



Article

Growth and K Nutrition of Sesame (*Sesamum indicum* L.) Seedlings as Affected by Balancing Soil Exchangeable Cations Ca, Mg, and K of Continuously Monocropped Soil from Upland Fields Converted Paddy

Cosmas Wacal ¹, Naoki Ogata ², Daniel Basalirwa ¹, Daisuke Sasagawa ¹, Tsugiyuki Masunaga ³, Sadahiro Yamamoto ⁴ and Eiji Nishihara ^{4,*}

¹ United Graduate School of Agricultural Sciences, Tottori University, 4-101 Koyama Minami, Tottori 680-8553, Japan; cwacal@gmail.com (C.W.); danielbasalirwa@gmail.com (D.B.); ssgw2653.02.06@gmail.com (D.S.)

² National Institute of Crop Science, National Agriculture and Food Research Organization (NARO), 2-1-2 Kannondai, Tsukuba, Ibaraki 305-8518, Japan; naokio@affrc.go.jp

³ Faculty of Life and Environmental Sciences, Shimane University, Matsue, Shimane 690-8504, Japan; masunaga@life.shimane-u.ac.jp

⁴ Faculty of Agriculture, Tottori University, 4-101 Koyama Minami, Tottori 680-8553, Japan; yamasada@tottori-u.ac.jp

* Correspondence: nishihar@tottori-u.ac.jp; Tel.: +81-(0)857-31-5385

Received: 5 September 2019; Accepted: 25 November 2019; Published: 29 November 2019



Abstract: Growth of sesame is known to be limited by poor K nutrition as a result of imbalance in soil exchangeable cations that cause a competitive ion effect in continuous monocropping from upland fields converted paddy. We hypothesized that balancing soil exchangeable cations will improve the K nutrition and growth of sesame plants. Therefore, the specific objectives of this study were to determine the effect of balancing soil exchangeable cations Ca, Mg, and K of continuously monocropped soils on the growth and cation uptake of sesame seedlings and also identify a suitable source of nutrients for improving K nutrition. A pot experiment was conducted under greenhouse condition in a 3 × 3 factorial design consisting of three levels of balancing treatments i.e. inorganic fertilizer for Ca, Mg, and K, rice husk biochar to increase K content, and the three durations of continuous monocropping soils of one year, two years, and four years from upland fields converted paddy. Balancing soil exchangeable cations was aimed at achieving optimal base saturations (CaO, 75%; MgO, 25%; and K₂O, 10%). Results showed that balancing exchangeable cations did not significantly affect growth and cation uptake in the one and two-year soils but significant effect was observed in the four-year soil. Overall, plant height and dry weight increased for the balancing treatments of inorganic fertilizer K and rice husk biochar. Balancing exchangeable cations with biochar was more beneficial than with inorganic fertilizers. The four-year soil's growth increase was attributed to an increase in K concentration and uptake due to the decrease in the soil Ca/K and Mg/K ratios to that of acceptable levels, which eliminated competitive ion effect as the soil K saturation increased above 5.0%, enhancing sesame growth. Therefore, a balanced soil exchangeable Ca, Mg, and K that eliminates a competitive ion effect will improve sesame growth and K nutrition although future research should focus on ensuring balanced cation ratios under field conditions in continuous monocropping.

Keywords: cation imbalance; plant height; growth; uptake of K; inorganic fertilizer; rice husk biochar; competitive ion effect

1. Introduction

Sesame (*Sesamum indicum* L.) is an important oilseed crop that is cultivated worldwide [1]. However, the productivity of sesame depends on the availability of adequate mineral nutrients such as N, P, and K that are applied as fertilizer [2]. For instance, the seed yield of sesame can increase by supplying adequate K in soil, which was initially low in K [3]. Therefore, potassium (K) is one of the key nutrients required for sesame productivity. It is known that potassium is a monovalent cation essential for the growth of higher plants and protein synthesis and is also the most abundant cation in plant tissues and plays an important role in various physiological and biochemical processes, including photosynthesis [4,5]. The availability of K is affected by several factors. Usually, K nutrition in plants is affected by the balance of both calcium (Ca) and magnesium (Mg). According to Bergmann [6], the Mg/K ratio in soil is very important for the uptake of mineral nutrients by plants because excess concentrations of one can negatively influence plant growth. Moreover, Loide [7] reported that the incorrect use of lime fertilizers alters Ca/Mg and Mg/K ratios, which is detrimental to plants as it decreases yields. Therefore, it is important to maintain the balance of soil cations for crops that show poor growth due to imbalances.

Sesame requires high concentration of K in the tissue, between 1.5% to 2.4%, and low K in the soil can cause poor growth [8]. However, our previous study reported that sesame growth is limited by poor K nutrition as a result of an imbalance in soil exchangeable cations that cause a competitive ion effect on continuous monocropping from upland fields converted paddy in Japan [9]. The decrease in the leaf tissue K content, and consequently its uptake, was attributed to an increase in soil exchangeable Ca and Mg in the long duration of continuous monocropping for four to six years, which caused a competitive ionic effect in the soil, thus negatively influencing the growth and yield. Moreover, the cation ratio of Ca/K and Mg/K significantly increased, leading to a relatively higher ratio of both Mg/K and Ca/K in the sesame leaf tissues, thus suggesting low content of K in the plant. Furthermore, Hannan [10] reported that an excess of Mg could cause a K deficiency in grapevine plants at a ratio of K/Mg < 0.30 in soil. These studies suggested that care should be taken while supplying a high amount of Ca and Mg in soil in order to avoid ionic imbalances in plants.

The imbalances in soil exchangeable cations indicated by their abnormal ratios could be corrected through increasing the concentration of the limiting nutrient so as to raise the base saturation percentages to optimal ranges [11]. Hodges [11] suggests that the ideal base saturations should be about 65% Ca, 10% Mg, and 5% K, resulting in the ratios of Ca/K as 13, Ca/Mg as 6.5, and Ca/Mg as 2, with any deviations in one could cause a deficiency of another. Therefore, balancing the soil exchangeable cations and their ratios through adding more nutrients could be important in correcting any deficiencies of one cation. For instance, increasing the concentration of K in soil which was limited by high exchangeable Mg content, leads to improved cotton growth [12]. Furthermore, high yields of annual grass were achieved with soil exchangeable sites occupied by 50–60% of Ca, 8–12% by Mg, and 4–5% by K, which improved the uptake of K [13]. Although imbalances in soil exchangeable cations Ca, Mg, and K has been reported to negatively influence sesame growth on an upland field converted paddy under continuous monocropping, the effect of balancing these to improve K nutrition and the growth of sesame is still unknown.

