Evaluation of grain cereals development after biochar application

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Abstract

Biochar is a fine ground charcoal having higher carbon content and is prominently sturdy to microbial decay. Biochar is produced through pyrolysis (combustion in low or total absence of oxygen) from organic matter. As a soil amendment, biochar application has gained a significant importance in improving the quality of soil.

To establish the influence of BC on the soil properties field experiments with wheat and maize on leached meadow-cinnamon soil were conducted. In the field experiments, three variants were realized: first is control variant, second with added 6 kg BC over an area of 300 m^2 (20 kg/da) and 20 kg/100m^2 (200 kg/da). The biometrical measurements, such as a weight and height of the plants during different stages of the vegetation are shown improved (between 8 and 10% heavier and higher). In all variants with applied BC plants are visibly darker green colour.

Keywords: yield; water regime; photosynthetic activity; pyrolisis; soil moisture; in frared temperature

The wheat is the most important plant for people food in the world. According to the data of the Agrostatistics Department of the Ministry of Agriculture and Food (MAF), the production of wheat from the harvest of 2016 amounts to a record 5 641 thousand tons. This is almost 13% more than in the previous year, as a result of an increase of both the harvested area – by 3%, to 11.420 thousand per decar and the average yield – by 9%, to 494 kg/ha.

Increasing the production and land preservation is the main goal of world scientists. Although moving wheat culture into non-traditional growing areas offers more area for cultivation, the production level is not stable due to abiotic and biotic stresses. The future production increases must come largely from greater output per unit area, which will require more intensive research for further improving cultivars and enhancing cultural technology (FAO, Curtis et al., 2002).

At the same time cereal grain crop production generates tremendous quantities of straw. For example, three million acres of wheat are grown in Washington State each year producing about three tons of straw per acre. While 0.5 tons of straw per acre are required to be maintained on the soil surface for erosion control and the excess straw often presents problems for subsequent field operations such as no-till seeding. Wheat straw can use for house building, in agriculture - livestock, vegetable production (as mulch) and as product for energy obtained. Wheat straw and other agricultural residues are used for biogas producing in anaerobic way and blue gas from the process of pyrolysis (Reeda, 2009).

Recently, extensive research, aiming at developing renewable energy resources from biomass, has been carried out, especially, the pyrolysis of biomass by the Pyrolysis Network (Ippolito, 2012; Alburquerque, 2013). Processes such as combustion, gasification and pyrolysis have been identified as possible routes for energy production. Pyrolysis is combustion of agricultural residues in limited oxygen accesses, products of which are blue gas, bio-oil and char coal (Bio Char – BC). Hard part from pyrolysis is char coal which usually use in metallurgy, energy produce – as coal, for BBQ and for soil improvement.

The definition for BC given by IBI is: "Biochar is a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment". Important properties of BC are carbon, porosities carbon sequestration and P, Mg and other chemical elements. The content of chemical elements depends of the feed materials – wheat straw, maize corncobs, cornstalks, oak and other. Incorporation of BC in soil increases the water field capacity, carbon content, decrease the leaching of nutrition (Verheijen, 2010), BC porosity incorporates a lot air in the soil and this is good place for microbes (Ippolito, 2012).

The technology of using BC as soil amendment was starting before 2500 years nearby Amazonian river. The Indians produce BC and used them on small earth pieces (1 – 80 ha). Terra Preta – the name of this part of Brasilia, remain fertile without fertilizing till now. The base properties of BC are high stability – high adsorption of nutrients and prevent them of washing from surface water and transition to the groundwater. Although some of scientist (Dempster, 2012) not found any different of yield between variants with BC and without BC.

Further experimental researches are needed with regard to long-term effects of biochar application on soil functions, as well as on its behavior in different soil types (e.g. disintegration, mobility, recalcitrance), and under different management practices.

The aim of the experiment was to study the effect of BC incorporated in soil on the maize and wheat yield as well as on some soil properties.

MATERIALS AND METHODS

Field experiments with Bulgarian sort Sadovo 1 winter wheat and maize Kn-509 were conducted in 2012-2013 on leached meadow - cinnamonic soil in the Tsalapitca village, Plovdiv district (East Middle South Bulgaria) on an area of 4 da in "maize-wheat" crop rotation. Those two varieties of maize and wheat are considered to be standard for Bulgaria.

