IMPACT OF SOOT POLLUTION ON RADIATION AND WATER BALANCE CHARACTERISTICS IN MAIZE

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Abstract

Investigations were carried out on maize contaminated with atmospheric soot (black carbon, BC) under field conditions. The examinations included basic plant growth and developmental properties (leaf area index, LAI), a few radiation indicators and water balance terms. Out of water balance members the evapotranspiration, from heat balance the albedo – reflecting the reflectance of solar radiation- and net radiation were taken into account in field study. Energy proportioning, the latent and sensible heat fluxes helped get information about relationship between two different budgets, the water and heat balances of contaminated maize. The advantage of our research was the pioneer work to simulate atmospheric soot pollution from transport under non-laboratory conditions.

Key Words: evapotranspiration, albedo, black carbon, maize

Összefoglalás

Kutatásunk során kukorica növényt szennyeztünk légköri eredetű korommal (black carbon, BC) szabadföldi körülmények között. Vizsgálataink kiterjedtek az alapvető növény növekedés-fejlődési mutatók (levélfelület-index (LAI)) mellett a növény sugárzásháztartására és vízháztartására. Vízháztartási méréseink során az evapotranszspirációt, a sugárzásháztartási jellemzők közül az albedót, mely a különböző felszínek sugárzás visszaverő képességét mutatja, a nettó sugárzási egyenleget, mely szoros összefüggésben van az albedó alakulásával, a látens és szenzibils hőt vizsgáltuk, melyek segítségével a párolgásról és az állományban maradt energiáról kaptunk információt.

Kutatásunk egyedisége a közlekedésből származó koromszennyezés hatásának szimulálása volt, mely során a nem laboratóriumi körülmények közötti kölcsönhatások megfigyelésére összpontosítottunk.

Kulcsszavak: evapotranszspiráció, albedó, korom, kukorica

Introduction

Black carbon (BC) is product of the incomplete combustion of carbonaceous fuels. This contaminant has direct contact with the plants and indirect one to animals or humans. BC emissions result in air pollution and can lead to a variety of health impacts (USAID, 2010). Recent studies show that BC is a major contributor to global warming and the warming effect of BC is surpassed only by carbon-dioxide gas (Baron et al., 2010). The road traffic emission have emerged as the major cause of poor air quality (Brophy et al., 2007). Diesel and petrol fuelled vehicles are responsible for the generation of wide range of pollutants, depending on vehicle technology (Colvile et al., 2001).

Zhan et al. (2012) reported that BC can make up a significant proportion of the organic carbon in soil, but the amount of bound BC differed considerably among soil types. Diesel exhaust BC contain nearly 40 hazardous pollutants. This mixture contains carbon particles that are very small in size. These small particles may be deeply inhaled and causes respiratory disease (Song et al., 2012; Wargo et al., 2006).

Most studies of human health effects of air pollution were not composition specific, but there is evidence that small soot particles are the most harmful pollutants (Künzli et al., 2000). These toxic materials such as carbon particles are also deposited on the surface of plants (Mondal et al., 2014).

In the literature little information is given on the impact of solid pollutants which come from dry deposition (Olszyk et al., 2003). The aim was to expand the knowledge of this slightly under-investigated research topic using maize as test crop.

Materials and Methods

The impact of black carbon on the growth, evapotranspiration and radiation balance of maize grown at various water supply levels was studied at the Agro-meteorological Research Station in Keszthely, Hungary during 2010-2012 growing season. Maize was selected as test plants because of its high acreage in the world (160 million ha (FAO 2010). A short growing season maize variety seemed to be suitable for our experiment. The plant responses were examined as a result of contamination, which is repeatable to other plant species even maize hybrids A Swiss-bred maize hybrid, *Sperlona* (FAO 340) was sown in the experiment at a plant density of 70,000 plants ha^{-1}, a widely used plant density under Hungarian climatic conditions for growing grain maize.

The soil was Ramann's brown forest soil with a mean bulk density of 1.46 mg m^{-3} in the top 1 m of the profile and an available water capacity of 150 mm m^{-1}. Nutrients (180, 80 and 120 kg ha–1 N, P and K, respectively) were applied in spring, immediately prior to sowing. The usual agronomic measures (plant protection, weed control) recommended for the location by the staff of the University of Agricultural Sciences, Keszthely, were applied.