To balance soil exchangeable cations, additional nutrients from inorganic fertilizers (Ca, Mg, and K) is required to supply adequate soil exchangeable Ca, Mg, and K in continuously monocropped soil. Other organic materials such as biochar could be used to increase the availability of these soil nutrients [14]. Biochar is a soil amendment produced from thermal degradation of organic materials through the process of pyrolysis and can supply a high amount of potassium [14,15]. Recently, we reported that rice husk biochar improved sesame growth through increasing soil exchangeable K and improving K nutrition on an upland field converted paddy in Japan [16]. However, there is lack of information on the use of biochar material and inorganic fertilizers to balance soil exchangeable cations in deteriorated soils from continuous monocropping fields.

In this study, we hypothesized that balancing soil exchangeable cations will improve the K nutrition of sesame plants. Therefore, the specific objectives of this study were to determine the effect of balancing soil exchangeable cations Ca, Mg, and K of different durations of continuous monocropping years (one, two, and four years) from an upland field converted paddy on the growth and cation uptake of sesame seedlings as well as to identify a suitable source of nutrients for improving K nutrition. It is important to understand the effect of balancing soil exchangeable cations Ca, Mg and K on K nutrition and growth in order to design nutrient management strategies that eliminate cation imbalances so as to improve sesame production under the continuous monocropping on upland fields converted paddies in Japan.

2. Materials and Methods

2.1. Soil Collection and Preparation

Soil from continuously monocropped sesame fields were collected from Tottori (35°29'14.85" N, 134°07'47.01" E), Japan on 6 May 2017. The collected samples were dug at a depth of 0–15 cm in the rhizosphere soils that had been continuously monocropped for 1 year (1-year, soil used to crop sesame for the last 1 year), 2 years (2-year, soil used to crop sesame for the last 2 years), and 4 years (4-year, soil used to crop sesame for the last 4 years). The soil samples were air dried, after removing all impurities, crushed and sieved through a 2 mm mesh before being used in the experiment.

2.2. Balancing Soil Cations

The collected soil samples from continuous monocropping fields were analyzed for exchangeable cations prior to balancing treatments (Table 1).

Table 1. Soil chemical properties of the different continuously monocropping soils (one, two, and four years) before the experiment.

Year	K (mg kg ⁻¹)	Ca (mg kg ⁻¹)	Mg (mg kg ⁻¹)
1	171.4	1143	244.0
2	142.7	1432	320.3
4	114.1	1645	323.0

The analysis of soil exchangeable cations indicated high exchangeable K in the 1-year soil compared to the 2- and 4-years whereas exchangeable Ca and Mg were high in the 2- and 4-year cropping soils compared to the 1-year soil which necessitated balancing soil exchangeable cation. According to Table 1, the exchangeable cation ratios in the 1-year soils were: 6.7, 1.4, and 4.7 for Ca/K, Mg/K, and Ca/Mg respectively. In the 2-year soils they were: 10.0, 2.3, and 4.5 for Ca/K, Mg/K, and Ca/Mg respectively. In the 4-year soils the ratios were: 14.6, 2.9 and 5.1 for Ca/K, Mg/K and Ca/Mg. This showed that the Ca/K and Mg/K ratios were higher than the acceptable range [11]. Therefore, balancing the exchangeable cations aimed to achieve optimal base saturations (CaO, 75%; MgO, 25%, and K₂O, 10%) to decrease the wide Ca/K and Mg/K ratios. In order to balance the soil exchangeable cation ratios, the soil cation exchange capacity (CEC) of each duration of continuous monocropping soil was determined and the formulae below was used to calculate the deficit or surplus of each exchangeable cation. However, the individual exchangeable cation was converted into the oxide to ease calculations, i.e. Ca to CaO, Mg to MgO, and K to K₂O and kg 10a⁻¹ was used instead of kg ha⁻¹.

Formulae: CaO in kg 10a⁻¹ =

$$\left(\left(\left(\frac{CEC \times optimal}{100} \right) \times 28 \right) - CaO \text{ in } \frac{mg}{100 \text{ g}} \right) \times prov. \text{ specific gravity} \times \frac{soil \text{ depth}}{10} \text{ cm} \quad (1)$$

K_2O in $kg\ 10a^{-1}$ =

$$\left(\left(\left(\frac{CEC \times optimal}{100} \right) \times 47 \right) - K_2O\ in\ \frac{mg}{100\ g} \right) \times prov.\ specific\ gravity \times \frac{soil\ depth}{10}\ cm \quad (2)$$

MgO in $kg\ 10a^{-1}$ =

$$\left(\left(\left(\frac{CEC \times optimal}{100} \right) \times 20 \right) - MgO\ in\ \frac{mg}{100\ g} \right) \times prov.\ specific\ gravity \times \frac{soil\ depth}{10}\ cm \quad (3)$$

where, optimal = optimal base saturations and prov. specific gravity = provisional specific gravity of soil. Please note that the optimal base saturations were CaO = 75%, MgO = 25%, and K_2O = 10%. CaO meq = 28, MgO meq = 20, K_2O meq = 47, 10a = 1000 m^2 , and 1 ha = 10,000 m^2 . Provisional specific gravity = 1.2 and soil depth = 15 cm. Any values in negative were considered a surplus.

The calculated deficient or surplus in Table 2 were then converted to mg/100g of soil considering 1 ha = 1,800,000,000 g of soil (Table 3). CaO was deficient by 28.9, and 8.22 mg/100g in the 1-year and 4-year soils respectively, whereas MgO was deficient by 4.35 and 2.96 mg/100g in the 1-year and 4-year soils respectively. K_2O was deficient by 21.7, 25.3, and 39.6 mg/100g in the 1-year, 2-year, and 4-year soils respectively. These values were further converted into mg/pot (filled with 740 g dry soil).

Table 2. Soil cation exchange capacity (CEC), cation oxides, and calculated deficient or surplus amount of each soil exchangeable cation for different duration of continuous monocropping soils of one, two, and four years.

Year	CEC ($cmol_c\ kg^{-1}$)	mg/100 g Soil			Deficit or Surplus					
		CaO	MgO	K_2O	(kg $10a^{-1}$)			(kg ha^{-1})		
					CaO	MgO	K_2O	CaO	MgO	K_2O
1	9.00	160	40.7	20.6	52	7.82	39.0	521	78.2	390
2	9.04	201	53.4	17.2	-19	-14.7	45.5	-192	-147	455
4	11.4	230	53.8	13.7	15	5.33	71.3	148	53.3	713

Negative = surplus (excess) and therefore no additional nutrients required, 10a = 1000 m^2 , 1 ha = 10,000 m^2 .

Table 3. Calculated fertilizer in mg/100g dry soil and mg of cation per pot in the different duration of continuous monocropping soils.

Year	(mg/100g DW Soil)			mg/pot (740 g DW Soil)		
	CaO	MgO	K_2O	CaO	MgO	K_2O
1	28.9	4.35	21.7	214.1	32.2	160.3
2	-10.7	-8.18	25.3	-78.8	-60.6	187.2
4	8.22	2.96	39.6	60.8	21.9	293.3

Negative = surplus (excess) and therefore no additional nutrients required.