In 2012, field experiment with maize variety Kn-509 in an area of 2 /da was established. The distance between the lines is 70 cm. Sowing densities from 4600 to 5100 plants per decare. The wheat experiment was sown in autumn after harvesting the corn, usually with density 600 germinated seeds per 1 m^2.

The soil characterizes as a loamy - sand to light sand - loamy with high content of the sand fraction and low content of the physical clay (0,01mm) and ill (0,001mm) for the upper soil layers and has a tendency to their increasing in the lower soil layers. The soil water - physical properties are as follows: bulk density - 1.6-1.63 g/cm^3 for the 0-100 cm layer, with excepting the 0-30 cm layer- 1.74 g/cm^3 and 1.5 g/cm^3 for120-160 cm layer; 16-18% FC for the layer 0-160 cm; wilting point- 5-6% for the layer 0-40 cm, 10-11% for 60-100 cm and 9% for 120-160 cm layer (Kirkova, 1991).

The field is with altitude 180-200 m, underground water level 3.8-4.2 m, the annual temperature sum is about 4000 C., Regarding the moisture conditions, this is one of the driest areas in Bulgaria. This requires an irrigation of the crops.

Agrotechnics and fertilization were optimal (Popov et al., 1966), none limiting the yield. The suitable technologies and preparations were applied for canopies without weeds, diseases and pests.

Fertilizers for maize: P and K are incorporate before plowing and N for pre-sowing: superphosphate - 30 kg/da fertilizer, potassium sulphate - 20 kg/da fertilizer, ammonium nitrate - 33 kg/da fertilizer. Feeding - when grooving before watering at the end of June - 18 kg/da of fertilizer - ammonium nitrate.

Fertilizers for wheat: P and K are incorporate before plowing, N with sowing treatment: superphosphate - 10 kg/da fertilizer, potassium sulfate-12 kg/da fertilizer, Urea-10 kg/da manure. Spring feeding-March (head development stage)-10 kg/ha fertilizer, ammonium nitrate.

The BC was produced by technology of one metal barrel, crushed to the small parts and buried into the soil in 0-10 cm depth. BC was obtained from maize stalks.

Three variants were realized: first is control variant- clean soil, second with added 6 kg BC over an area of 300 m^2 (20 kg/da) (BC1) and 20 kg/100 m^2 (200 kg/da) – (BC2), The rates of BC were selected from literature (Laird, 2008).

Soil moisture was evaluated by gypsum blocks, designed at "N. Poushkarov" ISS /ISSAPP/ (Kirkova, 1984; Stoimenov & Kirkova, 2012) and plant water status as a difference between canopy and ambient air temperature- Tc-Ta by Infrared thermometer ("TECPEL 510", spectral response 6-14μm, analogy output 1mV/°C), every day at 14 o'clock (Stoimenov, 2001) during the vegetation season. The precipitation, air temperature and relative air humidity were also read.

RESULTS AND DISCUSSION

The biochar used for conducted experiment was obtained from corn stalk. The chemical content in BC is shown on Table 1.

From the elements analyses, biochar was rich in soil nutrients such as N, P, Ca, Mg, and K. The chemical analysis shows a very low supply of basic nutrients (NPK). The high iron content - 225 was measured. Addition of Fe can increase crop yield. Similar results are obtained by another author's (Edye, 1993; Feng, 2004).

Monthly sums of precipitation for the period 1961-1990 and 2012 are presented on Figure 1.

