Effects of Biochar and Sugar Factory Lime Application on Soil Reaction in Acidic Soils

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Summary

Soil reaction, expressed as a pH value, is an indicator of acidity or alkalinity. The soil acidic reaction causes increased mobility of aluminium in the soil and can have negative effects on root growth. Plants grow and develop in soils of different soil reactions, but the optimum soil reaction is between slightly alkaline and slightly acidic. The aim of this research was to determine the impacts differences between the effects of biochar and sugar factory waste lime on soil reaction in acid soils. The research was carried out on stationary field trials at two locations on acid soils in Osijek-Baranja and Virovitica-Podravina County, Croatia. The treatments were: C - control, B1 - 5 t ha^{-1}, B2 - 10 t ha^{-1}, B3 - 15 t ha^{-1} of biochar and L optimal dose of sugar factory waste lime that was calculated for each field trial location. Two steps of sub factors were also applied, F0 - without fertilization and F1 – with recommended fertilization. Soil samples were taken in V3 and silking stages of maize growth from 0-25 cm. The average soil pH value in V3 stage of maize growth was 5.42 and in silking was 5.93. The highest pH values in both stages of maize growth were measured in treatment with liming. The lowest hydrolytic acidity was measured at the liming treatment, while all other treatments had a significantly higher value compared to lime. sugar factory lime is optimal conditioner if we want fast and cheap raise in soil pH values, but it must be noted that together with liming we usually must implement many other soil restauration measures, like humization, especially in degraded soils.

Key words

biochar, sugar factory waste lime, acid soil, soil restauration measures, soil reaction

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Introduction

Soil reaction expressed as pH value is one of the most frequently used indicators of soil quality. Through the analyses of pH value, not only that we can indicate whether soil reaction is acidic or basic, but we can predict various chemical (e.g. availability and toxicity of elements) biological (e.g. microbial activities) and physical (e.g. clay type) soil properties (Thomas, 1996; Upjohn et al. 2005; Đurđević et al. 2011). The soil pH is affected by climatic conditions, soil parent material, vegetative cover, human induced factors (fertilization, irrigation, etc.) (McLean, 1982; Brady and Weil, 2008). Some plant species can grow and develop in soils with different reactions, and for most of them the optimal soil reaction is neutral or weakly alkaline or acidic. One of the main problem of agricultural production in Croatia are acid soils. In Eastern part of Croatia, we have approximately 50% of acidic soils on predominate agricultural area (Vukadinović et al., 2008; Đurđević et al., 2011). The acidification process generates many problems in agricultural production, because in the acid soils the mineral-colloidal fraction of soil is subjected to long-lasting rinse with acidic solution (humic and other) and gradually passes into acid clays that can be easily moved into deeper layers of soil. Then, clay usually creates watertight zone at a certain depth, which is prerequisite for reduction reactions in soils. Usually in such circumstances (pH $<=5.5$), the excess of H^+ ions on adsorption complex, increased mobility of aluminium and iron ions which in larger concentrations can be toxic to plants and block availability of essential nutrients, especially phosphorus (Vukadinović and Vukadinović, 2011).