Therefore, in the 1-year soil, 214.1 mg of CaO was added from quick lime (70%, CaO) and in the 4-year soil, 60.8 mg of CaO was added from the quick lime into each pot. In the 1-year soil, 32.2 mg of MgO from the inorganic magnesium fertilizer (60%, MgO) was added and 21.9 mg of MgO was added into the 4-year soil. The 2-year soil did not require additional CaO since it showed a surplus (Table 3). To balance the K, 160.3, 187.2, and 293.3 mg of K_2O were added from muriate of potash (60%, KCl) into the 1-, 2-, and 4-year soils respectively in each pot. Additionally, the rice husk biochar was used to compare balancing with the biochar and fertilizer, muriate of potash. The rice husk biochar had a pH (1:5 water) of 10.5; the EC (1:5 water) was 1.66 $dS\ m^{-1}$; the C, N, and C/N ratio were 39.8%, 0.51%, and 78.3, respectively; the available P (Truog-P) was 647.9 $mg\ kg^{-1}$; the exchangeable K was 3640.7 $mg\ kg^{-1}$; the exchangeable Ca was 1207.8 $mg\ kg^{-1}$; the exchangeable Mg was 369.3 $mg\ kg^{-1}$.

For the biochar addition, to balance the soil exchangeable K (supplemental K), 36.5 g, 42.7 g, and 66.9 g respectively were added to the rice husk biochar. These amounts of biochar were equivalent to the deficient K in Table 3. There was no additional K from KCl added into the biochar treatment to balance the soil exchangeable cations. The treatments for balancing soil exchangeable cations are therein referred to as the control (unbalanced soil), exchangeable cations balanced with inorganic fertilizer (CaO and K₂O) referred to as fertilizer and the exchangeable K added from the biochar addition.

2.3. Experiment Design, Sesame Cultivation, and Growth Determination

The experiment was set up in a 3 × 3 factorial design consisting of three levels of balancing treatments and 3 types of soils collected from different durations of continuous monocropping years (1-year, 2-years, and 4-years), laid out in a randomized block design with 3 replicates under greenhouse condition at Tottori University, Japan. All pots had basal inorganic fertilizer N-P₂O₅-K₂O of 70–105–70 kg ha⁻¹ in the combination of both the cyclo-diurea (CDU) compound fertilizer (15%-15%-15%) and triple superphosphate (34%). The control treatment of each continuously monocropped soil received 1000 kg ha⁻¹ of dolomite following the normal practice in continuous monocropping of sesame. Sesame cultivar ‘Maruhime’ was sown on the 8 September 2017. All pots were watered twice a day, maintaining a relative moisture content of 60%. At 40 days after sowing, the sesame plants were sampled (17 October 2017). Prior to sampling, the plant heights and leaf chlorophyll content, expressed as SPAD values measured using a chlorophyll meter (SPAD-502, Minolta Co. Ltd, Osaka, Japan), were determined on 16 October 2017. Fresh weight was also determined after harvest and plant samples were oven dried at 72 °C for one week until the plants attained a constant dry weight and the dry weight was determined.

2.4. Plant and Soil Analysis

2.4.1. Plant K, Ca, and Mg Concentration and Uptake in Sesame Plants

All sesame plant samples were oven dried at 72 °C until a constant weight was attained (after one week). Samples were then ground to a fine powder and digested in a mixture of concentrated H₂SO₄ (98%) and H₂O₂ (30%). The plant K, Ca, and Mg concentration in the solution after digestion was determined by using an atomic absorption spectrophotometer with known standards (Model Z-2300, Hitachi Co., Tokyo, Japan). The nutrient uptake was calculated from the concentration and the dry weight of each sesame plant in the treatment.

2.4.2. Soil Exchangeable Cations and Cation Exchange Capacity (CEC)

After the removal of the plants from each pot, soil samples were air-dried, crushed, and all residues removed and sieved through a 2 mm sieve and then stored for analysis. Soil exchangeable K, Ca, and Mg were extracted in a 1 N ammonium acetate (pH 7.1) and analyzed by using an atomic absorption spectrophotometer (Model Z-2300, Hitachi Co., Tokyo, Japan). The cation exchange capacity (CEC) was measured by the 1 N (pH 7.1) ammonium acetate (NH₄OAc) extraction methods in which the NH₄⁺ saturated soil was equilibrated with 10% KCl and steam distilled by micro-kjeldahl distillation before titration with 0.1 N H₂SO₄ [17] and expressed to cmol_c kg⁻¹ soil.

The soil base saturations were calculated as the sum of Ca²⁺, Mg²⁺, and K⁺. The Na⁺ measurements were not considered in the calculation of the base saturation because of very low concentrations (< 1% of the CEC). The exchangeable base saturations were calculated as in Equation 4.

Exchangeable base saturation percentage =

$$\frac{\text{Exchangeable cation}}{\text{CEC}} \times 100 \quad (4)$$

2.5. Statistical Analysis

All experimental data presented are the means of three replicates. All data were analyzed using ANOVA using SPSS version 22.0 (SPSS for Windows Inc., Chicago, IL, USA). Tukey's multiple comparison test at $p < 0.05$ was used to compare means. When considering the differences between the duration of continuously monocropped soils, a two-way analysis of variance was used with the different balancing treatments (T) and duration of continuous monocropping years (Y) considered as two fixed factors.

3. Results

3.1. Effect of Balancing Soil Exchangeable Cations on the Fresh Weight, SPAD Value, Plant Height, and Dry Weight of Sesame Seedlings

The effect of balancing soil exchangeable cations (treatments) and the different duration of continuous monocropping soils (years) was significant on the mean fresh weight (Table 4). Although the fresh, dry weight, and plant height was significantly lower in the four-year soils compared to the one-year soil, adding more K fertilizer and rice husk biochar to supply K while balancing soil exchangeable cations significantly improved the fresh and dry weight, with the positive effect being more pronounced in the four-year than in the one- and two-years soils (Figures 1 and 2).

Table 4. The SPAD value and fresh weight of sesame plants under the different balancing treatments in the different continuously monocropped soils of one, two, and four years.

Year	Treatment	SPAD Value	Fresh Weight (g/plant)
1	Control	47.8 a	15.4 a
	Fertilizer	40.8 a	16.0 a
	Biochar	45.4 a	17.5 a
	ANOVA (<i>p</i> values)	ns	ns
2	Control	43.1 a	14.3 a
	Fertilizer	42.5 a	15.9 a
	Biochar	41.8 a	16.2 a
	ANOVA (<i>p</i> values)	ns	ns
4	Control	41.6 a	10.0 b
	Fertilizer	42.3 a	13.5 ab
	Biochar	44.0 a	15.5 a
	ANOVA (<i>p</i> values)	ns	*
Source of variation			
	Treatment (T)	ns	*
	Year (Y)	ns	*
	Y × T	ns	ns

Data represent means of three replicates ($n = 3$). Year represents the duration of continuous monocropping soil. Means followed by a different value within a column in the same year are significantly different at $p < 0.05$ according to Tukey's test. * Significant at $p < 0.05$; ns: Non-significant.