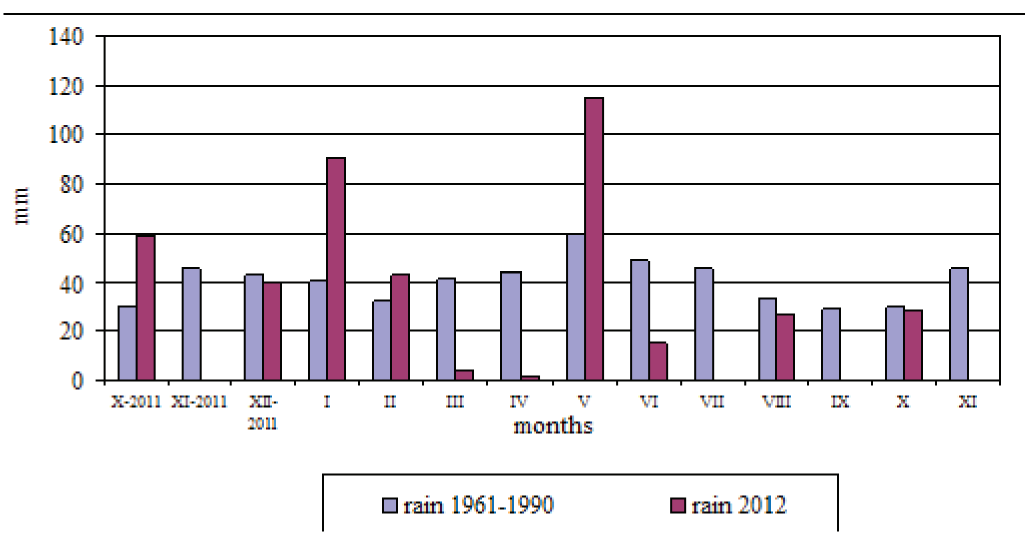
Figure 1 shows the distribution of rainfall for 2012 as well as monthly precipitation rate for a long period from 1961 to 1990. High rainfall sums (115 mm) were recorded in May compared to the norm (1961-1990). These precipitations provide a good water supply needed for the co-germination of maze seeds. In the months following months during the maze vegetation the rainfall is insignificant and in July is completely missing.

Taking into account ~~in~~ the total water consumption for the layer 0 to 100 cm, the largest relative share in its formation has a soil surface 0-25 cm (over 60%). In the surface layer, the main part of precipitation falls and the main part of the root system is located. At the same time, it's a most exposed to the influence of external factors zone. The participation of the intermediate layer (25-50 cm) in the formation of ET is barely about 20%.

However, the improvement of soil water-holding capacity by biochar addition could maintain a better moisture level between irrigation periods, being considered a key factor to obtain good grain yield in wheat (Gooding and Davies, 1997). In addition, the effects of biochar application on soil properties may have a significant effect under field conditions, where water availability and bulk density are important factors influencing plant growth, germination, and grain production.

Таблица 1. Химически характеристики на БВ, получени от царевично стъбло
Table 1. Chemical characteristics of BC obtained by corn stalk._

Chemical element	Zn	Cu	Mn	Fe	P%	K%	Ca%	Mg%	N%
Corn stalk BC	53	29	34	225	0.07	4.9	2.95	0.73	1



Фигура 1. Годишно разпределение на валежите – Цалапица 2012
Figure 1. Annual distribution of precipitation – Tsalapica 2012

In relation to this figure 2 and 3 show the dynamics of soil moisture measured by gypsum blocks for 0-20 and 20-40 cm soil layer.

Figures 2 and 3 show the dynamics of soil moisture in the different variants of maize crops. It is obvious that soil moisture decrease at a slower rate in the variants with BC.

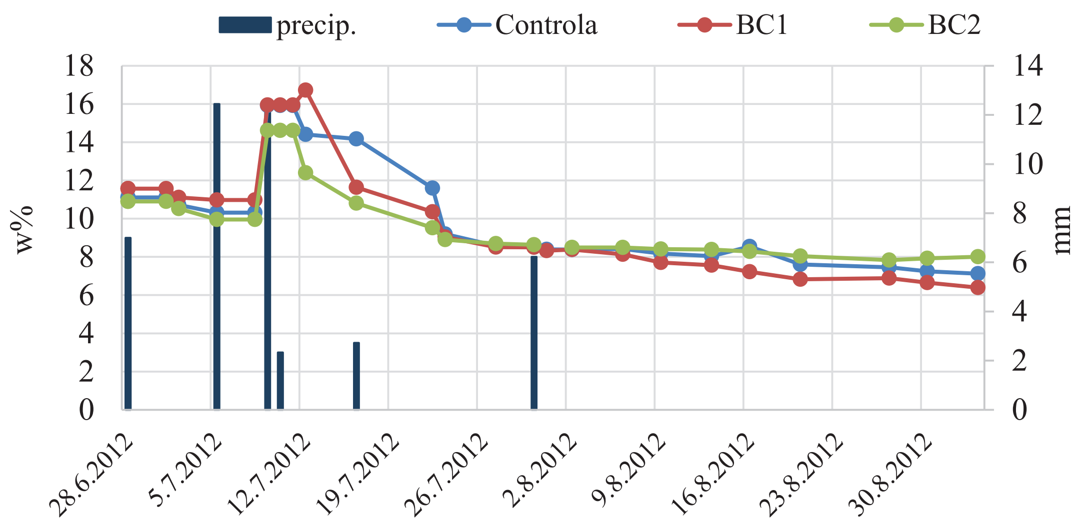
The obtained result during the field experiment with maize, show that the yield in variant with is higher in comparison to the other two.