The easiest way to neutralise soil acidity is liming (Mesić, 2001; Kisić et al. 2004; Đurđević et al. 2011; Vukadinović and Vukadinović, 2011). There are different types of soil conditioners that can be used for the restoration of such degraded soils like: carbonates, oxides, hydroxide, and different by-products like ash, sugar factory waste lime, biochar and others (van Straaten, 2002; Álvarez and Viadé, 2009; Mosley et al. 2015). Currently, mostly used and well researched soil conditioner for acid soils in Croatia is sugar factory waste lime, which is a by-product from the production of sugar and contains 30% Ca (Vukadinović et al. 2009; Đurđević et al. 2011). On the other hand, biochar is unexplored soil conditioner in Croatia. Biochar is the product obtained through pyrolytic processing of waste biomass which contains 60-95% of carbon. But biomass used for production must be exclusively waste material which cannot be used in human or animal nutrition (Lehmann, and Joseph, 2013). Biochar can be called the „electrical sponge", whose application in soil may possibly have a positive effect on a number of chemical, biological and physical soil properties (carbon sequestration, moderating of soil acidity, increased soil organic matter content, availability of nutrients and increased number of beneficial soil microbes etc.) (Lehmann, and Joseph, 2013; Kelpie, 2014). There are researchers that are reporting on neutralizing effect of biochar on acidic soils (Jeffery et al., 2011; Yuan et al., 2011), but most of experiments they have done are conducted in pots in controlled environment. Also, biochar can be produced using different biomass feedstock and through various pyrolytic processes which are associated with reaction mechanisms to reduce soil acidity (Chintala et al., 2014). So, the main aim of this paper was to determine does the wood biochar application increases the pH value of acid soil. To do this, we needed a benchmark, so we compared effects of different dosages of biochar to standard method of liming with sugar factory waste lime on soil reaction in acid soils of eastern part of Croatia.

Material and methods

The research was carried out on stationary field trials at two locations on acid soils in Osijek-Baranja (lon. 17.3327 lat. 45.6975), and Virovitica-Podravina County (lon. 17.8587, lat. 45.61125), Croatia (figure 1). The area around the selected locations can be described as mainly lowlands with partly hilly parts in the west of investigated area (Bašić et al. 2007). The temperatures of the research area increase from west towards the east, and from northwest to northeast. The mean annual temperature is from 9 to 11°C. The

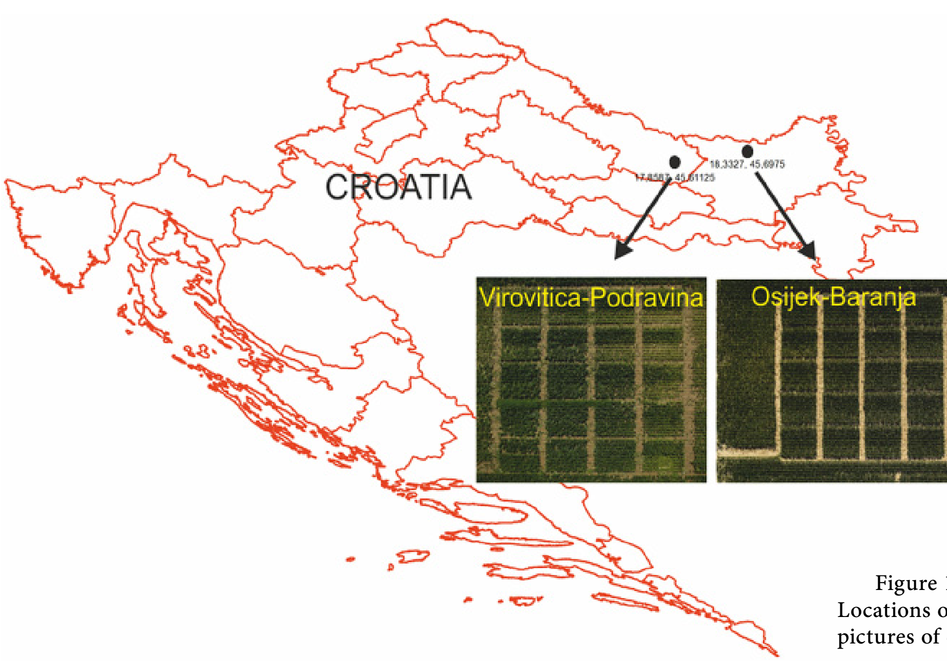

Figure 1.
Locations of experimental plots and pictures of experimental plots

Table 1. Initial soil analyses of both localities

Locality	pH (H_2O)	pH (KCl)	P_2O_5 (mg 100 g^{-1} soil)	K_2O (mg 100 g^{-1} soil)	SOM (%)	Hy (cmol kg^{-1})
Osijek-Baranja	5.12	4.00	6.20	16.20	1.40	5.80
Virovitica-Podravina	5.00	3.75	8.10	14.20	2.32	9.12

mean annual rainfall varies from the east (Osijek-Baranja locality) were it reaches 600 mm to the west (Virovitica-Podravina locality) where it reaches about 800 mm (Meteorological and Hydrological Institute of Croatia).