The plant height, fresh weight, and dry weight was higher by 24.1%, 35.6%, and 40.4% respectively for the biochar addition (rice husk biochar) compared to the control, whereas the plant height, fresh weight, and dry weight was higher by 18.1%, 25.9%, and 17.8% respectively in the fertilizer balancing treatment. This suggests that balancing soil exchangeable cation, K with biochar was more beneficial than with inorganic fertilizers (fertilizer treatment) in the four-year soils (Figures 1 and 2). There were no significant differences in balancing soil exchangeable cations between the biochar and fertilizer. In addition, the SPAD value was not affected by the cation balancing treatments. Overall, the balancing of soil exchangeable cations did not significantly (statistically) improve growth in the one- and two-year duration of continuous monocropping soils. In addition, there was no significant effect of the

duration of continuous monocropping soils (cropping) on the plant height although the growth was non-significantly lower in the four-year compared to the one-year soils as evidenced in the dry weight.

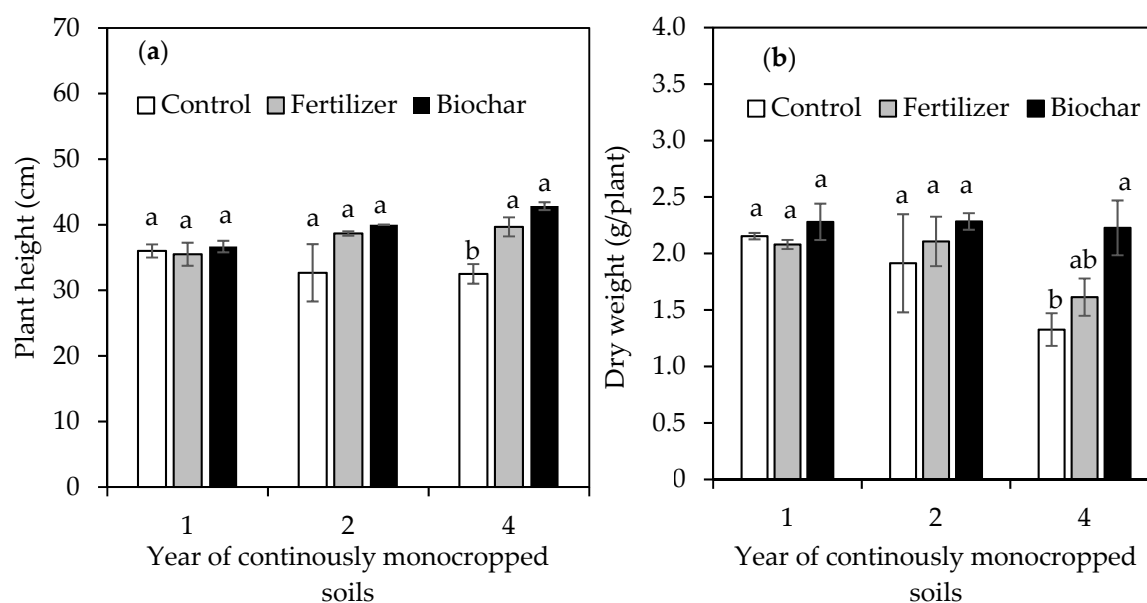


Figure 1. (a) Plant height and (b) dry weight per plant of sesame plants as affected by the balancing of soil cation imbalance with inorganic adjustment and biochar addition. The error bars represent standard error ($n = 3$). Different letters within each column are significantly different at $p < 0.05$ at Tukey's test.

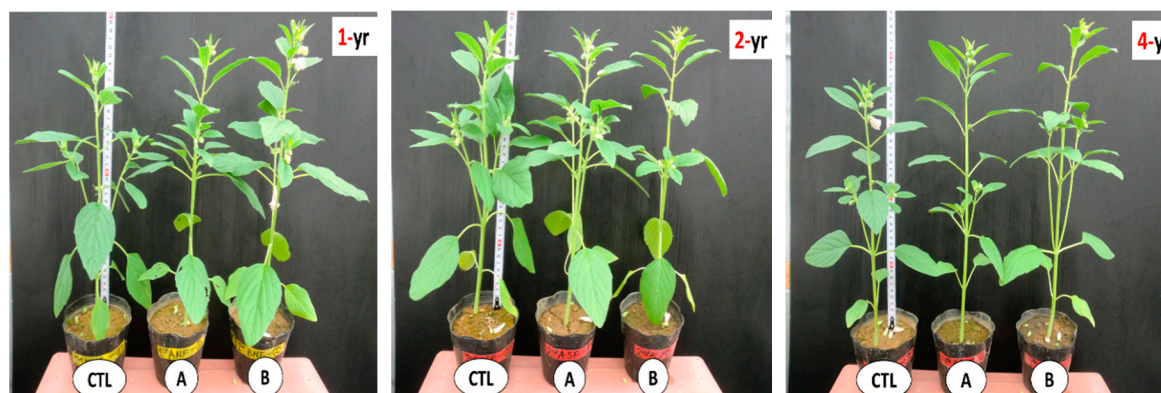


Figure 2. Plant heights of sesame plants in the one-, two-, and four-year soils after harvest as affected by amelioration of soil cation imbalance with the inorganic fertilizer and biochar addition. CTL, control; A, balanced with additional fertilizer; and B, balanced with rice husk biochar.

3.2. Effect of Balancing Soil Exchangeable Cations on the K, Ca, and Mg Concentrations and the Uptake of Sesame Seedlings

The effects of balancing soil exchangeable cations on the plant nutrient concentration of K, Ca, Mg and their uptake are shown in Table 5. In the one-yr soil, the balancing of soil exchangeable cations significantly improved K nutrition indicated by the higher concentration of K and the uptake of K in the shoot tissue from the fertilizer and biochar balancing treatments than in the control. The concentration of K was significantly higher by 29.8% in the fertilizer balancing treatment and by 22.2% in the biochar addition than the control. Similarly, the uptake of K was significantly higher by 27.3% in the fertilizer balancing treatment and by 26.7% in the biochar addition balancing, suggesting that balancing soil exchangeable significantly increased the concentration and uptake of K by the sesame plant in the one-year soil. There was no significant effect of balancing exchangeable soil cations on the plant Ca

and Mg concentrations and their uptake. In the two-year soil, the concentration of K was significantly higher by 29.7% in the fertilizer and by 19.0% in the biochar addition balancing treatments than in the control. Similarly, the uptake of K was significantly higher by 38.5% in the fertilizer balancing treatment and higher by 35.0% in the biochar balancing treatment suggesting that the balancing soil exchangeable cations significantly improved the nutrition of K by the sesame plant in the two-year soil. Conversely, the concentration of Ca was significantly lower by 1.2% and 52.8% in the fertilizer and biochar balancing treatments respectively compared to the control whereas the Ca uptake showed no significant differences among the treatments. There was no significant effect of balancing on plant Mg concentration and uptake.

