Soil Water Regime Evaluation after Biochar Amendment

Justina Vitkova 1, Peter Surda 1, Katarina Brezianska 1

1 Institute of Hydrology, Slovak Academy of Sciences, Dubravska cesta 9, 841 04 Bratislava, Slovakia
vitkova@uh.savba.sk

Abstract. In this paper, we have evaluated soil water regime in top soil layer based on agronomic classification. The study site was located in Malanta (near Nitra city, Slovakia). The whole site was divided into plots with the size 6 × 4 m separated by 0.5 m bands. Our field experiment began on March 2014 when a certificated biochar was applied to a depth 0-15 cm of soil profile in different rates. We have compared two plots: one with application of biochar in amount of 20 t/ha (B20) and second plot was without biochar amendment (Control). The soil water content in 0-15 cm depth was monitored by the 5TM sensors in 5 minute interval and stored using the EM 50 data loggers. Two sensors were installed at each plot and average value was used based on good correlation coefficient between them. Monitored period was from 12.8. to 22.10.2015 and the experimental area was cultivated with maize. Average daily value of soil water content and soil water storage were used to soil water regime evaluation. Results showed that 1) soil water content was higher at Control plot (we had expected higher values of soil water content at B20 plot based on scientific studies); 2) year 2015 was extremely hot and vegetation period and monitored period as well, were very dry. Therefor was soil water content below the hydrolimit wilting point (θWP) during a dominant part of monitored period. These results reflected also soil water regime evaluation, when deficit of soil water for plants was during long time of monitored period. Optimal soil water storage for plants was only 13 days at Control plot and 3 days at B20 plot. Our hypothesis, that this type of biochar (with specific characteristics) will improve soil water regime, was not confirmed.

1. Introduction
Soil water is part of the hydrosphere, which is located in the soil profile and together with groundwater and surface water it is the third water source which is directly involved not only in the hydrological but also in the production and biological cycle. This water source is non-alternative in the agricultural crop production process and sensitively responds not only to climate change but also to anthropogenic activity [1]. Changes in land use influence runoff processes, soil water regime and water balance [2]. Soil water content is one of the basic elements of water balance. One of the modern technologies for studying the water balance in the soil-groundwater-plant-atmosphere system are weighing lysimeters [3]. Soil water content can be influenced by surface runoff, soil erosion, infiltration process or management area process [4]. Relationship between plant and soil water content is used to characterization the hydrolimits. Hydrolimits are specific soil water contents which are defined for certain values of water potentials. Closer attention is paid to three hydrolimits: field water capacity (θFC), point of decreased availability (θPDA) and wilting point (θWP) [5]. The soil water content between field water capacity and wilting point is the interval at which the water in the soil is available for the plants at that site. However, each plant has a differentiated ability to take water through its root system, so the critical soil water content (wilting point) is affected by the plant during a year.
The soil water regime is the summary of all changes of content, physical state and relocation of the water in the soil for a certain time period and is the typical long time behaviour of the average values of these characteristics [6]. It is highly dependent on the grain size composition of the soil, which is, among other things, a stable feature of soil fertility. Perhaps, it is one of the most important soil regimes. In terms of overflow and deficit of soil water, the knowledge and assessment of the soil water regime is particularly important from the production and environmental point of view [7].

The soil water regime can be assessed on the three basic criterions from which we determine the name of classification [1]:

1. according to the direction and intensity of water circulation in the soil in the hydrological year – hydrologic classifications;
2. according to the predominant soil water content over a longer period of time – ecologic classification;
3. according to the relation between real and potentially accessible water for plants in the active root zone of grown agricultural crops – agronomic classification.

We have chosen the agronomic classification because it is the most suitable classification for soil water regime evaluation from the view of optimal crops state.

