Celal Bayar University Journal of Science
Volume 18, Issue 3, 2022, p 239-247
Doi:10.18466/cbayarfbe.961739

Celal Bayar University Journal of Science

Boron Adsorption on Lime Soil and Phytoremediation of Lime Soil by Potato Plant (Solanum Tuberosum L.)

Mustafa Korkmaz[1*], Cengiz Özmetin[1], Yeliz Süzen[1],Atilla Mutlu[1]

[1]Balıkesir University, Faculty of Engineering, Department of Environmental Engineering,Çağış Campus,Balıkesir, Türkiye
*korkmazm@balikesir.edu.tr
*Orcid:0000-0001-8424-6339

Received: 2 July 2021
Accepted: 13 September 2022
DOI: 10.18466/cbayarfbe.961739

Abstract

Boron adsorption onto lime soil from Balıkesir University campus was studied to evaluate the effects of irrigation water cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and soil clays (kaolinite, montmorillonite, clinoptilolite clays). The concentrations for cations and boron were in the range of 0-1,450 mg/L and 0-700 mg/L, respectively. The experimental maximum boron capacity for cation effect was 0.764 mg/g and this value was seen to obtain at high cation (Ca^{2+}=500 mg/L, Mg^{2+}=550 mg/L, K^{+}=1,450 mg/L and Na^{+}=550 mg/L) and middle boron concentration (300 mg/L). This capacity of cations effect in optimization graph were obtained as (Ca^{2+}=1,419.38 mg/L, Mg^{2+}=1,450 mg/L, K^{+}=1,450 mg/L and Na^{+}=1,438.59 mg/L) and middle boron concentration (304.49 mg/L). The maximum experimental boron capacity for clay effect was 1.08 mg/g and this value was obtained from experimental parameters of 0.16 g clinoptilolite, 0.38 g montmorillonite, 38 g kaolinite. This 1.08 mg/g capacity value was obtained from optimization graph at 0.5828 g clinoptilolite, 0.1936 g montmorillonite, 0.5852 g kaolinite amounts.These complexities in optimization and experimental parameters for cation and clay effect were due to near values of adsorption capacities. The borated-soil samples were successfully phytoremediated with potato plant and maximum intake of boron by the potato plant was 2,304.8 mg/kg plant.The studied soil concentrations for phytoremediation were 3.56, 13.56, 23.56, 33.56, 43.56, 53.56, 103.56, 203.56, 303.56, and 403.56 mg/kg boron**.**The plant dry weights decreased by increasing soil boron concentration and the green side of potato plants did not grow at 203.56, 303.56, 403.56 mg/kg boron concentrations exhibiting toxicity to seeds.

Keywords: Boron adsorption, Lime soil, RSM optimization, Phytoremediation, Potato plant

1. Introduction

The soils originate from the mother material on the Earth crust. The soils are classified as sandy, silty, clay, loamy, peaty and chalky. The components of the healthy soil are calcium, manganese, potassium, sulfur, carbon, nitrogen, phosphorus, organic matter, water, soil air and microorganism. The main boron types found in the soil are monoborate ($B(OH)_4^-$) and boric acid (H_3BO_3) [1]. The soils irrigated with domestic wastewater and sea water may contain toxic levels of boron. The soil boron concentration passing to irrigation water is generally 7-80 µg/g [1]. Boron adsorption onto soils is affected from pH, temperature, calcium carbonate content, organic matter, clay amount, metal oxides and ionic strength [2]. The soil texture is based on factors like clay content, organic matter content or particle size and the boron adsorption on soils in different regions shows changing capacity values because boron interaction has a complex mechanism based on texture. Some of the complex mechanisms are boron fixation with soil clay, fulvic or humic acids [2]. Generally, boron binding onto soils increases with pH raise to the alkaline pHs (7-9.5) due to the increasing of monoborate anion fraction at partially low hydroxyl ion competition [2]. The boron adsorption onto soils is an endothermic or exothermic process [2].

In this study, boron adsorption onto lime soil was studied under the effect of solution cations and soil clays. The boron concentration was selected from 0 to 700 mg/L for cation effect and as 500 mg/L for clay effect. The reason of selection of high boron concentration was that the boron concentration in sea waters, boron-containing lake waters, geothermal waters used for irrigation would cause to more boron accumulation in soils after repeated irrigation. We aimed to saturate the soil against boron at one time by applying high boron concentration. Also, irrigation waters contain cations.