Table 5. The concentrations and uptake of K, Ca, and Mg of sesame plants under the different balancing treatments in the different continuously monocropped soils of one, two, and four years.

Year	Treatment	Concentration (%)			Uptake (mg/plant)		
		K	Ca	Mg	K	Ca	Mg
1	Control	2.88 c	1.95 a	0.37 a	62.0 b	41.9 a	8.01 a
	Fertilizer	4.11 a	1.90 a	0.37 a	85.3 a	39.6 a	7.78 a
	Biochar	3.71 b	1.66 a	0.43 a	84.6 a	38.3 a	10.2 a
	ANOVA (<i>p</i> values)	***	ns	ns	*	ns	ns
2	Control	2.43 b	1.95 a	0.49 a	44.6 b	36.1 a	9.87 a
	Fertilizer	3.45 a	1.92 ab	0.35 a	72.5 a	40.2 a	7.43 a
	Biochar	3.00 ab	1.27 b	0.43 a	68.6 ab	29.4 a	9.73 a
	ANOVA (<i>p</i> values)	*	*	ns	*	ns	ns
4	Control	2.92 b	2.31 a	0.56 a	38.4 b	30.3 a	7.64 a
	Fertilizer	3.63 a	2.41 a	0.40 a	58.3 a	38.8 a	6.57 a
	Biochar	3.08 ab	1.43 b	0.36 a	67.8 a	31.2 a	8.16 a
	ANOVA (<i>p</i> values)	*	*	ns	**	ns	ns
Source of variation							
Year (Y)		***	***	ns	***	ns	ns
Treatment (T)		***	*	ns	***	ns	ns
T × Y		ns	ns	ns	ns	ns	ns

Data represent means of three replicates ($n = 3$). Year represents duration of continuous monocropping soil. Means followed by a different value within a column in the same year are significantly different at $p < 0.05$ according to Tukey's test. *** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$; ns: Non-significant.

In the four-year soil, the concentration of K was significantly higher by 19.6% and 5.4% in the fertilizer and biochar balancing treatments respectively. Similarly, the uptake of K was significantly higher by 34.2% and 43.4% in the fertilizer and biochar balancing treatments respectively compared to the control, suggesting that balancing soil exchangeable cations significantly improved the nutrition of K by the sesame plant in the two-year soil. The concentration of Ca was significantly higher by 3.9% in the fertilizer balancing treatment but was lower by 62.0% in the biochar balancing treatments compared to the control. On the other hand, the Ca uptake showed no significant differences among the treatments. In addition, there was no significant effect of soil balancing, soil exchangeable cations on the plant Mg concentration and its uptake.

Overall, the analysis of variance showed that the duration of the continuous monocropping soil (year) had a significant effect on the concentration and uptake of K indicating a lower K uptake in the four-year soil compared to the one-year soil. The analysis of variance also indicated that balancing soil exchangeable cations had a lower concentration of Ca in sesame plants compared to the control.

3.3. Effect of Balancing Soil Exchangeable Cations on the Soil Exchangeable Cations, Ratios, and Base Saturations

Balancing soil exchangeable cations significantly increased the soil exchangeable K content by 243.9 mg kg⁻¹ in the fertilizer balancing treatment and by 517.8 mg kg⁻¹ in the biochar balancing

compared to the control (Table 6). In addition, the exchangeable Ca content was higher in the fertilizer and biochar balancing treatments than the control. On the other hand, balancing soil exchangeable cations did not affect the soil exchangeable Mg content in the one-year soil. In the two-year soil, the exchangeable K content increased by 252.6 mg kg⁻¹ and 665.0 mg kg⁻¹ in the fertilizer and biochar balancing treatments compared to the control. Conversely, exchangeable Ca content was significantly lower in all the balancing treatments compared to the control with the lowest value (3302 mg kg⁻¹) in the biochar balancing treatment. Soil exchangeable Mg content was not significantly affected by all the balancing treatments. Furthermore, the exchangeable K content in the four-year soil was significantly higher in the biochar balancing (1046.3 mg kg⁻¹) than in the fertilizer balancing treatment (542.5 mg kg⁻¹) suggesting increasing K levels with the addition of biochar whereas the exchangeable Ca was significantly highest in the fertilizer balancing treatment (6386.1 mg kg⁻¹). The analysis of variance showed that the treatments and duration of continuous monocropping soils (years) affected the soil exchangeable K and Ca contents and with significant interactions indicating an increase in the exchangeable K content as and in the exchangeable Ca content decrease with balancing soil exchangeable cations. In addition, the duration of continuous monocropping soils (year) significantly decreased the exchangeable K contents while increasing the exchangeable Ca content.

Table 6. The soil chemical properties under the different balancing treatments in the different continuously monocropped soils of one, two, and four years.

Year	Treatment	Exchangeable Cations		
		K (mg kg ⁻¹)	Ca (mg kg ⁻¹)	Mg (mg kg ⁻¹)
1	Control	129.6 c	2753 b	281.7 a
	Fertilizer	373.5 b	3347 a	296.5 a
	Biochar	647.5 a	3329 a	299.4 a
	ANOVA (<i>p</i> values)	***	**	ns
2	Control	98.1 c	3921 a	352.0 a
	Fertilizer	350.7 b	3644 a	343.4 a
	Biochar	763.1 a	3302 b	331.5 a
	ANOVA (<i>p</i> values)	***	**	ns
4	Control	117.4 c	5645 a	373.5 a
	Fertilizer	542.5 b	6386 a	386.8 a
	Biochar	1046.3 a	4623 b	333.9 a
	ANOVA (<i>p</i> values)	***	**	ns
Source of variation				
Year (Y)		***	***	*
Treatment (T)		***	***	ns
T × Y		***	***	ns

Data represent means of three replicates ($n = 3$). Year represents duration of continuous monocropping soil. Means followed by a different value within a column in the same year are significantly different at $p < 0.05$ according to Tukey's test. *** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$; ns: Non-significant.

Balancing the soil exchangeable cations with additional K fertilizer and biochar significantly lowered the soil Ca/K, Mg/K, and Ca/Mg ratios except in the four-year soil where Ca/Mg ratio was unaffected (Table 7). However, there were no significant differences in the Ca/K and Mg/K ratios between balancing soil exchangeable cation with fertilizers and biochar. The Ca/K ratio was significantly lowered from 22.0 to 9.1 in the one-year soil, and from 42.3 to 10.4 in the two-year soil and then from 50.2 to 11.8 in the four-year soil with the balancing treatments and the duration of continuous monocropping soils (year) showing a significant effect and interactions on the Ca/K ratios. Similarly, the Mg/K ratio was lowered from 2.3 to 0.8 in the one-year soil, from 3.8 to 1.0 in the two-year soil, and from 3.3 to 0.7 in the four-year soil. On the other hand, the Ca/Mg ratio increased by the fertilizer balancing treatment in the one-year soil whereas it was lowered in the two-year soil.

Table 7. The soil exchangeable cation ratios, CEC, and base saturations under the different balancing treatments in the different continuously monocropped soils of one, two, and four years.

