers: a photoperiod of 14 h, relative air humidity of 60–70%, and 200 μmolm^{-2}s^{-1} photon flux density of photosynthetically active radiation. The pots in the chamber were watered sufficiently and regularly. All the treatments were run in 3 replicates.

Measurements of carbon sequestration were carried out at a 28-day period after the treatment. Subsamples of the above and below plant parts were dried in an electric air-forced oven at 70°C until a constant dry weight was obtained (at least 72 h) and were ground to a fine powder with a mill (Retsch HM400, Germany) for a chemical analysis. Organic carbon content was measured with Shimadzu TOC solid sample module SSM-5000A. The independent samples *t* test was applied to estimate the difference between reference and treatment values, and the p value < 0.05 was the threshold for significance. All the analyses were performed by STATISTICA, and the results were expressed as mean values and their standard errors ($p < 0.05$) (± SE).

Results and discussion

The results showed that after 4 weeks of treatment under elevated temperature and CO_2 conditions [25ºC/800 ppm], the amount of organic carbon in leaves of summer rape statistically significantly increased by 6.9% (379 mg g^{-1}, $p < 0.05$) as compared with the ambient climate [21ºC/400 ppm] conditions (355 mg g^{-1}) (Figure 1). Under both climatic conditions, the biggest amount of organic carbon was sequestrated in rape stems with an increase of 4.4% under conditions of [25ºC/800 ppm], although there was no statistically significant difference ($p > 0.05$) between the treatments. Roots of rape under conditions of [25ºC/800 ppm] sequestrated less organic carbon (-1.9%) as compared with the reference treatment; however, the difference was not statistically significant ($p > 0.05$).

After 4 weeks of treatment under conditions of [25ºC/800 ppm], wheat sequestrated a bigger amount of organic carbon in all plant parts as compared with the conditions of [21ºC/400 ppm]; however, the differences between the treatments in the above-ground parts of wheat plants were not statistically significant ($p > 0.05$). Contrary to the rape, roots of wheat under conditions of [25ºC/800 ppm] sequestrated a significantly bigger amount of organic carbon (388 mg g^{-1}, $p < 0.05$) as compared with the conditions of [21ºC/400 ppm].

Carbon is a structural element; it has not shown a higher variation in different crop (Kushwah, 2014). According to our results, organic C in summer rape and winter wheat increased by 3.4% and 5.5%, respectively, under elevated climate conditions compared with ambient climate conditions, but the differences were not statistically significant ($p > 0.05$) (Figure 2). Winter wheat sequestrated a bigger amount of organic carbon (52.4% C per plant) than summer rape (42.4% C per plant); for this reason, winter wheat would be a more useful crop in agriculture according to climate mitigation. In other studies, carbon content has varied between 42% and 46% in major crops (Brady, 2002).

Under conditions of [25ºC/800 ppm], both plant species sequestrated bigger amounts of organic C in above-ground parts compared with ambient climate conditions (Figure 3). Carbon partitioning in above-ground parts of plants accounted for 92% ($p < 0.05$) of the total plant C in summer rape and 81% ($p > 0.05$) in winter wheat under elevated climate conditions. In both plant species below-ground, carbon decreased under elevated climate conditions. Other studies also show that the portion of C translocated below-ground by cereals and used for root growth, respiration and exudation decreases during plant development (Kuzyakov and Domanski, 2000).

Some studies suggest that increases in ecosystem-level plant respiration in ecosystems exposed to elevated CO_2 mainly occur in below-ground plant tissues (Hamilton et al., 2002), which in turn may stimulate soil respiration rates (Pendall et al., 2003). This requires a substantial proportion of additional C assimilated by plants growing at elevated CO_2 to be allocated to roots for growth and turnover (Matamala et al., 2003). Greater plant C allocation below-ground can theoretically increase the contribution of root respiration to total soil respiration because of greater root biomass relative to ambient CO_2 (Gonzalez-Meler, 2004).

Fig. 1

Percent changes in carbon sequestration in different plant parts of winter wheat (*Triticum aestivum* L.) and summer rape (*Brassica napus* L.) grown at elevated CO_2 and temperature conditions [25ºC/800 ppm]. Mean ± SE (n = 3)

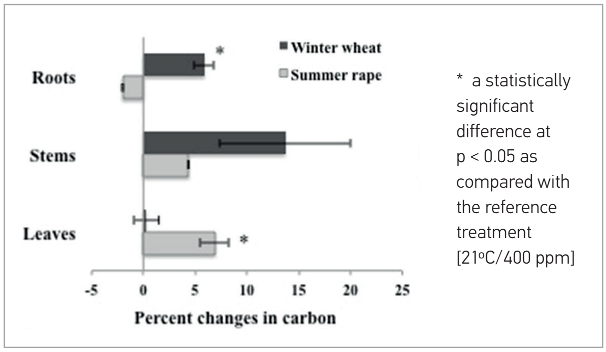


Fig. 2

Organic C (%) per plant in winter wheat (*Triticum aestivum* L.) and summer rape (*Brassica napus* L.) grown under ambient [21ºC/400 ppm] and elevated [25ºC/800 ppm] temperature and CO_2 conditions. Mean ± SE (n = 3)