The lowest result in BC1 variant is probably due to the low rate if biochar application.

According to many authors the result of BC is negligible in the first year of its application and grows with each year, being the highest in the third year (Major, 2010).

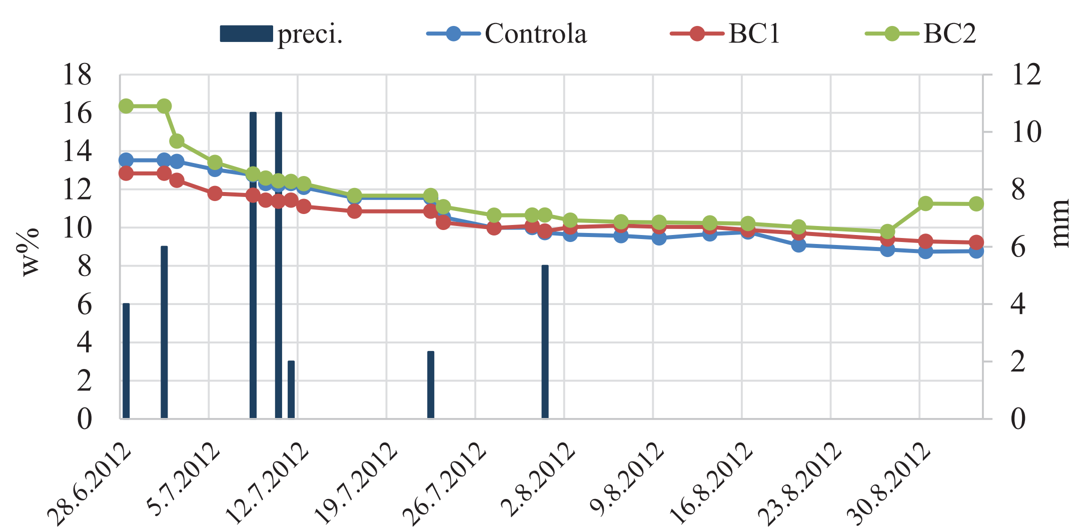
The annual air temperature and sums of precipitation in 2013 are presented on Figure 5.

The temperatures reported in 2013 are higher than those measured for a long time period. Winter



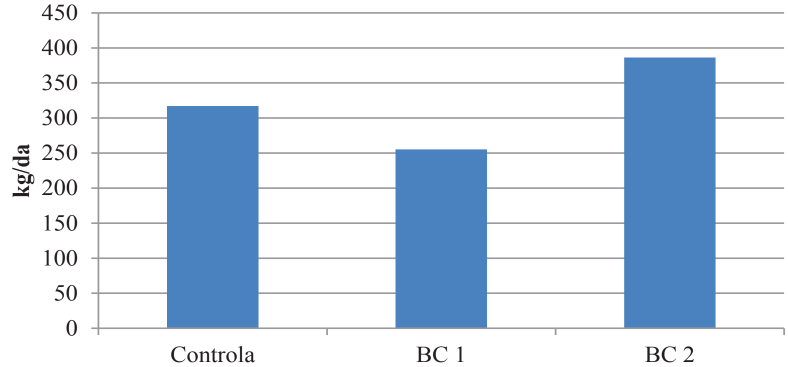
Фигура 2. Динамика на почвената влага на дълбочина 0-20 cm върху царевичното поле – Цалапица 2012

Figure 2. Dynamic of soil moisture on 0-20cm depth on maize field –Tsalapica 2012