Year	Treatment	Ca/K	Mg/K	Ca/Mg	CEC (cmol _c kg ⁻¹)	K sat (%)	Ca sat (%)	Mg sat (%)
1	Control	21.96 a	2.26 a	9.76 b	13.41 a	2.55 c	103.5 a	17.63 a
	Fertilizer	9.10 b	0.80 b	11.33 a	13.28 a	7.26 b	126.1 a	18.62 a
	Biochar	5.18 b	0.47 b	11.12 ab	13.81 a	12.04 a	121.5 a	18.21 a
	ANOVA (<i>p</i> values)	**	***	*	ns	***	ns	ns
2	Control	42.29 a	3.79 a	11.15 a	14.70 a	1.74 c	133.9 a	20.03 a
	Fertilizer	10.41 b	0.98 b	10.61 a	12.84 a	7.06 b	142.6 a	22.42 a
	Biochar	4.35 b	0.44 b	9.96 b	13.21 a	14.83 a	125.3 a	20.95 a
	ANOVA (<i>p</i> values)	**	**	**	ns	***	ns	ns
4	Control	50.26 a	3.33 a	15.11 a	14.89 a	2.06 c	191.5 ab	21.09 a
	Fertilizer	11.83 b	0.72 b	16.63 a	14.05 a	9.90 b	227.3 a	22.96 a
	Biochar	4.42 b	0.32 b	13.84 a	14.94 a	17.98 a	154.6 b	18.63 a
	ANOVA (<i>p</i> values)	***	***	ns	ns	***	**	ns
Source of variation								
Treatment (T)			***	***	*	ns	***	***
Year (Y)		**	ns	***	ns	***	***	**
Y*T		**	ns	*	ns	***	**	ns

Data represent means of three replicates ($n = 3$). Year represents duration of continuous monocropping soil. Means followed by a different value within a column in the same year are significantly different at $p < 0.05$ according to Tukey's test. *** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$; ns: Non-significant.

Results also showed that the soil CEC was unaffected by balancing the soil exchangeable cation whereas the soil saturation of K, mostly in the biochar balancing treatment was significantly higher in the one-, two-, and four-year soils with a higher increment observed in the four-year soil than in the one- and two-year soils. The Ca and Mg saturations was significantly higher by 35.8% and 1.9% respectively in the fertilizer balancing treatment of the four-year soil compared to the control whereas the biochar balancing treatment had a negative effect on these base saturations (Ca and Mg). The analysis of variance showed that the effect of duration of continuous monocropping soil (year) had significantly caused an increase in the Ca/K, Mg/K, and Ca/Mg ratios but through balancing the soil exchangeable cations these ratios significantly decreased. In addition, balancing soil exchangeable cations with the biochar improved the K saturation while lowering Ca saturation.

4. Discussion

In this study, results indicated that balancing the soil exchangeable cations with additional K fertilizer and biochar had no significant effect on the sesame plant height as well as in the fresh and dry weight of the one-year and two-year soils (Table 4, Figure 1, and Figure 2), suggesting that the short duration of continuous monocropping of sesame does not alter the balance in exchangeable soil cations that may lead to poor K nutrition. However, the significantly lower plant height as well as fresh and dry weights of sesame seedlings in the four-year soils without the balancing (control) when compared to balancing treatments suggests that the imbalance in the soil exchangeable cations occurred in the long duration of continuous monocropping of sesame on the upland field converted paddy. It is reported that the growth and yield of crops decreased in long-term continuous monocropping due to several factors such as diseases, pests, depletion in soil nutrients, and nutrient imbalances [18]. Our previous study indicated that imbalances in soil exchangeable cations Ca, Mg, and K led to poor K nutrition as a result of high Ca and Mg inhibiting the uptake of K by sesame plants which partly limited sesame growth and yield under continuous monocropping on the upland field converted paddy [9]. Therefore, the poor growth of sesame in the un-balanced soil (control) confirmed the occurrence of continuous monocropping obstacle due to a low uptake of K. Apart from imbalances in cations Ca, Mg, and K, the decrease in K availability from continuous monocropping fields could be attributed to the annual removal of crop because sesame requires a high amount of potassium for growth and the seed

usually accumulates a high amount of K as part of the mineral nutrient [8]. Furthermore, the uptake of K by crops is usually high resulting in a decline in the available K which is high in soils with low reserves of K under continuous monocropping [19]. Therefore, increasing K availability where it is limiting growth and yield through balancing nutrients is an important factor in mitigating continuous monocropping obstacles.

Our results also showed that the K nutrition improved through the balancing treatments of the fertilizer and biochar, indicated by the higher concentrations and uptake of K in treatments compared to the control (Table 5). This was evidenced in the increase of sesame growth in the balancing treatments, indicating that a sufficient uptake of K occurred and that the addition of more K in continuously monocropped sesame soils could improve growth and yield even under field conditions since K removal by sesame from soil is high. Both the fertilizers and biochar added sufficient K into the balanced soil, improving its availability as indicated by the high soil exchangeable K contents for sesame uptake, thus increasing sesame growth. It is reported that a low K content in soil leads to the development of short internodes in sesame plants [8]. Therefore, in the balancing treatments, an increase in the concentration and uptake of K in the shoot could indicate the development of long internodes in sesame leading to high plant heights. K plays a role in photosynthesis because it stimulates the activity of ribulose biphosphate carboxylase, thus a low uptake of K could cause low accumulation of photosynthate in sesame plants leading to low dry weight [20].

The improvement in the K nutrition especially in the four-year soil could be attributed to an increase in soil K saturation and the decrease in Ca/K and Mg/K ratios in the balancing treatment (Tables 5 and 7). In the control (unbalanced soil), the soil Ca/K, Mg/K, and Ca/Mg ratios were too wide, indicating high contents of Ca and Mg in the soil that could easily displace K from the soil exchange complex inducing a low uptake of K in a phenomenon referred to as 'competitive ion effect'. It is reported that a high magnesium and calcium content could induce a competitive ion effect in which K is less absorbed by plants [10,21]. However, this imbalance in soil exchangeable cations could be successfully mitigated with additional K from fertilizers and biochar that contain a high amount of K, as observed in this study. Therefore, balancing the soil exchangeable cations with more K fertilizers and rice husk biochar alleviated the competitive ion effect and supplied more K, increasing its uptake and consequently sesame growth. This result is consistent with other researches that report that balancing exchangeable cation and their ratios increases K availability which significantly improve crop growth and yield [12,13]. The balancing treatments increased the soil exchangeable K content because of the additional K from the fertilizer and the high K content of the biochar used. It is reported that rice husk biochar contains a high amount of K that is readily available for plants, indicated by its high ash content [22,23]. This increase in availability of K was indicated by the increase in the soil K saturations which increased more than 5.0% in both balancing with the fertilizers and the rice husk biochar.