The phytoremediation can be defined as the accumulation of soil pollutants in hyper-accumulator plants. The phytoremediation is a low-cost method and easy for application. The types of plant treatment of soils are phytoremediation, rhizofiltration, phytostabilization, rhizodegradation, phytodegradation, phytovolatilization, organic pumps, phytoextraction [3]. Some preliminary literature reviews aiming boron adsorption onto soils and phytoremediation of boron from soils by plants are given as follows. Alleoni and coworkers reported that the soil aluminum oxide and clay content increased the boron adsorption [4]. In other study, it was reported that boron adsorption onto soil increased with concentration, clay amount, organic matter and cation exchange capacity increase. In the same study, the sand amount of soil increased to desorption of soil boron, probably sand adsorbs the boron physically [5]. The boron intake by plants is based on clays, humidity, organic matter, aluminum and iron oxides, magnesium hydroxide in soil [6]. In a thesis study, it was studied the boron phytoremediation from soils by vetiver grass (Chrysopogon zizanioides L.)and above 40 mg/kg boron concentration, the plant dead occurred and dry weight and height of vetiver plant decreased with increasing boron concentration. The application of EDTA and DTPA extractants was determined as more effective before harvest compared with before planting [7]. Böcük and coworkers used various plants to study the phytoremediation of boron from soils and Puccinella distans subsp. distans (Poaceae) and Gypsophila perfoliata subsp. perfoliata (Caryophyllaceae) showed both the greatest tolerance and greatest B accumulation ratios [8]. Rees et al. studied boron removal from soil contaminated with borax by black poplar and hybrid poplar trees [9]. In the pot experiments made with black poplar and hybrid poplar, the boron pollution in the soil was kept in the range of 13-280 mg/kg. It has been reported that poplar trees were not affected by pollution up to a concentration of 93 mg/kg boron. It was also reported that growth in poplar decreased with the increase in the concentration of soil samples within 168-230 mg/kg boron pollution. The mean boron concentration in the poplar leaves was 3,500 mg/kg but this value was calculated to reach 7,000 mg/kg in leaf stains [9]. In this study, boron adsorption onto lime soil under irrigation water cation and clay type effects by central composite experimental design were studied and the borated lime soil was phytoremediated with potato plant. The use of potato plant for phytoremediation of soils is dense in heavy metal uptake and potato is a new alternative for boron uptake from lime soils by phytoremediation.The central composite experimental design tool of response surface method (RSM) was used in optimization.

2. Materials and Methods

2.1 The used chemicals and equipments

The lime-solid was used for cation, clay effects and potato phytoremediation experiments. The polyetilene 100 mL sample bottles were used to fill boron solutions for cation effect experiments. The solutions for cation and clay effect experiments were prepared on a magnetic stirrer (Hot Stirrer MS-300HS). The solution taking was done by automatic pipets (1, 5 mL) (Vitlab product). An incubator shaker was used for boron adsorption experiments on soil (JSR product). A pH meter was immersed into solutions for pH measurement and adjustment (WTW Multi 340i, Germany). A centrifuge was used for seperation of soil particles from boron solutions. Boric acid (Merck product) was used for preparation of boron solutions and borated soils. The special name of planted potato was not decided and purchated from market. The used clay minerals are belonging to Balıkesir city in Turkey. The typical XRF (X-ray Fluoroscence) analysis results of Balıkesir montmorillonite [10], clinoptilolite [11] and kaolinite [12] were reported by given references. The calcium, magnesium, potassium and sodium chloride salts were used for cation solutions preparation (Merck products).

2.1 Boron adsorption experiments for lime soil

The soil sample was supplied from Balıkesir University campus in Turkey. A volume of 50 mL solution with 0-700 mg/L boron concentration and 0-1,450 mg/L cation concentration transferred to 100 mL polyethylene bottles and 5 g soil was added for cation effect experiments. The cations were calcium, magnesium, sodium and potassium. Cation effects were studied at 0-1,450 mg/L concentration interval. The boron solution was treated with soil (5 g) during 24 hours at 200 rpm agitation speed in an incubator shaker. The water temperature during the experiments was 30 ^{o}C.The soil sample was sieved below 800 µm sieve fraction before addition to boron solutions for cation and clay effect. After reaction, the solutions were centrifugated at 5,000 rpm speed and the boron analysis of supernatant was carried by potentiometric titration. The procedure was as follows [13]: A volume of 5 mL boron solution was transferred to the 100 mL baker and 50 mL pure water was added and the pH of the solution was fixed to 7.6. D-mannitol was added up to constant pH value and then boron solution again titrated with 0.02 N KOH up to pH became 7.6. The boron concentration was determined from the base consumption. 1 mL of 0.02 N KOH solution is equal to 0.6964 mg B_2O_3. The used base solution was standardized against 500 mg/L boron solution daily. The clay effect was studied with clinoptilolite, montmorillonite and kaolinite clays as a mixture with soil at total 2.5 g soil-clay mixture weight. The studied boron concentration for clay type effect was constant 500 mg/L. The clays had 90-180 µm particle size. The clay effect was studied at 2.5 g mixture-to-25 solution ratio. The experiments for clay effect and cation effect were carried according to experimental matrix determined by central composite experimental design tool of respose surface method. Boron concentration and adsorption capacity were calculated by using the following equations.

$$Boron(mg/L) = \frac{(V_1 - V_2) \times 0.21627 \times 1{,}000 \times Sf}{V_3} \quad \textbf{(1)}$$

Here, V_1 is volume of consumed base during titration (mL), Sf is standardization factor, V_2 is base consumption for pure water at absence of boron (about 0.2 mL), and V_3 is the volume of boron solution taking after centrifugation (mL).

$$Qe = \frac{(C_0 - Ce)}{m} \times V \quad \textbf{(2)}$$

Here, Qe is the adsorption capacity (mg/g), C_0 is initial concentration (mg/L), Ce is the equilibrium concentration (mg/L), m is the soil amount (g) and V is the solution volume (L).