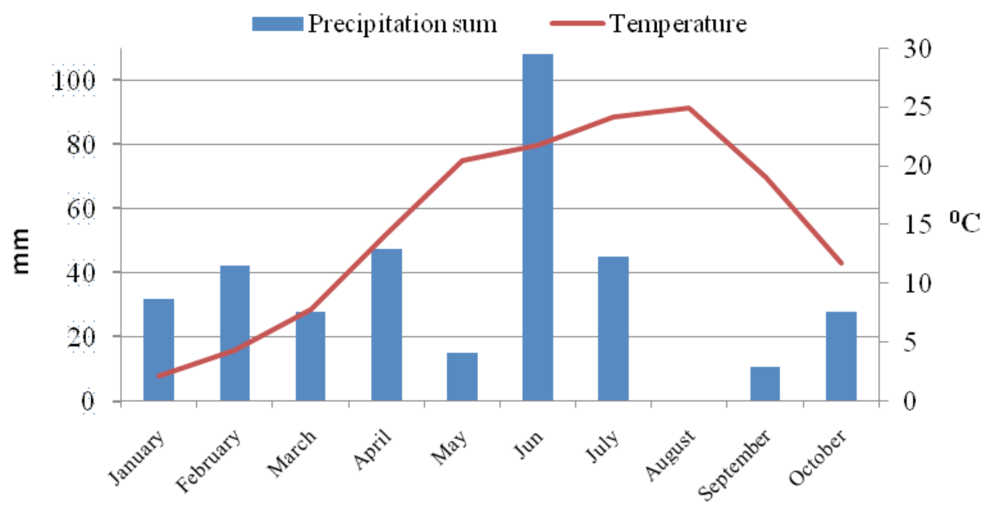


Фигура 3. Динамика на почвената влага на дълбочина 0-40 cm върху царевичното поле – Цалапица 2012

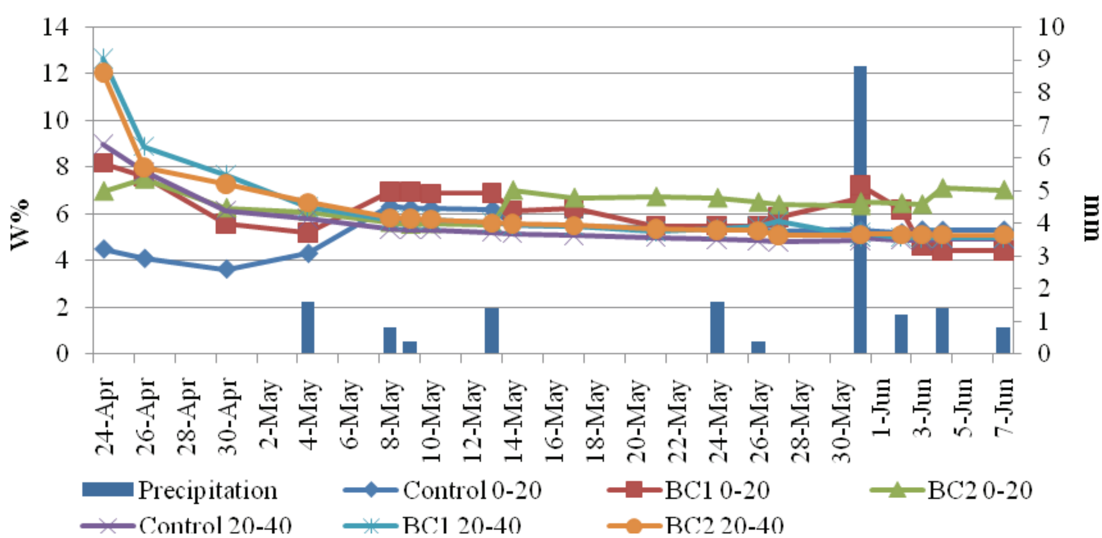
Figure 3. Dynamic of soil moisture on 0-40cm depth on maize field –Tsalapica 2012



Фигура 4. Среден добив на царевица в област експеримент – Цалапица 2012
Figure 4. Average maize yield in field experiment – Tsalapica 2012



Фигура 5. Годишно разпределение на валежите и температурата на въздуха – Цалапица 2013
Figure 5. Annual distribution of precipitation and air temperature – Tsalapica 2013



Фигура 6. Динамика на почвената влага върху пшеничното поле – Цалапица 2013
Figure 6. Dynamic of soil moisture on wheat field –Tsalapica 2013

is warm with temperatures of 1.2 to 1.8 °C. May is quite warm and the precipitations are 15 mm at an average rate for region of 59.9 mm for region. The average monthly temperature is 20.4 that are 3.4 °C higher than normal. This weather condition coincides with the wet- vulnerable crop period for wheat. June is quite humid, with an amount of rainfall 108 mm, the precipitation are manly in the first half of the month. The relative humidity is also very high - 75%. This may leads to plant lodging and development of fungal diseases.