Of the two water supply treatments, the rainfed variant was sown in field plots, while Thornthwaite type compensation evapotranspirometers were used for the "ad libitum" treatment. These were metal containers (ET-chambers) with a volume of 4 m^3 (2x2 m in area, with a depth of 1 m), filled with the monolith of the surrounding field, layered as in the natural state. The working principle was to record the components of the water balance each day, expressing evapotranspiration as the residual term. To minimise soil water and canopy differences, the area surrounding the ET was irrigated. Due to the fixed nature of evapotranspirometers, the experiment was laid out in a block design with four replications, while the dry plots were arranged in a randomised complete block design with five replications. The plots had the same area (4 m^2) as the evapotranspirometers. The treatment codes used in the experiment were as follows:

Treatment	Code
Water supplies:	
Rainfed plots	P
Evapotranspirometer chamber	ET

Contamination levels

No pollution (control)	C
Crop pollution with BC	BC

The BC used by the Hankook Tyre Company (Dunaújváros, Hungary) to improve the wear resistance of tyres was used as pollutant. This pollutant enters the atmosphere directly during vehicle transport. The size distribution is characterised by 10% below 3.13 µm, 50% below 18.8 µm and 90% of the total soot quantity below 50.6 µm. The pollutant is chemically "pure", i.e. it is free of other contaminants, such as heavy metals, so the reproducibility of the experiment is not problematic, unlike that of tests on other air pollutants. Relatively small doses were applied (3 g m^{-2}), repeated at weekly intervals. Although the experiment could not simulate the perfect composition of vehicles exhaust (lack of heavy metals), but any negative impact observed using "pure" BC, could be more intense in the field. A motorised sprayer (SP 415) was used to apply the pollutant.

The leaf area index was measured each week on the same 12 sample plants in each treatment using an LI 3000A automatic planimeter (LI-COR, Lincoln, NE).

Pyranometers of the CMA-11 type (Kipp & Zonen, Vaisala) were installed on columns of adjustable height in the centre of the 0.3 ha plots designated for albedo measurements. The height of the sensors was raised each week as the plants grew, so that they were always at least 1.5 m above the canopy. Data were collected using a Logbox SD (Kipp & Zonen, Vaisala) datalogger in the form of 10-minute means of samples taken every 6 seconds. Either these 10-minute means or the hourly or daily means calculated from them were used for the analysis.

The meteorological data were obtained from the local QLC-50 automatic climate station. Data analysis was performed using the STATA 5.0 computer package (Stata Corporation, 1997). The t-test was used to determine significant differences between the dry matter yields of polluted and control plants and of rainfed and ET-grown plants. In time series analysis two-tailed t-test was applied. Significant level was settled to 5% ($P<0.05$).

Results and Discussion

Weather conditions and the effects of maize phenology

The first year (2010) of the study period was characteristic of a humid weather, while the next two seasons were arid ones. Compared to the seasonal mean rainfall of the last century (1901-2000), there was 40% higher seasonal precipitation sum, during 2010. Oppositely, there were 44% and 29 % less amounts of rainfall in 2011 and 2012, respectively, comparing to the last century's seasonal average precipitation sum. The seasonal mean air temperatures were 1.2 °C and 1.6 °C higher in 2011 and 2012 than that of the long-term mean. In 2010, the season's mean air temperature was close to the climatic norm.

July is a significant month for maize development, because the tasselling happens at this time. Fortunately, neither the rainfall sum, nor the air temperatures differed significantly from the climatic norms each July of the observation.

The length and occurrence of maize phenophases was not affected by the soot pollution. Similarly, the plant height of the maize was also not impacted by the soot contamination (data not shown).

The BC had significant effect on LAI of maize only in 2011 (*Figure 1.*). Significant LAI increments of 14.9% ($P<0.0001$) and 10.7% ($P<0.0001$) were measured in the rainfed and ET (polluted) treatments respectively. BC also grew the LAI in the other two years of the experiment (2010 and 2012) to a certain extent (2-5%), but the changes were not significant. Study of Usman et al. (2016) confirmed our result. They demonstrated clearly that addition of BC increased the vegetative growth, yield and quality parameters of tomato in irrigated treatments.