2.2 Characterization of soil sample

The pH and conductivity values of the soil sample were measured by treating 50 g soil with 500 mL pure water during about 48 hours at room temperature (Multi parameter pH Meter). The phosphorus and boron contents of the soil were measured by treating 50 g soil with 500 mL pure water during about 72 hours at room temperature and phosphorus was measured with stanneous chloride and boron was measured with carmine method due to its low concentration sensivity [14]. The organic matter and lime contents of the soil were gently measured by Ataturk University Agricultural Engineering Department

2.3 Phytoremediation experiments

The potato plants were growth and harvested at date of 02/05/2018 (potato planting) and 02/08/2018 (harvest), respectively. The air temperature, air humidity and irrigation of the plant were as follow: (avarage temperature 17.9-25.5 ^oC for mounts, air humidity 50-90% and irrigation at per 14 days as 250 mL pure water/3 kg soil). Pure water was used as irrigation water. 3 kg samples of soil were treated with different concentrations of boron solutions and the solutions were prepared from boric acid (Merck product). The soil boron concentrations were prepared as 10, 20, 30, 40, 50, 100, 200, 300 and 400 mg/kg.Addition to these concentrations, orginal soil sample had 3.56 mg/kg boron concentration. Ten pieces of water bucked were filled with 3 kg borated soil sample separately and potatoes were seeded in the soil and the potato plants were regularly irrigated during 3 months. The potatoes were planted during 3 months and the potatoes vegetable under roots did not grow. Upper side the plants dried during 3 months at room temperature. The 0.5 g dried green potato plant was dissolved in concentrated nitric acid (50 mL) and boron analysis was done in ICP-OES instrument. Before analysis of boron by ICP-OES instrument, boron solutions were diluted at 100 fold. The characterization of soil is given in Table 1. Cation exchange capacity was measured by acetic acid method [15].

Table 1: Characterization of the soil sample.

Parameter	Value
pH	7.69
Total lime (% $CaCO_3$)	15.58
Organic matter (%)	2.66
Phosphorus (mg/g)	0.00185
Plant available boron (mg/g)	0.00356
Conductivity (µSc/cm)	175.8
Cation exchange capacity ($mmol_c$/kg)	3.872
Particle size (cation and clay effect experiments)(µm)	<800

3. Results and Discussion

3.1 RSM optimization for boron adsorption on soil

The response surface methodology was firstly defined by Box and Wilson [16]. They exposed to experimental matrix giving the optimum response by means of a very low experimental run. Generally, the RSM analysis is formed from three stages, namely the elimination study provides the low run, Anova analysis of the factor for regression model development, the analysis of factor levels to obtain the optimum conditions which are sometimes different from the investigated experimental matrix conditions. The general model in central composite design analysis was obtained by regression analysis. Model equation is Y=f(X1,X2,X3,…….,Xn) + ἑ. Here, the Y equation is the response variable and f is the quantitative variable and ἑ is random error term [16]. A general regression model is as follow:

$$\text{Capacity (mg/g)} = b + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_1X_1 + b_5X_2X_2 + b_6X_3X_3 + b_7X_1X_2 + b_8X_1X_3 + b_9X_2X_3 + b_{10}X_1X_2X_3 + ἑ \quad \textbf{(3)}$$

In this study, central composite experimental design (CCED) tool of response surface analysis method was applied. The central composite design analysis is formed from these stages: Firstly, selection of parameter number, selection of alpha (fold between parameter levels, i.e 2 for this study) and center point number, entering of parameter levels as low and high values, entering of confidence level (95%, i.e. 0.05 for this study), and optimization of response by selecting targed value in optimization tool in programme analysis.

The optimization of solution cations effect on boron adsorption by lime soil was studied by CCED analysis. The experimental matrix is given in Table2. The boron capacity values were in the range of 0-0.764 mg/g. The

Celal Bayar University Journal of Science
Volume 18, Issue 3, 2022, p 239-247
Doi:10.18466/cbayarfbe.961739

