Ca-Mg-K Balance in Volcanic Ash Soil to Maximize Vegetable Production*

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The optimum base status required for maximizing crop yields have been studied by several workers[1-12]. Some of the disorders in nutrient absorption by plants may be caused by the antagonisms due to unbalanced supply of nutrients, particularly among calcium, magnesium and potassium. Kondratev et al.[8] studied the optimum Mg/Ca ratio with sand culture of wheat, and reported that the maximum yield was obtained when the ratio of exchangeable magnesium to calcium was 2.5: 7.5, or 7 :3.

Mori et al[10] carried out similar studies with kidney beans in volcanic ash soils, and postulated that the ratio of exchangeable potassium to magnesium should be below 2.

Besides the optimum ratio among nutrients, the problem of an optimum base saturation is another aspect which is equally important. Dei[2] found in growing rye on volcanic ash soils that calcium saturation of the cation exchange capacity (CEC) should amount to 30 to 50%. Dawson[9] reported that the total base saturation of 80 to 100% was optimum for alfalfa cultivated on brown latosol. Bear[3], studying the growth of alfalfa cultivated on New Jersey soils, postulated that 80% base saturation with 65% calcium, 10% magnesium, and 5% potassium qualifies an ideal soil.

The author has studied to find out an optimum base composition in volcanic ash soils of Kanagawa Prefecture, central Japan. In this area, an intense leaching of bases which occurs under warm and humid climate is further accelerated by heavy dosage of nitrogenous fertilizers. On the other hand, in greenhouses where soils are scarcely leached by percolating rainwater, the significant accumulation of salts takes place. In both cases, amendment of unbalanced nutrient supply constitutes a fundamental part of the fertility management for upland soils under heavily fertilized cultivations[1-7].

Materials and methods

A soil derived from aeolian volcanic ash sediment was used. It was loam in texture, and had a humus content of 14.5%, CEC 41.1 meq/100g, exchangeable calcium 8.9 meq, magnesium 2.6 meq, and potassium 0.5 meq, and the total base saturation of 29.2%.

Different base conditions of soil were created in 1/5000 wagner pot by adding various amounts of $(MgCO_3)_4 \cdot Mg(CH)_2 \cdot 5H_2O$, K_2SO_4, and $CaCO_3$. Calculated amounts of $(NH_4)_2HPO_4$ and $(NH_4)_2SO_4$ were applied in solution to give 1 g each of nitrogen and phosphorus per pot. Nine different Ca:Mg:K ratios were combined with three levels of total base saturation, namely 100, 80 and 60% of CEC.

The experiment was conducted in a multifactorial design with 27 combinations replicated three times (Table 1). As the test plants, seven crops were grown including herb vegetables (spinach, lettuce, cabbage), fruit vegetables (sweet pepper and egg plant) and

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Table 1. Design of experimental plots

Item			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Base composition		MgO	11	11	11	25	25	25	39	39	39
		K_2O	5	15	25	5	15	25	5	15	25
		CaO	84	74	64	70	60	50	56	46	36
Degree of base saturation	100% (me)	MgO	4.5	4.5	4.5	10.3	10.3	10.3	16.0	16.0	16.0
		K_2O	2.1	6.2	10.3	2.1	6.2	10.3	2.1	6.2	10.3
		CaO	34.5	31.0	26.3	28.8	24.6	20.6	23.0	18.9	14.8
	80% (me)	MgO	3.6	3.6	3.6	8.2	8.2	8.2	12.8	12.8	12.8
		K_2O	1.7	5.0	8.2	1.7	5.0	8.2	1.7	5.0	8.2
		CaO	27.6	24.8	21.0	23.0	19.7	16.5	18.4	15.1	10.2
	60% (me)	MgO	2.7	2.7	2.7	6.2	6.2	6.2	9.6	9.6	9.6
		K_2O	1.3	3.7	6.2	1.3	3.7	6.2	1.3	3.7	6.2
		CaO	20.7	18.6	15.8	17.3	14.8	12.4	13.8	11.3	8.9

Note: Treatment: 9 (base composition)×3 (degree of base saturation)×3 (repetition)=81 plots

root vegetables (carrot and turnip).

Results and discussions

The influence of exchangeable base composition on nutrient uptake by crops.

1) Result for spinach

Analysis of variance and factorial effect for spinach are shown in Table 2 and Fig. 1. Main effect on plant height was observed with degree of base saturation and with magnesium on Nov. 17, and with degree of base saturation and potassium on Dec. 2. Main effect on yield was observed with degree of base saturation and potassium. Effects on nutrient uptake by plant were observed as follows: For the calcium uptake, magnesium, and potassium, showed main effect, and their interaction of magnesium × potassium was also observed. For magnesium uptake, effect of magnesium was recognized. For potassium uptake, degree of base saturation, magnesium, and potassium showed main effect, and interaction of degree of base saturation × potassium was also observed.