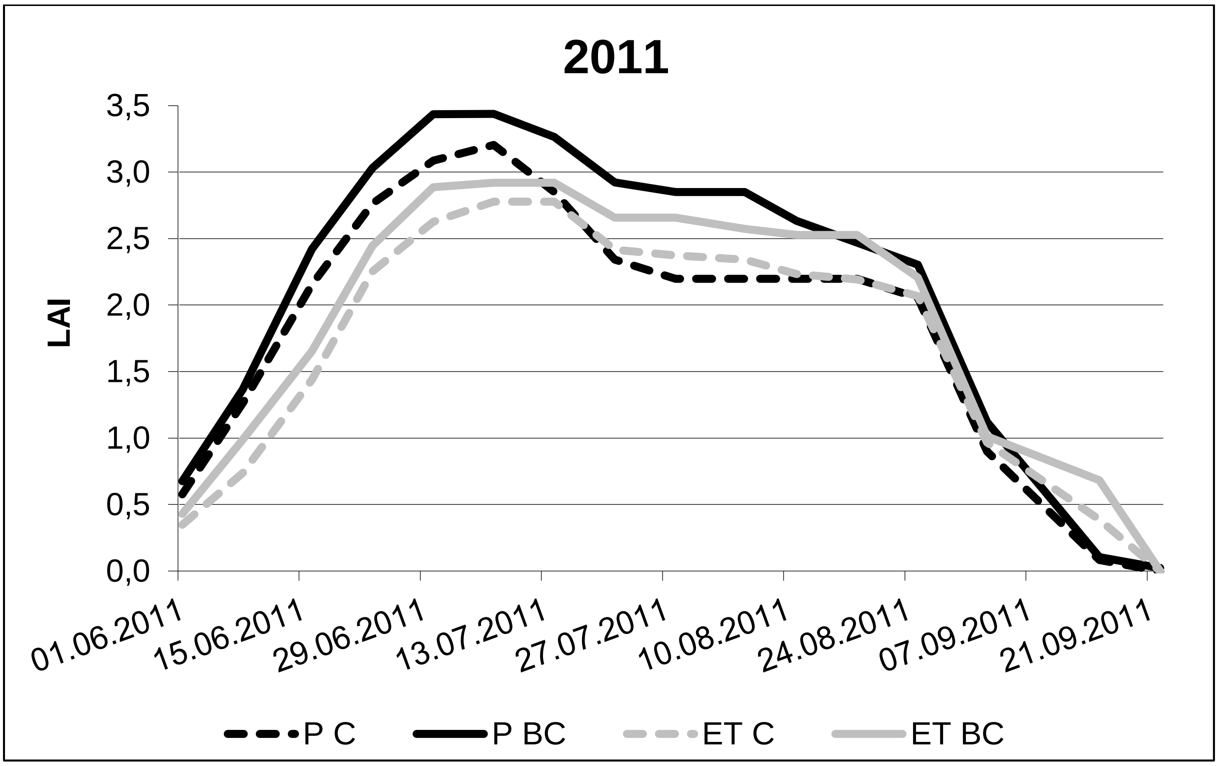

Figure 1. Variation in maize leaf area indexes (LAI) measured in the plots (P) and evapotranspirometers (ET), (BC-Black Carbon, C-Control) in 2011

Changes in irradiation and water regime parameters

The evapotranspiration rate was greatly influenced by the season's actual weather conditions. Cumulative evapotranspiration was the lowest in 2010, when the weather was wet/humid. Increases in total water losses of the control maize were 1.2% and 19.8% during 2011 and 2012 in comparison to rainy 2010. For the same time period (2011-2012), the upward tendency in the amount of water loss was the same for the contaminated plants; 11.5% and 22.5% higher water uses were observed in polluted plants comparing to the season's results of 2010. Water loss in dry 2011 was closer to cumulative evapotranspiration of wet 2010 than water loss in dry 2012 due to variation in seasonal temperatures. Seasonal mean air temperature in arid 2011 was nearer to wet 2010 than to dry 2012. In evapotranspirometers, as the water supply is unlimited, the impact of precipitation is less than the effect of temperatures.