Anova analysis (student-t test and confidence factors, p) was performed and is given in Table 3. The confidence limit value (p) for main and interaction effects of parameters was selected as 95% ($p<0.05$). The P values (probability constants) were used as a control parameter to check the reliability of the developed statistical model, individual and interaction effects of the parameters. In general, the larger the magnitude of t and the smaller the value of P, the more significant is the corresponding coefficient term [17]. The constant term, magnesium, potassium-potassium, sodium-boron terms were found as statistically important. It can be seen that the cations have a very low effect on boron adsorption.The surface plots of the cation effect on boron adsorption onto lime soil are given in Figure 1.The experimental matrix for clay effect is given in Table 4. The Anova analysis for clay-soil mixture (clay amount in 2.5 g mixture) is given in Table 5. The boron adsorption capacity was in the range of 0.297-1.08 mg/g for the clays of kaolinite, montmorillonite and clinoptilolite at 2.5 g/25 mL soil-clay mixture dosage. The Anova analysis of factors for clay-soil mixture showed that the all factors p values were under confidence level ($p<0.05$). The presentation of clay type effects is given in Figure 2. The boron adsorption increased with kaolinite increase and montmorillonite decrease. Also, the adsorption capacity decreased with clinoptilolite decrease and middle kaolinite amount. The capacity increased with clinoptilolite decrease and montmorillonite middle value. The optimizer graphs of the cation effect and clay effect are given in Figure 3-4. The targeted maximum boron adsorption value of cation effect (0.764 mg/g) was obtained for 1419.3814 mg/L calcium, 1438.5952 mg/L sodium, 1450 mg/L potassium,1450 mg/L magnesium, and 304.4906 mg/L boron. The reason of 304.4906 mg/L boron was probably due to boric acid-polyborate equilibrium because above 0.25 M boron concentration, polyborates increase.The targeted maximum boron adsorption value of clay effect (1.08 mg/g) was obtained for 0.5828 g clinoptilolite, 0.1936 g montmorillonite, 0.5852 g kaolinite. The experimental matrix for cation effect in maximum boron adsorption was formed from 550 mg/L calcium, 550 mg/L sodium, 1450 mg/L potassium, 550 mg/L magnesium and 300 mg/L boron for reaching 0.764 mgB/g targeted capacity. The experimental targeted value (1.08 mg/g) for clay effect was obtained at 0.16 g zeolite, 0.38 g montmorillonite and 0.38 g kaolinite in the matrix.The difference between experimental and optimization values were due to data proximity in experimental results (Table 6). The soils generally contain clay minerals as constituent and the clays have boron binding property that causes to unusable boron fraction by plants in the soil body. The clay minerals have positive sites like silisium and aluminum at broken edge on the frame work adsorbing specifically the boric acid and monoborate anion. Also the hydroxilated aluminum and silisium sites complex the boron. The solution cations in soil-solution medium cause the positive surface charge development with cation adsorption onto soil surface and thus much more boron adsorbed on to soil due to increasing zeta potential.

Table 2: Cation effect on boron adsorption (Temperature 30 ^oC, 200 rpm, Natural pH, Total soil weight 5 g, Solution volume 50 mL, concentration units of cations and boron are in mg/L)(a: 0 mg/L concentration).

Run	Ca^{2+}	Na^+	K^+	Mg^{2+}	B	Capacity (mg/g)
1	100	100	100	100	500	0,284552
2	1000	100	100	100	100	0,491870
3	100	1000	100	100	100	0,369919
4	1000	1000	100	100	500	0,487804
5	100	100	1000	100	100	0,512195
6	1000	100	1000	100	500	0,325203
7	100	1000	1000	100	500	0,487804
8	1000	1000	1000	100	100	0,004065
9	100	100	100	1000	100	0,349593
10	1000	100	100	1000	500	0,345528
11	100	1000	100	1000	500	0,345528
12	1000	1000	100	1000	100	0,004065
13	100	100	1000	1000	500	0,528455
14	1000	100	1000	1000	100	0,105691
15	100	1000	1000	1000	100	0,308943
16	1000	1000	1000	1000	500	0,569105
17	-350[a]	550	550	550	300	0,317073
18	1450	550	550	550	300	0,235772
19	550	-350[a]	550	550	300	0,215447
20	550	1450	550	550	300	0,317073
21	550	550	-350[a]	550	300	0,235772
22	550	550	1450	550	300	0,764227
23	550	550	550	-350[a]	300	0,357723
24	550	550	550	1450	300	0,520325
25	550	550	550	550	-100[a]	0,000000
26	550	550	550	550	700	0,455284
27	550	550	550	550	300	0,195122
28	550	550	550	550	300	0,296748
29	550	550	550	550	300	0,032520
30	550	550	550	550	300	0,276422
31	550	550	550	550	300	0,296748
32	550	550	550	550	300	0,276422