During the past decade, numerous articles focusing on the use of biochar have been published, but have shown inconsistent results. Reactions in the soil after the addition of biochar depend on the characteristics of biochar, soil, climate and soil-inhabiting organisms. However, due to high variability in the quality of biochar, its effects on soils and plants are likely to differ [8]. Biochar, a product of the thermal degradation of biomass rich in carbon, may alter the physical properties of the soil [9]. Moreover, most trials with biochar have been carried out in the laboratory over short time periods making translation of these results to field conditions difficult. Another aspect of these studies is that most have tended to focus on problematic soils (e.g. with excessive soil acidity or salinity, severe nutrient imbalances, critically low soil organic matter) where the responses of biochar addition can often be dramatic. However, these soils are not representative of fertile agricultural areas where the likelihood of biochar application from a practical and economic perspective may be greatest [10]. Our experiment is very special because it has been carried out in field conditions, during normal agricultural management. We tried to study direct impact of biochar on soil water content and soil water storage.

2. Material and methods

2.1. Studied area and used biochar

The study site was located at experimental area in Malanta, which is located approximately 5 km northeast of the city Nitra in west part of Slovakia (N 48°19'00"; E 18°09'00") (figure 1). Altitude location is 175 MASL [11]. The soil type is classified as the Haplic Luvisol [12], with the content of sand 15.2%, silt 59.9% and clay 24.9% – silt loam.

The whole site was divided into plots with the size 6×4 m separated by 0.5 m bands. Our field experiment began on March 2014 when a certificated biochar was applied to a depth 0-15 cm of soil profile in different rates. Biochar, used for the field experiment, was produced from paper fiber sludge + grain husks, 1:1 per weight (Sonnenerde Company, Austria) by pyrolysis at 550 °C for 30 minutes in a Pyreg reactor. Table 1 shows the basic biochar characteristics. We have compared two plots in our analyses: one with application of biochar in amount of 20 t/ha (B20) and second plot was without biochar amendment (Control). Monitored period was from 12.8. to 22.10.2015 and the experimental area was cultivated with maize.
Figure 1. Localization of experimental area in Malanta (Slovakia) (© Google maps 2018)

Table 1. Basic biochar characteristics

| Element | C  | N  | H  | O  | pH |
|---------|----|----|----|----|----|
| Biochar | 531| 14 | 18.4| 53 | -  |

2.2. Soil water content and soil water storage determination

The measurements of soil water content were performed with 5TM dielectric sensors (by Decagon Devices, USA) (figure 2). Two sensors were installed in 5-10 cm depth at each experimental plot. Correlation coefficient between two sensors at the same plot was 0.95 or 0.98, respectively [13]. The soil water content data were collected in a 5-minute interval and stored using the EM 50 data loggers (by Decagon Devices, USA). Based on good correlation coefficients, an average value of soil water content for a plot was analyzed. There was calculated soil water storage in top soil layer (0-15 cm depth) using measured soil water content.

Figure 2. The 5TM sensor used to monitoring soil water content
2.3. Soil water regime evaluation

In 1988 [14] was published an equation (1) to determine soil water regime based on soil water content and hydrolimits. Original equation was modified in 2007 [15] and there was used soil water storage and relevant values of hydrolimits (2). There were distinguished 10 types of soil water regime at agronomic classification (table 2). Although a longer time period is used to determination of soil water regime, we have decided to apply this calculation to daily step in order to analyse the impact of biochar on soil water regime. Average daily values of soil water storage were used to daily soil water regime determination based on equation (2).

\[
A = \frac{1}{n} \sum_{i=1}^{n} \frac{\theta_i - \theta_{WP}}{\theta_{FC} - \theta_{WP}}
\]  

(1)

\[
A = \frac{1}{n} \sum_{i=1}^{n} \frac{W_i - W_{WP}}{W_{FC} - W_{WP}}
\]  

(2)

where:

- \( A \) - agronomic coefficient to soil water regime evaluation (-)
- \( \theta_i \) - average soil water content of the active root zone in i-day of the monitored period (m³.m⁻³)
- \( \theta_{WP} \) - hydrolimit wilting point (m³.m⁻³)
- \( \theta_{FC} \) - hydrolimit field water capacity (m³.m⁻³)
- \( W_i \) - soil water storage of active root zone of soil profile in i-day of the monitored period (m.m⁻¹)
- \( W_{WP} \) - soil water storage equal to soil water content for wilting point \( \theta_{WP} \) (m.m⁻¹)
- \( W_{FC} \) - soil water storage equal to soil water content for field capacity \( \theta_{FC} \) (m.m⁻¹)
- \( n \) - number of days in monitored period.