On the other hand, the increasingly high exchangeable cation ratios (Ca/K, Mg/K) in the control treatment especially in the four-year soil compared with the fertilizer and biochar balancing treatments could be attributed to the increase in the exchangeable Ca and Mg supplied through dolomite lime in the continuous monocropping fields [24]. Hence, the low growth of the control compared to balancing treatments could be mainly attributed to a lack of K absorption since the uptake of K was lower than in biochar and fertilizer balancing treatments due to the high exchangeable Ca and Mg contents. This study agrees with the findings that high exchangeable Ca content in soil could lead to competitive ionic effect among Ca, Mg, and K in which excess Ca and mg are absorbed by plants as K absorption is reduced [25]. The results are also consistent with the report of Huu Nguyen et al. [26] where high contents of Mg in soil could inhibit the uptake of K in tomato plants. It was also demonstrated that the content of plant Ca ions depend on the lime content in soil and excess of this could hinder physiological roles of potassium in plants [27]. Furthermore, the high content of exchangeable Ca and Mg in the imbalanced soil significantly affected the uptake of K, suggesting that decreasing the dolomite lime application could mitigate the occurrence of a competitive ion effect. Since poor K nutrition occurs in sesame plants when Ca/K and Mg/K ratios are high [28], the balancing treatment increased the uptake

of K, indicating that continuous monocropping obstacles of sesame could be mitigated through adding more K and reducing Ca and Mg. On the other hand, there was no significant effect of balancing treatments on the uptake of Ca and Mg by sesame seedlings and therefore, it could be speculated that changes in the Ca/Mg ratio does not affect sesame growth and yield in the field. This is also consistent with the report that increasing the Ca/Mg ratio does not necessarily affect crop yield [29].

Although it is reported that if the soil contains adequate quantities of Ca, Mg, and K, the ratios of these cations will not usually affect crop yields in most agricultural soils [30,31], our study indicated that the soil cation ratios under continuous monocropping of sesame could influence the growth and consequently the yield. This finding agrees with Lombin [32] who reported that soil Ca/K ratio influenced maize yield in which the imbalance between Ca and K resulted in low Ca saturation in the soil thereby becoming a critical limiting nutrient for maize yield when higher rates of K and Mg in fertilizers were applied. Therefore, care should be taken while supplying large quantities of one exchangeable cation at the expense of others as observed in continuously monocropped soils under sesame production with the high exchangeable Ca and Mg affecting nutrition of K by sesame plants.

Our study also showed that balancing soil exchangeable K was more suitable with rice husks biochar compared to the K fertilizer suggesting that the biochar used could offer other benefits apart from increasing K, especially from rice husk biochar. Biochar addition is known to increase crop growth [33,34]. Although we did not focus on other benefits of biochar, this could be attributed to the biochar increasing other nutrients such as N, apart from the large quantities of K than inorganic fertilizer, detoxifying phytotoxic compounds from continuously monocropped soils and thereby improving sesame seedling growth [16,35]. Furthermore, the high CEC of the biochar and the increase in soil CEC in the biochar balancing treatment is an indicator of nutrient retention for sesame growth suggesting that rice husk biochar could improve soil nutrient status in continuous monocropping [16]. Therefore, the rice husk biochar addition could be recommended for improving sesame growth to alleviate the imbalances in soil exchangeable cations on continuously monocropped soils where K is a limiting factor.

5. Conclusions

Our study indicated that soil exchangeable cations could be balanced with additional fertilizers and biochar to increase cation uptake especially in K, increasing sesame growth and thereby contributing to the mitigation of sesame growth decline under continuous monocropping. Balancing the exchangeable soil cation significantly decreased the Ca/K and Mg/K ratios to acceptable levels while increasing K saturations to above 5.0%, suggesting an increase in the availability of K in the soil to enhance sesame growth especially in the long duration of continuous monocropping (four-year soil). Our study also demonstrated that a balanced nutrition and fertilization should take into consideration the ratios among Ca, Mg, and K that eliminate the competitive ion effect to improve sesame growth and K nutrition for sesame production. However, balancing cations with biochar tended to be more beneficial than with the inorganic fertilizer since the rice husk biochar provided larger quantities of K than the inorganic fertilizer. Future research should focus on ensuring balanced exchangeable cation ratios under field conditions to mitigate growth and yield decline in continuous monocropping on upland fields converted paddy.

Author Contributions: C.W., N.O., D.B., and E.N. conceived and designed the experiment; C.W., D.B., and D.S. performed the experiments; C.W. and D.B. analyzed the data; T.M., S.Y., and E.N. supervised the research; C.W. wrote the paper; and E.N. revised the final draft manuscript.

Funding: This research received no external funding.