Soil moisture from the beginning of the measurement at a depth of 0-20 cm is between 3.36 to 8.17% and for the 20-40 cm layer is between 8.98 and 12.67% by weight. After rising of temperatures in May to the end of vegetation, it remains around 6%, slightly increasing in the surface layer after the 9 mm rainfall.

The reported increase in soil moisture in variants with BC application is probably due to the influence of biochar on soil water holding capacity. The similar result are obtained by (Yu, O. Y., et al., 2013), they reported 1.7% increases water holding capacity of a loamy sand soil.

Infrared thermometer (IRT) is an affordable tool for researchers to monitor canopy temperature. A hand-held infrared thermometer (IRT) allows canopy temperature (CT) to be directly and easily measured remotely and without interfering with the crop. Studies have shown that CT is correlated with many physiological factors: stomatal conductance, transpiration rate, plant water status, water use, leaf area index and crop yield.

Figure 7 shows the dynamics of the temperature differences dT measured with IRT. At the beginning of the reported period, which coincides with the stem extension, the air temperature rises and the rainfall drops to less than 2 mm. dT in all variants is positive which is an indicator of water deficit.

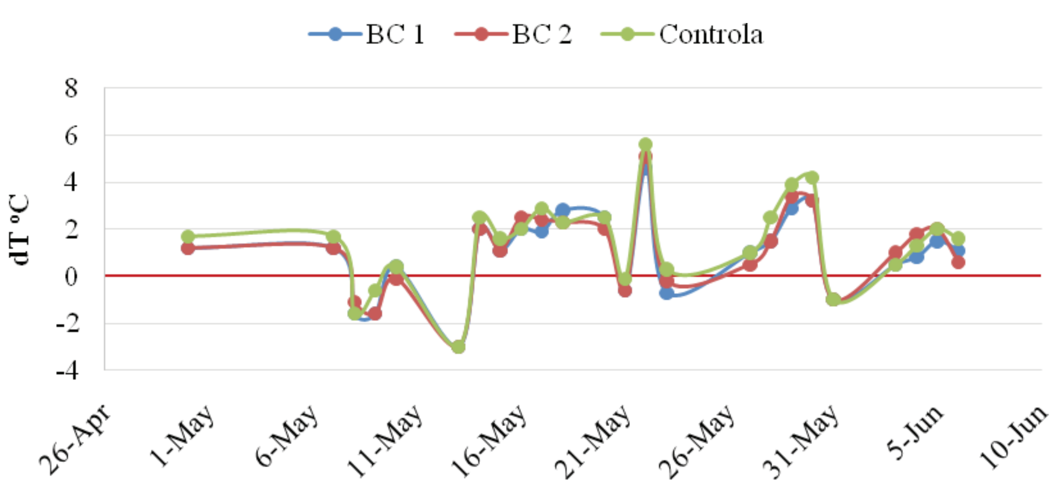
Despite the small amount of precipitation falling in May, the temperature difference falls to -3°C, which means that wheat does not in temperature and water stress, which is a guarantee of good development.

The figure shows that the temperature of the control variant is higher - about 0.5 to 1°C, in compared to the variants with BC application.

Surveys on the impact of different biochar application norms and plants water stress levels are more effective if they are carried out in a comprehensive way, including growth parameters, plant status, physiological and biochemical processes, as well as relevant soil and climatic conditions.

The biometrical measurements, such as a weight and height of the plants during ear formation stages of the vegetation are improved (between 8 and 10% heavier and higher), the difference between two variants is 1-2% in favor of BC 2. In all variants with applied BC plants are visibly darker green color.