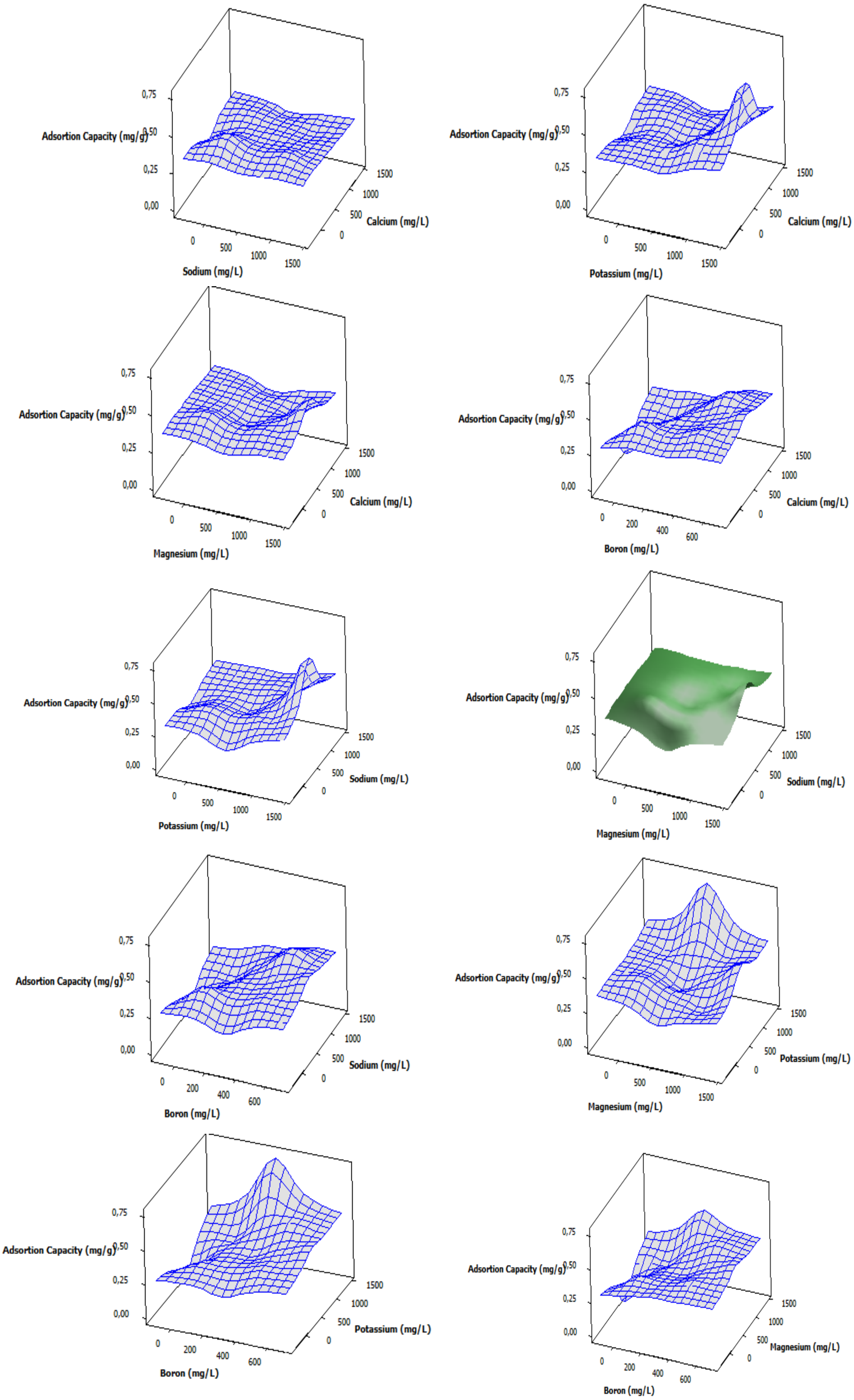

Figure 1: Surface plots for cation effect.

Table 3: Anova analysis results for cation effect.

Term	Constant	t-value	p-value
Constant	0.71112	3.664	**0,004**
Ca	-0.000173	-0.737	0.477
Na	-0.000335	-1.426	0.182
K	-0.000403	-1.719	0.114
Mg	-0,000568	-2.421	**0.034**
Boron	-0.000910	-1.654	0.126
Ca*Ca	0.000000	0.305	0.766
Na*Na	0.000000	0.199	0.846
K*K	0.000000	2.644	**0.023**
Mg*Mg	0.000000	2.006	0.070
Boron* Boron	-0.000000	-0.205	0.841
Ca*Na	-0.000000	-0.079	0.939
Ca*K	-0.000000	-1.570	0.145
Ca*Mg	-0.000000	-0.314	0.759
Ca*Boron	0.000001	1.963	0.075
Na*K	0.000000	0.314	0.759
Na*Mg	0.000000	0.314	0.759
Na*Boron	0.000001	2.277	**0.044**
K*Mg	0.000000	1.492	0.164
K*Boron	0.000001	1.413	0.185
Mg*Boron	0.000001	1.570	0.145

Table 4: Soil-clay mixture effect (Temperature 30 °C, 200 rpm, Natural pH, Total soil-clay mixture weight 2.5 g, volume 25 mL, Boron 500 mg/L).

Run	Clinoptilolite (g)	Montmorillonite (g)	Kaolinite (g)	Experimental Capacity (mg/g)
1	0.25	0.25	0.50	0.86865
2	0.38	0.38	0.38	0.29661
3	0.38	0.16	0.38	0.63559
4	0.38	0.38	0.38	0.50848
5	0.16	0.38	0.38	1.08051
6	0.38	0.38	0.38	0.86865
7	0.25	0.50	0.50	0.44492
8	0.38	0.59	0.38	0.84746
9	0.38	0.38	0.38	0.46610
10	0.38	0.38	0.59	0.84746
11	0.50	0.50	0.25	0.80509
12	0.38	0.38	0.38	0.46610
13	0.50	0.25	0.25	0.46610
14	0.38	0.38	0.16	0.63559
15	0.25	0.50	0.25	0.76271
16	0.50	0.50	0.50	0.67797
17	0.38	0.38	0.38	0.88983
18	0.59	0.38	0.38	0.63559
19	0.50	0.25	0.50	0.76271
20	0.25	0.25	0.25	0.72034

Table 5: Anova analysis for clay-soil mixture.