Experiments on both locations follow a split-split-plot design with four repetitions while the test crop was maize. Biochar was the main factor which was compared to liming with sugar factory waste lime. The treatments were: C - control, B1 - 5 t ha^{-1}, B2 - 10 t ha^{-1}, B3 - 15 t ha^{-1} of biochar and L optimal dose of sugar factory waste lime that was calculated using ALxp computer program for fertilizer recommendations (Vukadinović and Vukadinović, 2011). Two steps of sub factors were also applied, F0 - without fertilization and F1 – with recommended fertilization.

Soil samples were taken in V3 and silking stages of maize growth with an agrochemical probe with sample recovery depth of 25 cm. Average soil samples from plots were homogenized, dried, milled and analysed in a laboratory according to Đurđević, 2014. Soil pH was measured at a ratio of 1:5 (w/v) in a H_2O and 1 mol dm^{-3} KCl suspension respectively, using pH meter. Hydrolytic or potential acidity of the soil is determined by titration where we used alkaline hydrolytic salts (Ca-acetate) to exchanged H^+ and Al^{3+} ions from the soil adsorption complex Soil organic matter was analysed using modified Walkley-Black method.

Biochar used in this research is produced from waste wood material that is collected in nearby woods (oak and beech blend). After collecting the needed material, slow pyrolysis process was conducted at 400°C for 24 hours under limited oxygen conditions. The produced biochar had a particle size of 1 to 10 mm and contains 70.13% C, 1.9% Ca, 0.28% K, 0.12% Mg, 0.04% P. The content of heavy metals was below the limits allowed for fertilizers or soil improvers. The sugar factory waste lime was the second conditioner. Its consistency is powder-like and has a tendency to glue into larger particles due to the influence of moisture. It contains about 30% of Ca, 1.1% P, 0.4% N, 0.1% K, Mg and microelements in trace. Incorporation of biochar and sugar factory waste lime to the soil was done using reduced soil tillage (Chisel tillage) to the depth of 25 cm. Incorporation was done six months before sowing because we wanted to incubate biochar and sugar factory waste lime in soil.

The effects of main treatments biochar and sugar factory lime application and sub treatments (with and without fertilizer application) on soil reaction in acidic soils (two localities) was tested by ANOVA of the split-split-plot design.

Results and discussion

Initial soil analyses

Examining a soil profiles, the soil type in the localities is determined. According to WRB 2014 soil classification, in Osijek-Baranja locality Gleysol type was determined, and in Virovitica-Podravina Stagnosol. Initial soil analyses result revealed a strongly acidic soil reaction at the locality Osijek-Baranja (pH 5.12) and very strongly acidic reaction at locality Virovitica-Podravina (pH 5.0). Low concentration of phosphorus and soil organic matter (SOM) content was found at both localities (Table 1.). The availability of phosphorus (P) varies according to pH. Soils with low pH usually express deficiency in P, so in soils where experiment was conducted, supply of P to plant roots occurs mainly from the applied fertilizer (Ernani and Barber, 1995; Đurđević et al., 2014). Values of SOM below 3%, that are measured in both localities, in temperate regions can mean that some degradation process has been started, and that we can expect decline in the soil quality (Loveland and Webb 2003). Furthermore, the highest hydrolytic acidity was measured in Virovitica-Podravina locality (9.12 cmol kg^{-1}), which can be a good indicator of aluminium toxicity (Đurđević et al. 2014) (Table 1). Through the above mentioned most important soil indicators, we can easily determine the decrease of soil quality on both examined localities.