The effect of soot pollution was also investigated within the seasons on (*Figure 2.).* Although only moderate differences were occurred during 2010 and 2012, the impact of BC contamination on total water loss was significant. Sum of evapotranspiration of BC treated maize was higher with 11.82% (P<0.0001) in 2011, than the total water loss of control maize. The relationship between evapotranspiration and size of LAI was very close. The higher the change in LAI, the larger water losses were observed. Accordingly to largest LAI sizes, the highest total water losses were measured during 2011.

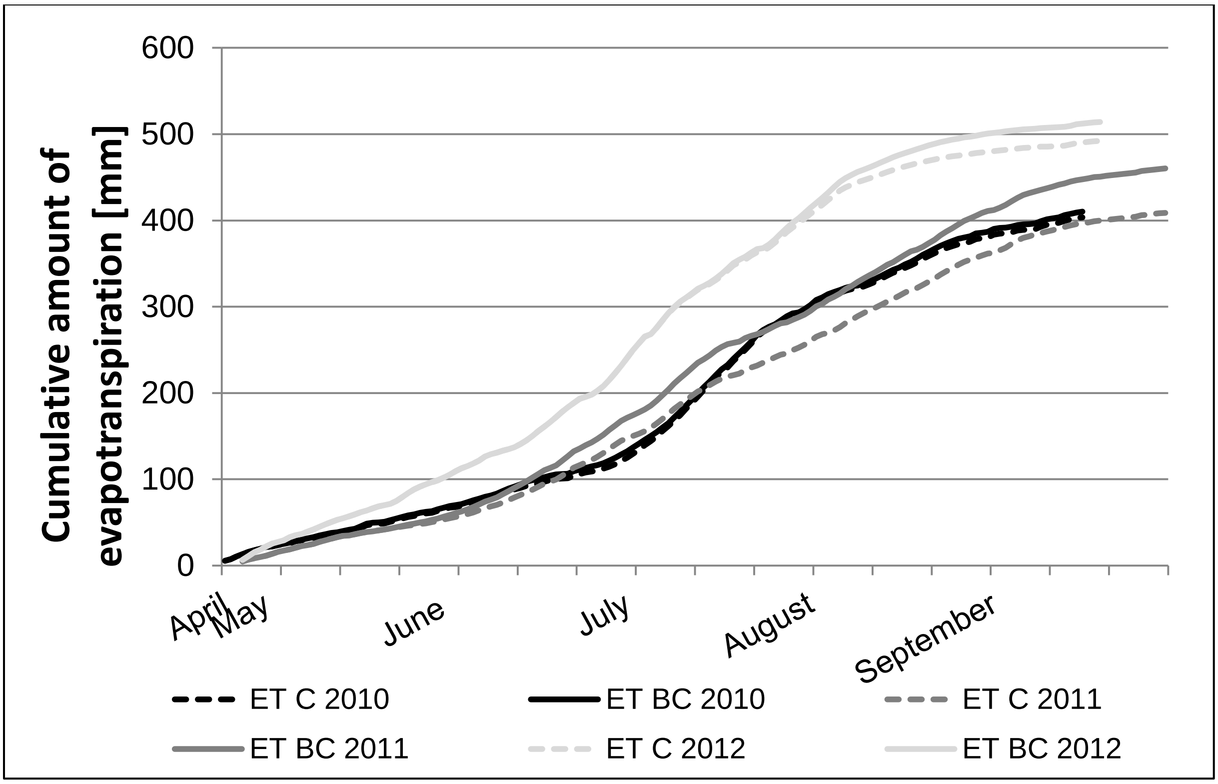

Figure 2. The cumulative amount of evapotranspiration (mm) in the control (C) evapotranspirometer (ET) and in the soot contaminated (BC) evapotranspirometer between 2010 and 2012

The evapotranspiration rate was also studied depending on the leaf surface size. The treated maize lost significantly more water (6.41% (P<0.008)) only in 2010. Evapotranspiration results of polluted maize increased like a tendency during the next two seasons (2011: 2.61% ns; 2012: 4.37% ns).