Constant	Constant	t-value	p-value
Constant	2.0375	1.435	0,182
Clinop.	-6.9253	-1.983	0.076
Montm.	-0.8328	-0.238	0.816
Kaol.	0.1357	0.039	0.970
Clinop*Clinop	4.7264	1.434	0.182
Montm*Montm	2.2688	0.688	0.507
Kaol.*Kaol.	2.2760	0.690	0.506
Clinop.*Montm.	5.0349	1.102	0.296
Clinop.*Kaol.	2.6464	0.579	0.575
Montm.*Kaol.	-6.9640	-1.524	0.158

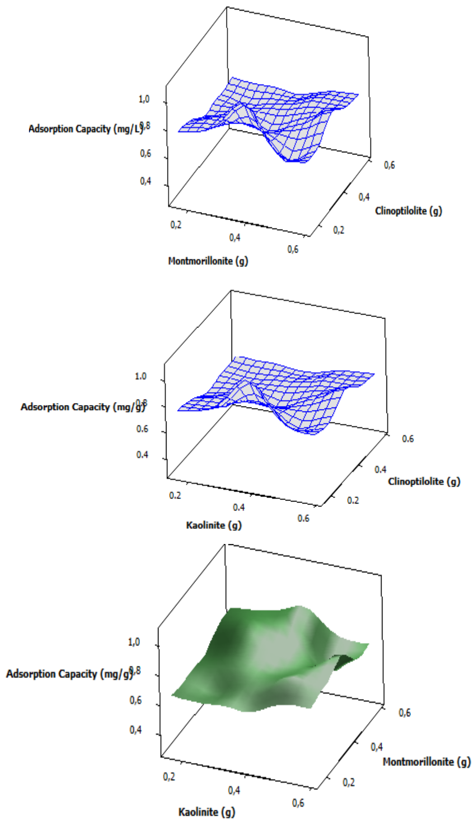

Figure 2: Surface plots for clay effect.

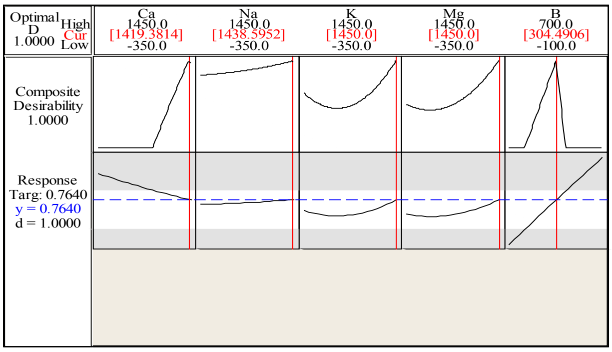

Figure 3: Optimizer graph of irrigation water cations.

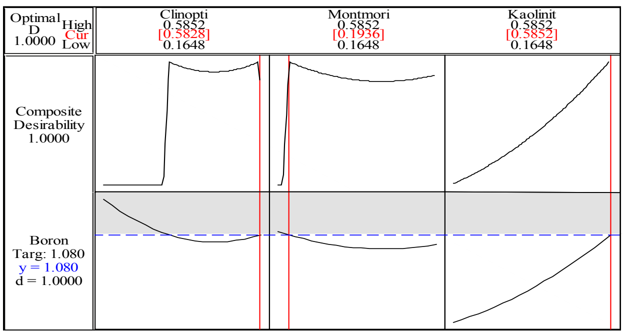

Figure 4: Optimizer graph of clay effect.

Celal Bayar University Journal of Science
Volume 18, Issue 3, 2022, p 239-247
Doi:10.18466/cbayarfbe.961739

The regression models for cation effect and clay effect were given as follows:

Capacity (mg/g) (Cation effect)= 0.71112-0.000173*Ca–0.000335*Na– 0.000403*K-0,000568*Mg– 0.000910*Boron+0.000000*Ca*Ca+0.000000*Na*Na+0.000000*K*K+0.000000*Mg*Mg-0.000000*Boron*Boron-0.000000*Ca*Na-0.000000*Ca*K-0.000000*Ca*Mg+0,000001*Ca*Boron+0.000000*Na*K+0.000000*Na*Mg+0.000001*Na*Boron+0.000000*K*Mg+0.000001* K*Boron + 0.000001*Mg*Boron

Capacity (mg/g) (Clay effect)=2.0375–6.9253*Clinop-0.8328*Montm + 0.1357*Kaol + 4.7264*Clinop*Clinop + 2.2688*Montm*Montm + 2.2760*Kaol*Kaol + 5.0349*Clinop*Montm + 2.6464*Clinop*Kaol–6.9640*Montm*Kaol

The comparison of model and experimental values were given in Table 6 and estimations were distorted some degree.

Table 6: Comparison of experimental and model responses.