Soil reaction (pH-H_2O and pH-KCl)

Soil conditioner and fertilization treatment significantly affected on pH value in V3 stage which was in average 5.42. The highest pH values were measured in treatment with liming. Treatments without fertilization (V3 – H_2O both localities) had a higher measured pH values ($P <0.01^{**}$) than treatments with recommended dose of fertilizer (Table 2 and Figure 2). The application of nitrogen fertilizers can often impact soil pH values and cause topsoil acidification (Tang et al. 2000; Álvarez and Viadé, 2009). This was obviously the case with the soils in this study. The average pH (KCl) value was 4.17 and its variation was under significant ($P <0.01^{**}$) impact of conditioner. Liming treatment had the highest pH value measured in 1 mol dm^{-3} KCl and it was, statistically, significantly higher than in all other treatments. Differences in pH values between other treatments were not statistically justified (Table 2 a,b and Figure 2 a,b).

The average pH value in silking was 5.93 and its variation was under very significant influence of soil conditioner treatment. The highest soil pH values were measured in soil samples with liming. Soil conditioner and fertilization treatment significantly affected on pH value in KCl and in averaged was 4.34. Liming treatment again had the highest values of pH measured in KCl (Table 3 a,b and Figure 2 c,d). Increases of pH in water and in KCl were observed in silking and that effect is possibly due to better dissolution of the conditioners because of the heavier rainfall in June which correlated with Álvarez and Viad (2009). Also, we have noticed the increase of pH values in control treatments. That variation relates to seasonal fluctuations in pH values on which many different soil factors (temperature, moisture, active soil fungi) can have an effect (Wuest, 2015) and it is often hard to determine which factor influences pH value the most. Although application of biochar has no significant effect on pH values, the higher values of pH on treatments with 15 t ha^{-1} of biochar were noticed (table 1 a,b and table 2 a,b). That is very important because biochar is more stable than the organic matter from which it is made. Because of this biochar can buffer acidity in the soil for longer period of time (Lehmann, and Joseph, 2013; Mosley et al 2015) and continued monitoring

Table 2. Treatments, sub-treatments and their average values in the V-3 phase of maize growth for a) pH H_2O, b) pH KCl and c) Hy cmol kg^{-1}. Lowercase letters indicate P<0.01** differences between individual locality and uppercase letters indicate significant differences between mean values of two localities

		Locality						
a)	V-3 (pH H_2O)	Osijek-Baranja			Virovitica-Podravina			
	Fertilization	Fert 0	Fert R	x̄	Fert 0	Fert R	x̄	x̄Lo
Conditioner	C	5.30	4.94	5.12^b	5.46	5.13	5.28^b	5.21^B
	B1	5.14	4.88	5.01^b	5.39	5.10	5.25^b	5.13^B
	B2	5.20	4.95	5.08^b	5.44	5.14	5.29^b	5.18^B
	B3	5.37	5.06	5.22^b	5.74	5.25	5.49^b	5.35^B
	L	6.28	6.07	6.18^a	6.52	6.03	6.30^a	6.24^A
	x̄	5.45^a	5.18^b	5.32	5.71^a	5.34^b	5.53	5.42
b)	V-3 (pH KCl)	Osijek-Baranja			Virovitica-Podravina			
	Fertilization	Fert 0	Fert R	x̄	Fert 0	Fert R	x̄	x̄Lo
Conditioner	C	4.09	4.00	4.04^b	3.77	3.68	3.72^b	3.88^B
	B1	4.02	4.00	4.00^b	3.68	3.65	3.66^b	3.84^B
	B2	4.08	4.05	4.06^b	3.73	3.76	3.74^b	3.90^B
	B3	4.27	4.19	4.23^b	3.85	3.90	3.87^b	4.05^B
	L	5.42	5.02	5.22^a	5.10	5.16	5.13^a	5.17^A
	x̄	4.37	4.25	4.31	4.03	4.03	4.03	4.17
c)	V-3 (Hy cmol kg^{-1})	Osijek-Baranja			Virovitica-Podravina			
	Fertilization	F0	FR	x̄	F0	FR	x̄	x̄Lo
Conditioner	C	4.62	4.87	4.75^b	8.36	9.45	8.90^b	6.83^B
	B1	4.65	4.68	4.67^b	8.75	8.39	8.57^b	6.62^B
	B2	4.48	4.25	4.37^b	8.21	8.15	8.18^b	6.27^B
	B3	3.34	3.57	3.45^b	7.05	7.67	7.36^b	5.41^B
	L	1.31	2.09	1.70^a	2.70	2.54	2.62^a	2.16^A
	x̄	3.68	3.89	3.79^A	7.01	7.24	7.13^B	5.21