As shown in Fig. 1 plant height on Nov. 17 was greater with 80% degree of base saturation than with 60% and 100%. It was also greater with 25% magnesium composition than 39%.

Plant height on Dec. 2 was greater with 80% degree of base saturation than with 60%, and was greater with 15% potassium composition than 5% and 25%.

Fresh plant yield was greater with 80% degree of base saturation than with 60% and was greater with 15% and 25% potassium composition than 5%.

Calcium uptake by plant was increased in the order of 11%>25%>39% of magnesium composition, and in the order of 5%>15%>25% of potassium composition. As to the interaction of magnesium and potassium, it was observed that calcium uptake was increased by the decrease in percent magnesium composition at any level of potassium, but it was decreased with the increase in percent potassium composition at any level of magnesium.

Magnesium uptake was greater at 25% and 39% magnesium composition than 11%.

More potassium uptake was observed at 80% and 100% degree of base saturation than 60%, at 11% magnesium composition than 39%, and at 15% and 25% potassium composition than 5%. As to the interaction of degree of base saturation and potassium, it was shown that potassium uptake was greater with 15% and 25% potassium composition than 5% at any level of base saturation. However, at 5%

Table 2. Result of analysis of variance for spinach

Factors	Degree of freedom	Plant height		Yields (fresh wt.)	Nutrient uptake		
		Nov. 17	Dec. 2		CaO	MgO	K_2O
Repetition	2	4.136	14.594**	997.48**	849.00*	5,169.35*	34,016.20*
Treatment	26	2.038	3.669*	451.68**	2,939.29**	5,325.81**	117,229.03**
Main effect							
D	2	7.796**	19.281**	534.71**	241.37	3,427.76	126,018.83**
MgO	2	6.482*	4.554	75.15	19,435.26**	49,330.54**	51,922.76**
K_2O	2	3.021	9.621*	4,384.59**	14,389.93**	194.54	1,181,091.28**
Interaction							
D×M	4	0.352	0.554	47.80	306.13	2,388.86	2,762.60
D×K	4	0.559	1.837	186.85	155.13	2,542.97	41,122.12**
M×K	4	1.406	0.859	86.24	972.24**	857.08	13,611.72
D×M×K	8	1.138	1.558	58.89	319.31	1,176.23	12,487.90
Error	52	1.319	2.005	97.61	236.94	1,175.56	9,116.62
Mean		14.15cm	17.09cm	101.9g/p	82.5mg/p	258.6mg/p	838.4mg/p
Coefficient of variation (%)		8.1	8.3	9.7	18.7	13.3	11.4

Note: D refers to degree of base saturation in % of CEC. mg/p=mg/plant
MgO and M: Mg saturation of CEC
K_2O and K: K_2O saturation of CEC
* 1% lsd ** 5% lsd

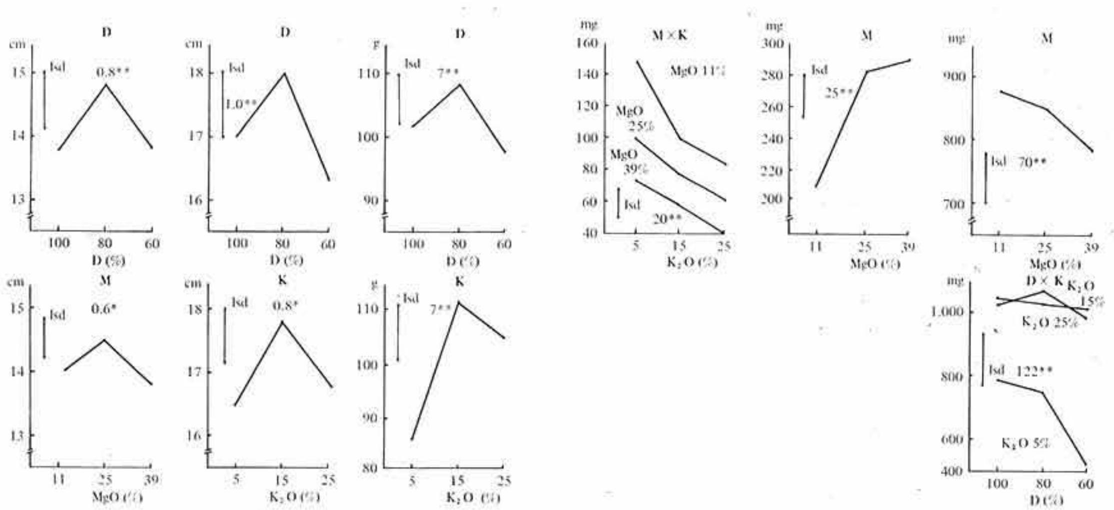

Fig. 1. Factorial effect for spinach

Note: Abbreviations are same as in Table 2.

potassium composition, potassium uptake decreased sharply with the change of base saturation from 80% to 60% while only slightly for the change from 100% to 80%.