Run	Cation Exp. Value (mg/g)	Cation Model Value (mg/g)	Clay Exp. Value (mg/g)	Clay Model Value (mg/g)
1	0.284552	0.30822	0.86865	0.947006
2	0.491870	0.44652	0.29661	0.583327
3	0.369919	0.30072	0.63559	0.658283
4	0.487804	0.75102	0.50848	0.583327
5	0.512195	0.23952	1.08051	0.90324
6	0.325203	0.68982	0.86865	0.583327
7	0.487804	0.54402	0.44492	0.608388
8	0.004065	-0.03768	0.84746	0.716652
9	0.349593	0.09102	0.46610	0.583327
10	0.345528	0.54132	0.84746	0.730901
11	0.345528	0.39552	0.80509	0.80245
12	0.004065	-0.18618	0.46610	0.583327
13	0.528455	0.33432	0.46610	0.391138
14	0.105691	-0.24738	0.63559	0.644036
15	0.308943	-0.39318	0.76271	0.852813
16	0.569105	0.77712	0.67797	0.723425
17	0.317073	0.17037	0.88983	0.583327
18	0.235772	0.39897	0.63559	0.70475
19	0.215447	0.31617	0.76271	0.747363
20	0.317073	0.25317	0.72034	0.756181
21	0.235772	0.37737		
22	0.764227	0.19197		
23	0.357723	0.52587		
24	0.520325	0.04347		
25	0.000000	-0.23133		
26	0.455284	0.80067		
27	0.195122	0.28467		
28	0.296748	0.28467		
29	0.032520	0.28467		
30	0.276422	0.28467		
31	0.296748	0.28467		
32	0.276422	0.28467		

3.2 Phytoremediation of boron from lime soil by potato plant

Boron phytoremediation from borated-lime soils containing 3.56, 13.56, 23.56, 33.56, 43.56, 53.56, 103.56, 203.56, 303.56, and 403.56 mg/kg boron was studied using potato plant growing May, June and July months in the 2018 year. Generally, the potato plants remained short at high concentration and the plantation did not occur at high concentrations (203.56, 303.56, 403.56 mg/kg concentrations). The boron uptake profile of potato plant is given in Figure 5. As can be seen in Figure 5, the maximum boron uptake was obtained at 103.56 mg/kg concentration as 2,304.8 mg/kg plant. The boron uptake capacities of plants were 406.5, 952.8, 729.5, 241.3, 180.2, 2058.8, 2304.8 mg/kg plant for 3.56, 13.56, 23.56, 33.56, 43.56, 53.56, 103.56 mg/kg soil boron concentrations. The raw soil had 3.56 mg/kg boron concentration. The dry weights of potato plants were 5.78, 3.60, 6.34, 4.94, 4.88, 2.86, 2.92 g for 3.56, 13.56, 23.56, 33.56, 43.56, 53.56, 103.56 mg/kg soil boron concentrations. The dried weights of the green potato plants were given in Figure 6. The borated potato plants were dried during three months at room temperature at subsequent months after plant dieing and the plants were retended in bucket for drying.

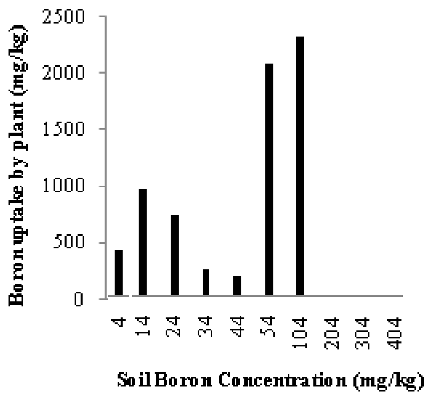

Figure 5: Boron phytoremediation by potato plant.

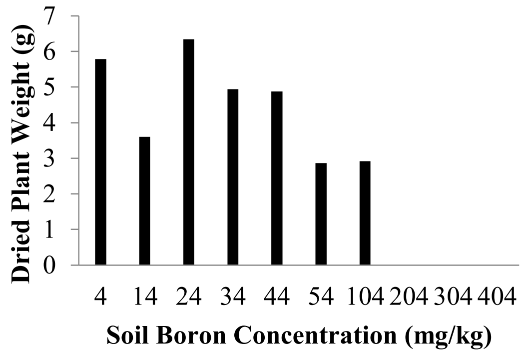

Figure 6: Dry weights of potato plants after phytoremediation.

4. Conclusions

Boron adsorption from solution onto lime soil under cations effect and soil clay effect was studied. The cations were calcium, magnesium, sodium and potassium. The clays mixed with soil were montmorillonite, clinoptilolite and kaolinite. Also, the borated soils were phytoremediated with potato plant. The results of the study can be summarized as follows. Boron adsorption onto soil under cation effect increased with increasing cation concentration and moderate boron concentration (around 300 mg/L). Maximum boron adsorption capacity of the soil under cation effect was calculated as 0.764 mg/g. The reason of the increase of soil boron capacity was increasing surface zeta potential of soil at high cation effects. The optimum clay amounts for 1.08 mg/g boron adsorption were calculated from optimizer graph as 0.5828 g clinoptilolite, 0.1936 g montmorillonite, 0.5852 g kaolinite for 2.5 g soil-clay mixture. The targeted value of cation effect (0.764 mg/g) from optimization graph was obtained for 1419.3814 mg/L calcium, 1438.5952 mg/L sodium, 1450 mg/L potassium,1450 mg/L magnesium, and 304.4906 mg/L boron. The phytoremediation studies by potato plant were carried out at 3.56, 13.56, 23.56, 33.56, 43.56, 53.56, 103.56, 203.56, 303.56, 403.56 mg/kg boron concentration. The raw soil had 3.56 mg/kg boron concentration. The boron uptake capacities of plants were 406.5, 952.8, 729.5, 241.3, 180.2, 2058.8, 2304.8 mg/kg plant for 3.56, 13.56, 23.56, 33.56, 43.56, 53.56, 103.56, mg/kg soil boron concentrations. The dry weights of potato plants were 5.78, 3.60, 6.34, 4.94, 4.88, 2.86, 2.92 g for 3.56, 13.56, 23.56, 33.56, 43.56, 53.56, 103.56 mg/kg soil boron concentrations. The potato plant did not grow at 203.56, 303.56, 403.56 mg/kg boron concentrations. The potato plant was found as effective for phytoremediation of boron from lime soils. The plant dry weights decreased by increasing soil boron concentration and the potato plants did not grow at 203.56, 303.56, 403.56 mg/kg boron concentrations exhibiting toxic effects for potato plant.