The plastid pigments content depends on the leaves age, illumination, mineral nutrition uptake and many other ambient factors. Many of the environmental factors lead to the destruction of plastid pigments. Besides to the critical periods of plants development, the loss of pigment due to the stress



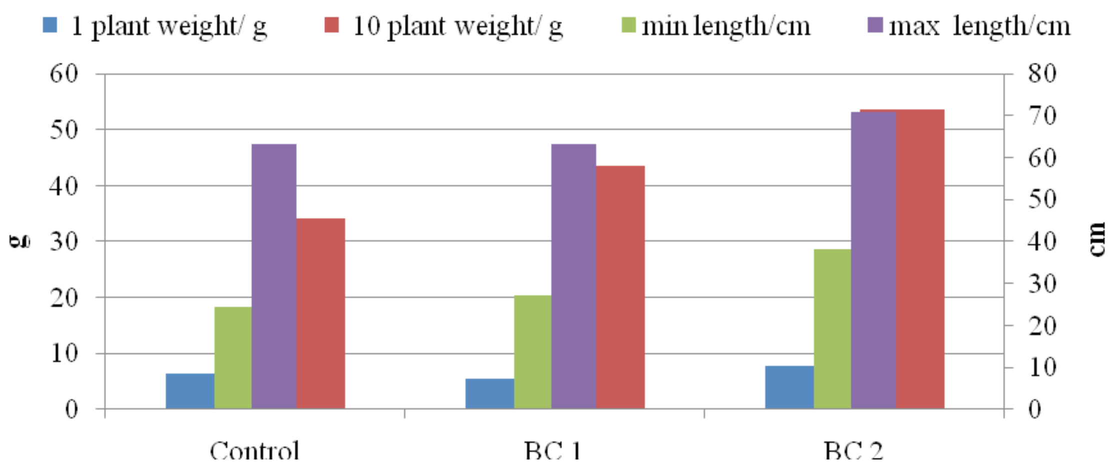
Фигура 7. Динамика на температурните разлики dT при пшеницата – Цалапица2013
Figure 7. Dynamic of temperature differences dT in wheat crop – Tsalapica 2013

factors is an obvious indicator of: disease, application of herbicides, water deficiency and temperature extremes (Hendry & Grime, 1993). This allows chlorophyll to be used as an indicator of stress response (Berova, 2004).

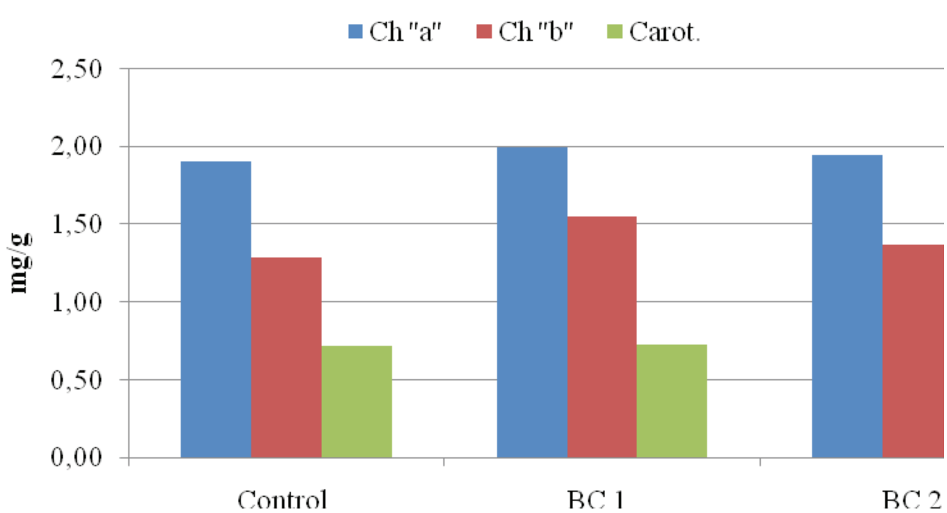
During the experiment, samples were taken to determine the content of plastid pigments through different stages of wheat development. The chlorophyll content Ch ‘’a’’ recorded at wheat germination is highest for the BC1version, followed by BC2. An increased amount of carotenoids has been reported, which may be an indicator of the presence of plant stress, since the carotenoids synthesis has an adaptive character and its biological role is protective (Lalova, 1981).

During the ear formation phase, which is the critical for wheat development, the chlorophyll content is close for all three variants as the highest values were recorded in BC 1 with imported 200 kg/da of biochar.