Acknowledgments: This research was supported by the Ministry of Education, Culture, Sports, Science, and Technology, MEXT of Japan under the Japanese Government MEXT scholarship of the first author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ashri, A. Sesame. In *Oil Crops of the World*; Robbelen, G., Downey, R.K., Ashri, A., Eds.; McGraw–Hill: New York, NY, USA, 1989; pp. 375–387.
2. Shehu, H.E.; Kwari, J.D.; Sandabe, M.K. Nitrogen, phosphorous and potassium nutrition of sesame (*Sesamum indicum*) in Mubi, Nigeria. *Res. J. Agron.* **2009**, *3*, 32–36.
3. Jadav, D.P.; Padamani, D.R.; Polara, K.B.; Parmar, K.B.; Babaria, N.B. Effect of different level of sulphur and potassium on growth, yield and yield attributes of sesame (*Sesamum indicum* L.). *Asian J. Soil Sci.* **2010**, *5*, 106–108.
4. Munson, R.D. *Potassium in Agriculture*; ASA-CSSA-SSSA: Madison, WI, USA, 1985.
5. Leigh, R.A.; Wyn Jones, R.G. Cellular compartmentation in plant nutrition: The selective cytoplasm and the promiscuous vacuole. *Adv. Plant Nutr.* **1986**, *2*, 249–279.
6. Bergmann, W. *Nutritional Disorders of Plants. Development, Visual and Analytical Diagnosis*; Gustav Fisher Verlag: Jena, Germany, 1992.
7. Loide, V. About the effect of the contents and ratios of soil's available calcium, potassium and magnesium in liming of acid soils. *Agron. Res.* **2004**, *2*, 71–82.
8. Mitchell, G.A.; Bingham, F.T.; Yermanos, D.M. Growth, mineral composition and seed characteristics of sesame as affected by nitrogen, phosphorus and potassium nutrition. *Soil Sci. Am. Proc.* **1974**, *38*, 925–931. [[CrossRef](#)]
9. Wacal, C.; Ogata, N.; Basalirwa, D.; Sasagawa, D.; Ishigaki, T.; Handa, T.; Kato, M.; Tenywa, M.M.; Masunaga, T.; Yamamoto, S.; et al. Imbalanced Soil Chemical Properties and Mineral Nutrition in Relation to Growth and Yield Decline of Sesame on Different Continuously Cropped Upland Fields Converted Paddy. *Agronomy* **2019**, *9*, 184. [[CrossRef](#)]
10. Hannan, J.M. Potassium-Magnesium Antagonism in High Magnesium Vineyard Soils. Master's Thesis, Iowa State University, Ames, IA, USA, 2011.
11. Hodges, S.C. *Soil Fertility Basics*; Soil Science Extension, North Carolina State University: Raleigh, NC, USA, 2010; pp. 1–75.
12. Pettiet, J.V. The influence of exchangeable magnesium on potassium uptake in cotton grown on Mississippi delta soils. In Proceedings of the Beltwide Cotton Production Research Conferences, New Orleans, LA, USA, 3–8 January 1988; pp. 517–518.
13. Zalewska, M.; Nogalska, A.; Wierzbowska, J. Effect of basic cation saturation ratios in soil on yield of annual ryegrass (*Lolium multiflorum* L.). *J. Elem.* **2018**, *23*, 95–105. [[CrossRef](#)]
14. Biederman, L.A.; Harpole, W.S. Biochar and its effects on plant productivity and nutrient cycling: A meta-analysis. *GCB Bioenergy* **2013**, *5*, 202–214. [[CrossRef](#)]
15. Lehmann, J.; Joseph, S. Biochar for environmental management: An introduction. *Biochar Environ. Manag. Sci. Technol.* **2009**, *1*, 1–12. [[CrossRef](#)]
16. Wacal, C.; Ogata, N.; Basalirwa, D.; Handa, T.; Sasagawa, D.; Acidri, R.; Ishigaki, T.; Kato, M.; Masunaga, T.; Yamamoto, S.; et al. Growth, seed yield, mineral nutrients and soil properties of sesame (*Sesamum indicum* L.) as influenced by biochar addition on upland field converted from paddy. *Agronomy* **2019**, *9*, 55. [[CrossRef](#)]
17. Chapman, H.D. Cation–exchange capacity. In *Methods of Soil Analysis—Chemical and Microbiological Properties*; Black, C.A., Ed.; American Society of Agronomy: Madison, WI, USA, 1965; pp. 891–901.
18. Bennett, A.J.; Bending, G.D.; Chandler, D.; Hilton, S.; Mills, P. Meeting the demand for crop production: The challenge of yield decline in crops grown in short rotations. *Biol. Rev.* **2012**, *87*, 52–71. [[CrossRef](#)] [[PubMed](#)]
19. Panda, R.; Patra, S.K. Depletion and Contribution Pattern of Available Potassium in Indian Coastal Soils under Intensive Cropping and Fertilization. *Int. J. Pure Appl. Biosci.* **2017**, *5*, 1144–1152. [[CrossRef](#)]
20. Demmig, B.; Gimmler, H. Properties of the Isolated Intact Chloroplast at Cytoplasmic K Concentrations: I. Light-Induced Cation Uptake into Intact Chloroplasts is Driven by an Electrical Potential Difference. *Plant Physiol.* **1983**, *73*, 169–174. [[CrossRef](#)] [[PubMed](#)]
21. Marschner, H. *Marschner's Mineral Nutrition of Higher Plants*, 3rd ed.; Academic press: Cambridge, MA, USA, 2012.
22. Major, J.; Rondon, M.; Molina, D.; Riha, S.J.; Lehmann, J. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant Soil* **2010**, *333*, 117–128. [[CrossRef](#)]

23. Abrishamkesh, S.; Gorji, M.; Asadi, H.; Bagheri-Marandi, G.H.; Pourbabae, A.A. Effects of rice husk biochar application on the properties of alkaline soil and lentil growth. *Plant Soil Environ.* **2015**, *62*, 475–482. [[CrossRef](#)]
24. Anderson, N.P.; Hart, J.M.; Sullivan, D.M.; Christensen, N.W.; Horneck, D.A.; Pirelli, G.J. *Applying Lime to Raise Soil pH for Crop Production (Western Oregon)*; Oregon State University Extension Publication EM: Corvallis, OR, USA, 2013; p. 9057.
25. Garcia, M.; Daverede, C.; Gallego, P.; Toumi, M. Effect of various potassium-calcium ratios on cation nutrition of grape grown hydroponically. *J. Plant Nutr.* **1999**, *22*, 417–425. [[CrossRef](#)]
26. Huu Nguyen, H.; Maneepong, S.; Suraninpong, P. Effects of Potassium, Calcium, and Magnesium Ratios in Soil on Their Uptake and Fruit Quality of Pummelo. *J. Agric. Sci.* **2017**, *9*, 110. [[CrossRef](#)]
27. Gluhic, D.; Herak Custic, M.; Petek, M.; Coga, L.; Slunjski, S.; Sincic, M. The content of Mg, K and Ca ions in vine leaf under foliar application of magnesium on calcareous soils. *Agric. Conspec. Sci.* **2009**, *74*, 81–84.
28. Kumar, P.; Sharma, M.K. *Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management*; CAB International: Wallingford, UK, 2013; p. 243.
29. Rosanoff, A.; Capron, E.; Barak, P.; Mathews, B.; Nielsen, F. Edible plant tissue and soil calcium:magnesium ratios: Data too sparse to assess implications for human health. *Crop Pasture Sci.* **2015**, *66*, 1265–1277. [[CrossRef](#)]
30. Kopittke, P.M.; Menzies, N.W. A Review of the Use of the Basic Cation Saturation Ratio and the “Ideal” Soil. *Soil Sci. Soc. Am. J.* **2007**, *71*, 259–265. [[CrossRef](#)]
31. Vieweger, A.; Measures, M.; Amos, D. *Review of Literature and Farm Experience on Base Cation Saturation Ratio (BCSR) Based on the Work of W.A. Albrecht*; Rural Development Programme for England (RDPE) 2014–2020; The Organic Research Centre: England, UK, 2017.
32. Lombin, G. The effects of continuous fertilization on nutrient balance and crop yield in the Northern Nigerian savannah: A preliminary assessment. *Can. J. Soil Sci.* **1981**, *61*, 55–65. [[CrossRef](#)]
33. Carter, S.; Shackley, S.; Sohi, S.; Suy, T.; Haeefele, S. The Impact of Biochar Application on Soil Properties and Plant Growth of Pot Grown Lettuce (*Lactuca sativa*) and Cabbage (*Brassica chinensis*). *Agronomy* **2013**, *3*, 404–418. [[CrossRef](#)]
34. Albuquerque, J.A.; Salazar, P.; Barrón, V.; Torrent, J.; Del Campillo, M.D.C.; Gallardo, A.; Villar, R. Enhanced wheat yield by biochar addition under different mineral fertilization levels. *Agron. Sustain. Dev.* **2013**, *33*, 475–484. [[CrossRef](#)]
35. Elmer, W.H.; Pignatello, J.J. Effect of Biochar Amendments on Mycorrhizal Associations and *Fusarium* Crown and Root Rot of Asparagus in Replant Soils. *Plant. Dis.* **2011**, *95*, 960–966. [[CrossRef](#)] [[PubMed](#)]



© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).