Acknowledgement

The authors are grateful for financial support of Balıkesir University Scientific Research Project Department.

Author's Contributions

Mustafa Korkmaz: Performed the experiments, result analysis and manuscript preparation.
Cengiz Özmetin: Helped in result analysis.
Yeliz Süzen: Helped in result analysis.
Atilla Mutlu: Helped in experimental starting.

Ethics

There are no ethical issues after the publication of this manuscript.

References

[1] Tariq, M, and Mott, C.J.B. 2007. The significance of boron in plant nutrition and environment-a review. *Journal of Agronomy*; 6 (1):1-10.

[2] Chaudhary, D.R, Shukla, L.M, and Gupta, A. 2005. Boron equilibria in soil-a review. *Agricultural Reviews*; 26(4):288-294.

[3] Başcı, N. 2009. Cr (VI) iyonunun süs bitkileri kullanarak topraktan gideriminin araştırılması. Çukurova Universitesi, Yüksek Lisans Tezi, Adana, Turkiye (In Turkish).

[4] Reynaldo, L, Alleoni, F, Antonio Decamargo, O. 2000. Boron adsorption in soils from the state of sao Paulo, Brazil. *Pesquisa Agropecuária Brasileira*; (35) 2:413-421.

[5] Arora, S, Chahal, D.S. 2010. Effect of soil properties on boron adsorption and release in arid and semi-arid benchmark soils. *Communications in Soil Science and Plant Analysis*; 41:2532–2544.

[6] Goldberg, S. 1997. Reactions of boron with soils. *Plant and Soil*; 193:35–48.

[7] Memişoğlu, B.A. 2008. Bor ile kirletilmiş toprakların yeşil ıslah (Phytoremediation) yöntemi ile arıtılması. . Ataturk Üniversitesi, Doktora Tezi, Erzurum,Turkey (In Turkish).

[8] Böcük, H, Türe, C. 2014. Phytoremediation possibilities of boron contaminated environments by wild plants growing on boron reserve areas in Turkey. *Communications in Soil Science and Plant Analysis*; 45:1784–1798.

[9] Rees, R, Robinson, B.H, Menon, M, Lehmann, E, Guunthardt-Goerg, M.S, and Schulin R. 2011. Boron accumulation and toxicity in hybrid poplar (Populus nigra euramericana). *Environmental Science and Technology*; 45:10538–10543.

[10] Fil, B.A. 2007. Montmorillonitin tekstil boyar maddesi (metilen mavisi) gideriminde kullanımının araştırılması, Balıkesir Universitesi, Yüksek Lisans Tezi, Balıkesir, Turkey (In Turkish).

[11] Korkmaz, M, Özmetin, C, Fil, B.A, Özmetin, E,Yaşar, Y. 2013. Methyl violete dye adsorption onto clinoptilolite (natural zeolite): isotherm and kinetic study. *Fresenius Environmental Bulletin*; 22: 1524-1533.

[12] Bayülken, S, Başçetin, E, Güçlü, K, Apak, R. 2011. Investigation and modeling of cesium(I) adsorption by Turkish clays: Bentonite, zeolite, sepiolite, and kaolinite. *Environmental Progress & Sustainable Energy*; 30:70-80.

[13] Korkmaz, M, Özmetin, C, Özmetin, E, Süzen, Y. 2020. Modelling of boron removal from solutions by ion exchange for column reactor design in boron mine wastewater treatment. *Desalination and Water Treatment*; 179:63–74.

[14] Clesceri, F.S, Greenberg, A.E, Eaton, A.D. 1999.Standard Methods for the Examination of Water and Wastewater, 20th edition, Water Environment Federation: American Water Works Association, Washington, DC, USA.

[15] Aprile, F, Lorandi, R. 2012. Evaluation of cation exchange capacity (CEC) in tropical soils using four different analytical methods. *Journal of Agricultural Science*; 4(6):278-289.

[16] Turan, M.D, Altundoğan, H.S, 2011. Hidrometallurjik araştırmalarda yanıt yüzey yöntemlerinin (YYY) kullanımı. Madencilik; 50 (3): 11–23 (In Turkish).

[17] Korkmaz, M, Fil, B.A, Özmetin, C, Yaşar, Y. 2014. Full factorial design of experiments for boron removal from colemanite mine wastewater using Purolite S 108 resin. *Bulgarian Chemical Communucation*; 46:594–601.