2) Integrated results

Table 3 summarizes the results obtained from all the test plants. Maximum crop growth and yields were observed in plots

Table 3. Base status to maximize plant growth, yields and nutrient uptake

Item			Plant growth	Yield		nutrient uptake		
				Fresh weight	Dry weight	CaO	MgO	K_2O
Hurb vegetable	Spinach	D	80	80	—	—	—	80-100
		MgO	25	—	—	11	25- 39	11
		K_2O	15	15- 25	—	5	—	15- 25
	Lettuce	D	—	80-100	—	100	100	80-100
		MgO	—	—	—	11	25- 39	—
		K_2O	—	15- 25	—	5	—	25
	Cabbage	D	—	—	—	—	100	100
		MgO	—	—	—	11	39	—
		K_2O	—	—	—	5	5	25
Fruit vegetable	Sweet pepper	D	80	—	80	80	80-100	80-100
		MgO	—	—	—	11	39	11- 25
		K_2O	25	—	25	5	5	25
	Egg plant	D	80	—	100	80-100	80-100	80-100
		MgO	39	—	*39	11- 25	39	—
		K_2O	—	—	—	—	5	15- 25
Root vegetable	Carrot	D	80-100	—	—	—	—	80-100
		MgO	—	—	—	11	39	—
		K_2O	—	—	15- 25	5- 15	5- 15	15- 25
	Turnip	D	80-100	—	—	100	100	100
		MgO	25- 39	—	25- 39	11- 25	39	25- 39
		K_2O	15	—	—	5	—	15- 25

Notes: 1) D stands for degree of base saturation in percent of CEC. MgO and K_2O stand for the optimum Mg- and K- saturation of CEC, respectively.

2) Dry weight:
Leaf dry weight for fruit vegetables
Root dry weight for root vegetables
* Fruit dry weight

having the total base saturation of 80 to 100% of CEC. Maximum uptake of nutrients by crops was likewise observed in the same plots. Optimum Mg- and K-saturation of CEC was found to lie with many crops at 25-39% and at 15-25%, respectively.

Uptake by crops of each nutrient was found to be influenced by the relative amount of other nutrients. Namely, the antagonistic or promotive effects in nutrient uptake were recognized. An increase of Mg+K saturation of CEC caused a decreased calcium uptake by crops while a decrease in Mg+K saturation induced an increased calcium uptake. Similarly, magnesium uptake by crops decreased with higher potassium saturation of CEC but it increased with lower potassium saturation. Potassium uptake by crops was influenced similarly by magnesium saturation. On the other hand, promotive effect on nutrient uptake was observed in some crops. Calcium uptake by egg plants and potassium uptake by turnip were increased by increasing the magnesium level in soil. In all plots, the base uptake by crops followed the order of K>Mg>Ca.

An optimum exchangeable base composition

Based on the results, an optimum exchangeable base composition in volcanic ash soils is inferred as follows:

1) Optimum ratio for Ca:Mg:K is 60:25:15.
2) Optimum Ca-, Mg-, and K-saturation of CEC is 48%, 20%, and 12% of CEC, respectively, and optimum total base saturation degree is 80%.

When expressed in pairs of base, $CaO/MgO = 2.4$, $CaO/K_2O = 4.0$, and $MgO/K_2O = 1.7$.

Advantage of multi-factorial experiment design

The above studies with the aid of multi-factorial analysis seem to have succeeded in obtaining comprehensive information on effects of base status of soil: an optimum Ca:Mg:K ratio (an intensity factor) was determined concurrently with Ca-, Mg-, and K-saturation of CEC (capacity factor). Furthermore, several crop species were included in a set of experiment with 27 plots, and the effect of the base status of a volcanic ash soil on yields could be analyzed.

The result of this study using the factorial experimental method indicated the same level of total base saturation, a lower Ca-saturation and a higher Mg-, and K-saturation of CEC as compared to the Bear's ideal soil as the most favorable base status of the volcanic ash soil for vegetable production.

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