The next studied parameter was the albedo, a widely applied solar radiation property. The albedo is an easily measurable indicator of surface reflectance that allows the comparison of radiation characteristics of different surfaces, including plants. The albedo showed the highest stability among the studied parameters. The soot pollution reduced significantly the values of the albedo each season. The albedos of BC treated maize were 17.34% (P<0.0001), 21.75% (P<0.0001) and 14.45% (P<0.0001) lower in 2010, 2011 and 2012, respectively, than the albedo of the non-contaminated control maize. The reflectance of solar radiation depended on weather conditions. The difference was higher when there was less precipitation.

The following solar radiation balance characteristics provide information about the energy use and distribution of maize. The latent heat is the energy applied for evapotranspiration, and the sensible heat is used for heating processes (plant canopy air, the plants itself etc.). In the latent heat, there was no significant difference between the polluted and control plants in 2010 (*Figure 3.*).

However the higher evapotranspiration rates in the treated plots were due to higher LAI in 2011. This was confirmed by the 10.9% ($P<0.0001$) increase in latent heat of soot contaminated plots. In 2012, the increase was only 1.13% ($P<0.0001$), but it was also significant.

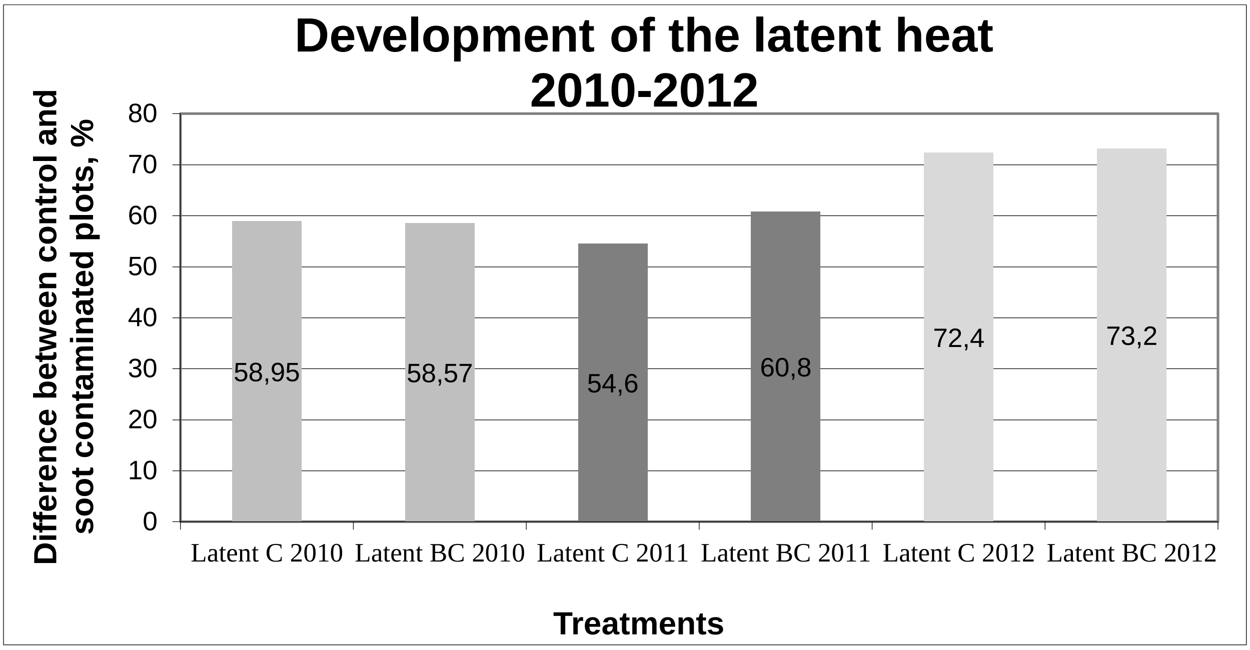

Figure 3. Development of the latent heat between 2010 and 2012 in the soot contaminated (BC) and in the control (C) plots.

Analysing the canopy structure of different maize treatments, we found that the soot contaminated plot had more closed plant stand each season than that of the control ones. Closed plant stands hinder radiation penetration causing cooler canopy microclimate. This modification was reflected in the amount of sensible heat (*Figure 4*). In 2010, like a tendency, but later on 14.8% ($P<0.0001$) and 3.02% ($P<0.0001$) significant decreases in sensible heat flux of polluted maize canopies were observed in comparison to sensible heat flux of control maize.