| A       | Type of soil water regime                          |
|---------|----------------------------------------------------|
| < 0.11  | Total deficit of the soil water for plants         |
| 0.11 - 0.20 | Very dry                                           |
| 0.21 - 0.30 | Considerable dry                                   |
| 0.31 - 0.40 | Dry                                               |
| 0.41 - 0.50 | Rotate dry                                         |
| 0.51 - 0.60 | Rotatwe moist                                     |
| 0.61 - 0.75 | Moist                                             |
| 0.76 - 0.90 | Considerable moist                                 |
| 0.91 - 1.00 | Wet                                               |
| > 1.00  | Overflow of the soil water                        |

Value \( A > 1 \) (overflow of water in soil profile) we calculate when \( \theta_i > \theta_{FC} \), then is also \( W_i > W_{FC} \). Deficit of soil water content (\( A < 0.01 \)) is when \( \theta_i \) is near \( \theta_{WP} \), subsequently \( W_i \) is near to \( W_{WP} \). If \( \theta_i = \theta_{WP} \) then also \( W_i = W_{WP} \), the value \( A \) is equal to 0. In case if \( W_i < W_{WP} \) the value \( A \) is negative. It means that it is going about total deficit of soil water content for plants for both examples, which prefigures critical situation for plants. For that reason, it would be good to show these facts in the agronomic classification of types of soil water regime, as it is in table 2 [15].
3. Results and discussions

The shown methods of evaluating the soil water regime are applicable for long-term measurements of soil water content. In our study we tried use them to evaluate daily soil water regime at plots with biochar amendment and without biochar. Monitored period (12.8.-22.10.2015) was in the end of the maize vegetation period. Based on previous research of biochar application (e.g. [16]) we had expected that at B20 plot would be higher values of soil water content and soil water storage as well. But the results were the opposite. Soil water content was higher at Control plot that’s why the soil water storage in 0-15 cm depth was also higher at Control plot (figure 3.). The year 2015 was extremely hot and vegetation period and monitored period as well, were very dry. The deficit of the soil water was caused mainly by very small amounts of precipitation totals, by high air temperatures and high evapotranspiration in top soil layer during monitored period. Therefor was soil water storage below the hydrolimit wilting point \( W_{WP} \) from middle of August 2015 and during a dominant part of September 2015. These results reflected also soil water regime evaluation, when deficit or total deficit of soil water for plants was during long time of monitored period (figure 4.). Optimal soil water content for plants was only 13 days at Control plot and 3 days at B20 plot during monitored period.

![Figure 3. Soil water storage (W) at Control and B20 plots in 0-15 cm depth with hydrolimits comparison and precipitation totals at Malanta area during monitored period of 2015](image)
Figure 4. Types of daily soil water regime at Control and B20 plots based on agronomic classification at Malanta area during monitored period of 2015

4. Conclusions

Soil water regime evaluation is important for developing a prognosis of the soil water regime changes caused by technical actions in landscape and also by water balance in certain areas. With respect to keeping optimal conditions for plants it seems to be as the best agronomic classification, which is applied in this paper. We have used this classification to daily soil water regime evaluation even though it is used for longer time period. Our priority was found out if the biochar amendment should improve soil water content and soil water storage, as well. Results showed that soil water content and soil water storage were higher at Control plot during all monitored period and they were below the hydrolimit wilting point during a dominant part of monitored period. That’s why deficit or total deficit of soil water storage was calculated based on agronomic classification at Malanta area. It must be said that a deficit or overflow of soil water is extreme and installs critical conditions for the growth of vegetation. But monitored period was in the end of maize vegetation period so this situation did not affect the root system. In addition, we have analysed a top soil layer in time, when root system of maize was deep enough to avoid damage the crops. Our hypothesis, that this type of biochar (with mentioned characteristics) will improve soil water regime, was not confirmed.

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