Since 2013 is climatically dry during the period of wheat vegetation, the increase in yield is clearly expressed in variants with biochar application. The reported average yield of the control variant is 192 kg/da, while in the case of variants whit biochar it reaches 448 kg/da. The yield increase with about



Фигура 8. Биометрически данни на пшеница в етап изкласяване – Цалапица 2013
Figure 8. Biometrical data of wheat in ear formation stage – Tsalapica 2013



Фигура 9. Съдържание на хлорофил в експеримент с пшеница във фаза изкласяване – Цалапица 2013
Figure 9. Chlorophyll content in field experiment with wheat in ear formation phase – Tsalapitsa 2013

40% on average is due to the biochar input into the soil, which has improved the soil water and physical properties. Albuquerque et al., (2013), reported for 3-42% increased wheat grain production in compared to the control soil. These results are in agreement with several authors (Chan et al., 2008; Van Zwieten et al., 2010), who found little responses of crop yield and nutrient status to the sole use of biochar, which are likely due to its nature: a carbon-rich but nutrient-poor material.

The hectolitre mass and the mass of 1000 grains are important physical indicators when qualifying wheat grain.

According to data, the parameters of wheat quality are relatively high, in variants with applied biochar compared to the control variants.

Lehmann et al. (2006) and Subhan et al. (2014), suggested that this increase in almost all the attributes of wheat yield was due to biochar application that not only improves the availability of nutrients but also promotes vegetative growth by improving the photosynthetic pigments productions in T. Aestivum L., which was observed by biochar addition at rates 1% and 2%.

CONCLUSIONS

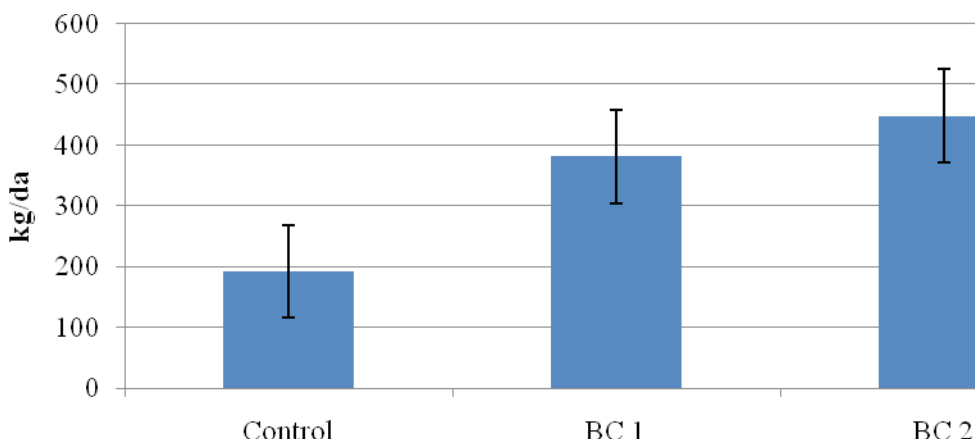
The BC incorporated in soil makes changes of soil moisture more slowly than the soil moisture from places without BC. Data obtained during the soil moisture measuring reveals that the water content in the layer 70-100 cm remains for a long time with high value in the variants with added biochar.

In experiment with maize, the yield depends mainly on soil moisture and irrigation norms. The introduction of higher BC rates leads to an increase in average yield of 70 kg/da.

The number of days with a temperature difference – dT <0 °C is greater for variants BC 1 and BC 2, indicating that they were less exposed to the plant water stress in compare to the control.

The yield of wheat in the variants with imported BC is higher, the yield increase with about 40% on average is due to the biochar, which has improved the soil water and physical properties.

The wheat quality indicators (hectolitre mass and mass per 1000 grains) are also higher, for the variants with incorporated biochar.



Фигура 10. Среден добив на пшеница в полевия експеримент – Цалапица 2013

Figure 10. Average wheat yield in field experiment – Tsalapica 2013

Таблица 2. Параметрите за качество на добива от пшеница на зърно от 2013

Table 2. Quality parameters of wheat yield grain from 2013

Variants	Hectolitre mass kg/hl	Mass 1000 grain/ g
Control	68.7	38.4
BC 1	74.5	39.6
BC 2	75.2	41.2

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