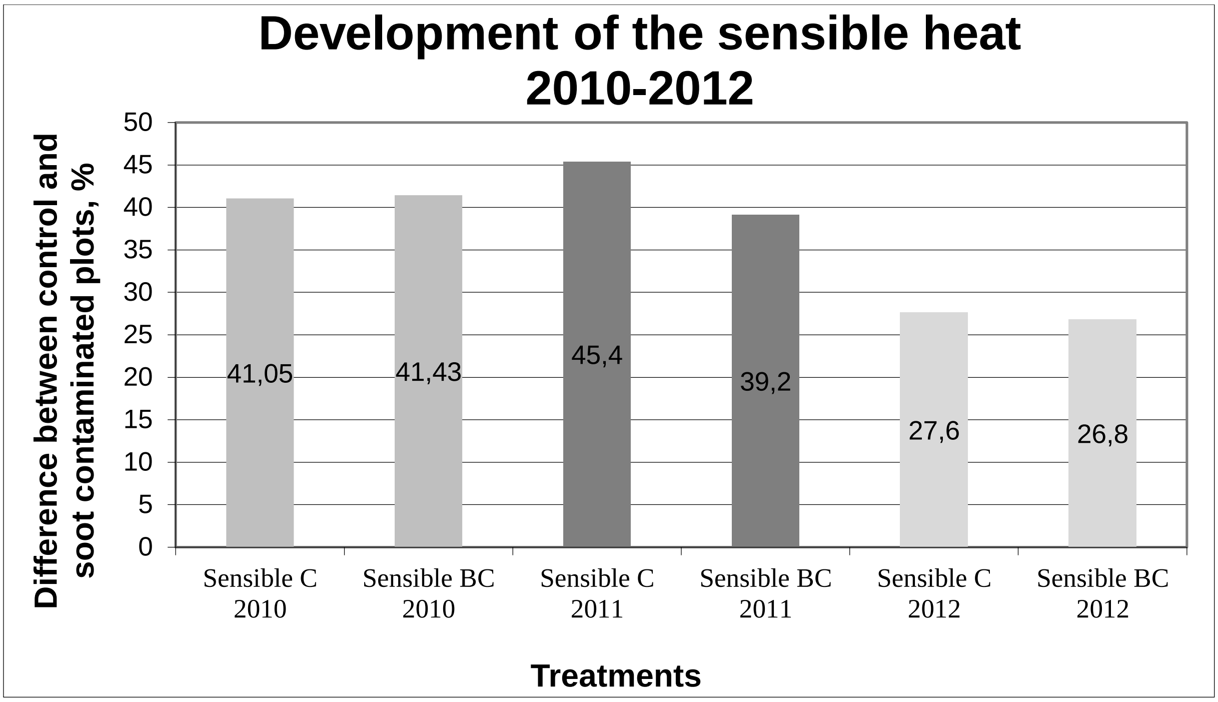

Figure 4. Development of the sensible heat between 2010 and 2012 in the soot contaminated (BC) and in the control (C) plots

The last observed parameter was the net radiation that was closely related to the size of albedo. Decline in albedo resulted in higher radiation absorption (*Figure 5.*). Significant differences in net radiation between the treated and control maize was detected each season. The increments of net radiation of the soot contaminated maize were 3.83% ($P<0.0001$), 4.21% ($P<0.0001$) and 3.16% ($P<0.0001$) in 2010, 2011 and 2012, respectively than that of the net radiation of control maize.