C- control B1 - 5t ha^{-1} of biochar; B2 - 10t ha^{-1} of biochar; B3 - 15t ha^{-1} of biochar; L – recommended liming with sugar factory lime; F0 – without fertilization; FR – recommended fertilization; $\bar{x}$ - average; $\bar{x}$Lo - average values of two localities.

Table 3. Treatments, sub-treatments and their average values in the V-3 phase of maize growth for a) pH H2O, b) pH KCl and c) Hy cmol kg-1. Lowercase letters indicate P<0.01** differences between individual locality and uppercase letters indicate significant differences between mean values of two localities

		Locality						
a)	Silking (pH H_2O)	Osijek-Baranja			Virovitica-Podravina			
	Fertilization	F0	FR	x̄	F0	FR	x̄	x̄Lo
Conditioner	C	6.28	6.06	6.17^b	5.62	5.25	5.43^b	5.80^B
	B1	5.89	5.86	5.87^b	5.46	5.22	5.34^b	5.60^B
	B2	5.97	5.93	5.95^b	5.47	5.40	5.43^b	5.69^B
	B3	6.21	6.13	6.17^b	5.70	5.51	5.60^b	5.85^B
	L	7.08	7.00	7.04^a	6.05	6.59	6.32^a	6.68^A
	x̄	6.29	6.20	6.24	5.66	5.59	5.62	5.93
b)	Silking (pH KCl)	Osijek-Baranja			Virovitica-Podravina			
	Fertilization	F0	FR	x̄	F0	FR	x̄	x̄Lo
Conditioner	C	4.37	4.30	4.33^b	3.85	3.72	3.79^b	4.06^B
	B1	4.31	4.16	4.24^b	3.79	3.67	3.74^b	3.99^B
	B2	4.40	4.27	4.33^b	3.78	3.81	3.79^b	4.06^B
	B3	4.48	4.45	4.47^b	3.93	3.93	3.93^b	4.20^B
	L	5.99	5.55	5.77^a	4.40	5.61	5.00^a	4.39^A
	x̄	4.71^a	4.55^b	4.63	3.95	4.15	4.05	4.34
c)	Silking (Hy cmol kg^{-1})	Osijek-Baranja			Virovitica-Podravina			
	Fertilization	F0	FR	x̄	F0	FR	x̄	x̄Lo
Conditioner	C	3.63	4.17	3.90^b	6.89	8.37	7.63^b	5.76^B
	B1	3.88	4.49	4.19^b	5.82	7.03	6.42b	5.31^B
	B2	3.74	4.13	3.93^b	7.05	7.41	7.28^b	5.58^B
	B3	3.35	3.71	3.53^b	6.53	6.18	6.36b	4.94^B
	L	0.61	1.06	0.84^a	5.28	2.13	3.67^a	2.27^A
	x̄	3.04^a	3.51^b	3.28^A	6.31	6.22	6.27^B	4.77

C- control B1 - 5t ha^{-1} of biochar; B2 - 10t ha^{-1} of biochar; B3 - 15t ha^{-1} of biochar; L – recommended liming with sugar factory lime; F0 – without fertilization; FR – recommended fertilization; $\bar{x}$ - average values; $\bar{x}$Lo - average values of two localities.