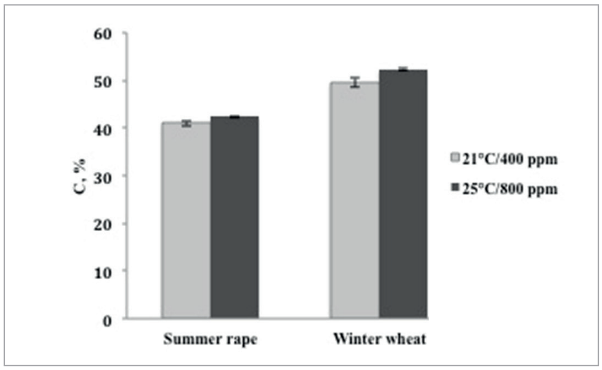
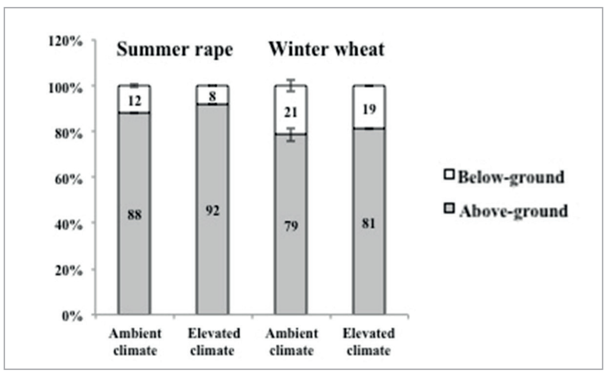


Fig. 3

Percent carbon partitioning in above- and below-ground parts of winter wheat (*Triticum aestivum* L.) and summer rape (*Brassica napus* L.) grown under ambient [21ºC/400 ppm] and elevated [25ºC/800 ppm] temperature and CO_2 conditions. Mean ± SE (n = 3)



Conclusions

Under elevated climate conditions, both plant species sequestrated bigger amounts of organic C in above-ground plant parts, and carbon partitioning in above-ground parts of plants accounted for 92% of the total plant C in summer rape and 81% in winter wheat. However, winter wheat sequestrated a bigger amount of organic carbon (52.4% C per plant) than summer rape (42.4% C per plant) in the entire plant. We also found that after 4 weeks of treatment under elevated temperature and CO_2 conditions both species of crop sequestrated the biggest amount of organic carbon in stems, whereas significant differences ($p < 0.05$) between [25ºC/800 ppm] and [21ºC/400 ppm] treatments were observed only in leaves of summer rape and in roots of winter wheat. Our results suggest that under future elevated temperature and CO_2 conditions both investigated crop species will sequester more carbon in their biomass but in a different manner.

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Gauta:
2016 m. spalis
Priimta spaudai:
2016 m. gruodis

Aukštos temperatūros ir CO_2 poveikis anglies izoliavimui žieminiuose kviečiuose ir vasariniuose rapsuose

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Siekiant nustatyti organinės anglies akumuliaciją skirtingose augalo dalyse, kontroliuojamos aplinkos uždarose augalų auginimo kamerose buvo atliktas eksperimentas su žieminiais kviečiais (*Triticum aestivum* L.) ir vasariniais rapsais (*Brassica napus* L.) esant dabartinei [21°C/400 ppm] ir padidintai [25°C/800 ppm] oro temperatūrai ir CO_2 koncentracijai ore. Anglies kiekio matavimai atlikti po 28 d. periodo poveikio su Shimadzu TOC-V serijos bendrosios anglies analizatoriumi, naudojant kieto mėginio modulį SSM-5000A. Tyrimo rezultatai parodė, kad esant padidintai oro temperatūrai ir CO_2 koncentracijai ore abi tirtos žemės ūkio augalų rūšys didžiausią anglies kiekį sukaupė stiebuose (575 mg g^{-1} kviečiai ir 545 mg g^{-1} rapsai). [25°C/800 ppm] sąlygomis augusių vasarinių rapsų lapuose, palyginti su dabartinio klimato sąlygomis, organinės anglies kiekis padidėjo 6.9% ($p<0.05$). Akumuliuotos anglies kiekis [21°C/400 ppm] ir [25°C/800 ppm] sąlygomis augusių vasarinių rapsų stiebuose ir šaknyse reikšmingai nesiskyrė ($p>0.05$). Priešingai, žieminių kviečių šaknys esant [25°C/800 ppm] sąlygoms akumuliavo reikšmingai didesnį (6%, $p<0.05$) organinės anglies kiekį, palyginti su [21°C/400 ppm] sąlygomis augusiais augalais. Tuo tarpu antžeminėje kviečių dalyje reikšmingų anglies kiekio pokyčių tarp dabartinės ir padidintos temperatūros ir CO_2 koncentracijos ore augintų augalų nebuvo. Gauti rezultatai rodo, kad ateityje, padidėjus oro temperatūrai ir CO_2 koncentracijai ore, abi tirtos žemės ūkio augalų rūšys savo biomasėje akumuliuos didesnį kiekį anglies, bet skirtingu būdu.