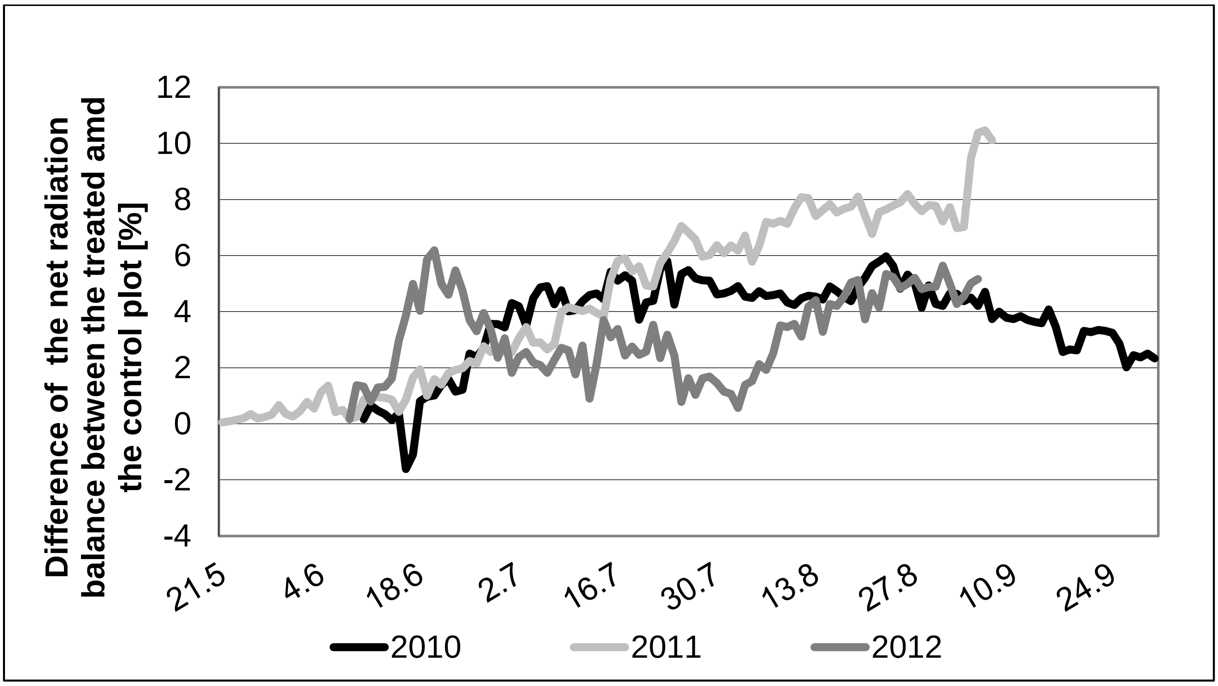

Figure 5. Difference of the net radiation of the soot contaminated plot compared to the control plot in %

Conclusions

The soot pollution did not affect the length and occurrence of the maize phenological phases. Assimilatory surface sizes of plants (LAI) showed significant changes, but only in 2011. However, in the remaining two seasons, the soot increased the leaf area of plants like a tendency. This modification was not expected when starting the experiment. The possible reason of this unexpected event may be that the maize used the soot such as extra carbon source, as demonstrated in foliar fertilization experiment earlier by Glaser (2007). Zhu et al. (2014) also reported positive effects of maize biomass in all soils amended with biochar compared to soils without biochar. The authors observed that liming effect of biochar improved plant growth through alleviating Al toxicity and P deficiency, especially in poor acidic red soils.

Small sized LAI of 2011 was probably due to low precipitation amounts. Slighter rainfall sum for 2012 also influenced the maize LAI, but more moderately than in the course of previous season. Plentiful precipitation probably washed out the soot from the contaminated leaf surface during 2010 limiting the development of soot influence on plant characteristics (LAI).

Size of LAI strongly influenced the evapotranspiration intensity. The greater transpiratory surface of BC treated crops might be one of the reasons of their increased evapotranspiration rates (Anda and Illes, 2012).

The season's weather highly influenced plant's radiation characteristics. Declines in albedo regarding soot contaminated plants were significant each season. Decrease in albedo caused better energy retention of maize. This extra energy was devoted to increasing evapotranspiration rate of polluted plants. In rainy weather conditions, when the soot has been washed out from the plant surface, decrease in size of albedo is more limited and the obtained evapotranspiration water loss is also less. However, in arid weather conditions the BC adhering to the plant surface forced the evapotranspiration of contaminated plants.

Solution for reducing the negative impacts of the soot deposition could be the irrigation, as characteristics of maize grown in ET (non-limited water supply) demonstrated better plant characteristics than polluted rainfed maize. To get more generalizable results about impacts of BC on crops, further investigations are needed with respect to other crop species.

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