Figure 2. Effect of biochar and sugar factory lime on pH H_2O, pH KCl and Hy cmol kg^{-1}. C- control B1 - 5t ha^{-1} of biochar; B2 - 10t ha^{-1} of biochar; B3 - 15t ha^{-1} of biochar; L – recommended liming with sugar factory lime; F0 – without fertilization; FR – recommended fertilization

will provide deep insight in overall effect of performed treatments on acid soils. The same is not the case with liming, which can lose his availability three years after application and lead to reacidification of limed soils as confirmed by many authors (Tang et al. et al. 2000; Debreczeni and Kismanyoky, 2005; Fettell et al., 2007; Álvarez and Viadé, 2009).

Hydrolytic acidity

Soil conditioner and fertilization treatment significantly affected on hydrolytic acidity (Hy) in V3 stage which was in average 5.21 cmol kg^{-1}. The highest value was measured in Virovitica-Podravina locality and it was, statistically significantly higher in relation to Osijek-Baranja locality. Conditioners C, B1, B2 and B3 did not differ significantly, while all treatment values were higher in relation to liming (P <0.01**) (Table2 c and Figure 2 a).

In silking the average Hy in soil was 4.77 cmol kg^{-1}. Experimental site and conditioner had significant effect on the values of Hy. Significant interactions of conditioners and fertilizers, as well as the interaction of all three parameters, have been observed. The highest hydrolytic acidity was measured in Virovitica-Podravina locality and in relation to the values measured in the soil samples from the Osijek-Baranja locality, significance was at the P<0.01**. The lowest Hy was measured at the liming treatment, while all other treatments had a very significantly higher value of Hy compared to lime (Table 3 c and Figure 2 d).

The Hy acidity represents total potential soil acidity (Chesworth, 2008). The values of Hy higher than 4 cmol kg^{-1} indicate high saturation of the adsorption complex of soils with acid ions (H^+ and Al^{3+}) and in this case, it is necessary to consider the need for conditioning of soil (liming, humization etc.) (Vukadinović and Vukadinović 2011). Liming has the strongest impact on the reduction of Hy on both localities (figure 2 a,b,c,d), but it should be noted that the problem of low pH values cannot be solved easily and quickly. A change from very strongly acid to neutral soil reaction radically influences on various soil properties, especially on oxido-reduction reactions where it can lead to an increased decomposition of soil organic matter in soil. Because of this, after initial growth (caused by liming), a drop-in soil productivity inevitably follows. Therefore, for extremely acid soils, liming should be more moderate (Vukadinović et al., 2009; Đurđević et al. 2011). Although, biochar application in this research did not statistically affected the soil reaction compared to liming, it must be noted that it is powerful soil enhancer that positively affects several important physical, chemical and biological soil properties (Chintala et al. 2013; Knox et al. 2015), and because of this it can easily be used as soil conditioner for acid soils, especially if we consider its prolonged action in soil (Lehmann, and Joseph, 2013; Burrell et al. 2016).

Conclusion

The differences between the effects of biochar produced from waste wood material and standard method of liming with sugar factory waste lime on soil reaction of acid soils were determined in this study. The highest pH values, in both stages of maize growth (V3 and silking), were measured on treatment with liming, and compared to other treatments the differences were significant. Also, hydrolytical acidity measured on both localities was significantly lower in comparison to other treatments, so it can be concluded that the most common soil conditioning measure for increasing pH value on acid soils is liming, which has already been proven to be the fastest way to rise soil pH. However, it must be noted that in parallel with liming we usually must implement many other different soil restoration measures, especially in severely degraded soils, and often, after some period of time, reacidification can happen, especially when using small particle size lime material. Future research will reveal the nature of biochar in soils, because it has an ability to influence a wide range of soil properties, which potentially makes it a good investment when opting for soil conditioners. However, it is necessary to better understand its function and its interactions in soil. To do so, it is important to conduct long-term field experiments with different feedstock, which is a precondition for successfully acceptance of biochar as an effective soil amendment in the future.

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