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9. ABSTRACT

Sorghum seeds planted in Hydric Dystrandepts Paauhau soil, a silty clay loam, were studied to determine the effects of various treatments of calcium silicate and calcium carbonate. The plants were allowed to grow until they were in heading stage, when they were harvested and analyzed. The rates of applications of calcium silicate or calcium carbonate in tons per hectare were 0, 6.72, 13.44, and 26.88. Other fertilizers used with all treatments were phosphorus, potassium, nitrogen, and zinc sulfate. The calcium silicate increased the yield of sorghum. The calcium carbonate decreased the yield. The percent of nitrogen in the plant tissue was generally increased with increasing rate of calcium carbonate and decreased with increasing rate of calcium silicate. Calcium carbonate significantly increased phosphorus in the plant tissue, while calcium silicate did not have any significant effect. Plant tissue K was found to decrease with increasing calcium silicate, while calcium carbonate had no significant effect. An increase in tissue Ca was found with increasing rates of calcium silicate as well as calcium carbonate. Findings concerning Mg, Si, and soil pH are also discussed.

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the effect of calcium silicate and calcium carbonate on growth of sorghum

Y.N. TAMIMI and D.T. MATSUYAMA**

Yield response by several crops to applications of soluble silicates to Hawaiian soils have been reported by several investigators [1,3,5,6,10]. In most cases T.V.A. slag, sodium silicate or $CaSiO_3$ were the silicon carriers. Research on silicates have been most extensive in Japan and Taiwan with rice as the major crop. Yield responses have also been recorded. Functions of Si as well as possible reasons for these responses have been reviewed by Comhaire [4], Sherman [8], Silva [9], and Plucknett [7]. The objective of the following investigation was to determine the effect of $CaSiO_3$ in combination with $CaCO_3$ on sorghum plants grown in an Inceptisol from Hawaii.

Materials and methods

Paauhau silty clay loam soil at depth of 50-105 cm was collected for this study. This soil belongs to the Hydric Dystrandepts Great Soil Group of the Inceptisols. The soil has the following properties: pH paste 5.40, organic matter 7.26 %, cation exchange capacity (at pH 7) 50 me/100 g soil, Ca 3.75 me/100 g soil, Mg 1.24 me/100 g soil, with 157.6 % moisture at field capacity.

Two kg of soil at field conditions (100 % H_2O) were placed in pots of 1 gallon (US, 3.78 l) capacity. $CaSiO_3$ or $CaCO_3$ rates were 0, 6.72, 13.44 and 26.88 tons (m)/hectare. A factorial design of 4 × 4, ($CaSiO_3$ × $CaCO_3$) with 3 replicates was selected. $CaSiO_3$ was obtained from Fisher Chemical Company and was leached with H_2O until free of Cl. $CaCO_3$ was U.S.P. precipitated powder produced by Van Waters and Rogers Chemical Company. Partial chemical analyses of these liming materials are reported in table 1. The soil was mixed properly with increments of above, watered to field capacity, and allowed to equilibrate for a week. Phosphorus, from treble superphosphate at a rate of 500 ppm, potassium as KCl at 200 ppm, nitrogen as urea at 200 ppm, and 30 ppm Zn as zinc sulfate were added to all pots and mixed thoroughly with the soil.

Eight seeds of sorghum (*Sorghum vulgare* cultivar Rox Orange) were planted and later thinned to 6 seedlings/pot. Treatments were randomized in the greenhouse. Tap water was used for irrigation where soil was maintained at near field capacity. All pots were fertilized every 2 weeks with solutions supplying 200 ppm N and 200 ppm K from urea and KCl. Plants were allowed to grow until they were in heading stage, then harvested for yield. Whole plants were oven-dried at 75 °C, weighed and ground for further tissue analysis. Pots were emptied of soil and soil was mixed thoroughly and samples were taken for chemical analysis. Analysis of variance was conducted on all results and Duncan Multiple Range Test was used for comparisons of means.

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Table 1 Partial chemical analysis of $CaSiO_3$ and $CaCO_3$

Analysis	Material	
	$CaSiO_3$	$CaCO_3$
Ca, %	15.3	42.5
Mg	nil	nil
K	nil	nil
Si, %	33.7	0.0136
pH (paste)	8.90	8.45

Results and discussion

The plant :
Dry matter yield of sorghum was significantly increased with increasing rate of calcium silicate in absence of $CaCO_3$ (fig. 1). The average dry weight per pot in the zero $CaSiO_3$ rate was less than ½ that of the 26.88 T/Ha rate. Increasing rates of calcium carbonate caused a great reduction in plant growth (fig. 1). When $CaSiO_3$ and $CaCO_3$ were applied at different rates together, it appears that $CaSiO_3$ tended to alleviate the « harmful » effect on growth of sorghum that was associated with the application of $CaCO_3$ (fig. 1).

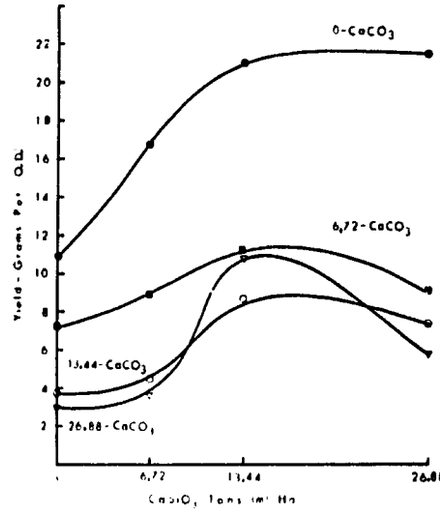

Fig. 1 Growth Response of Sorghum to Rates of $CaSiO_3$ and $CaCO_3$.

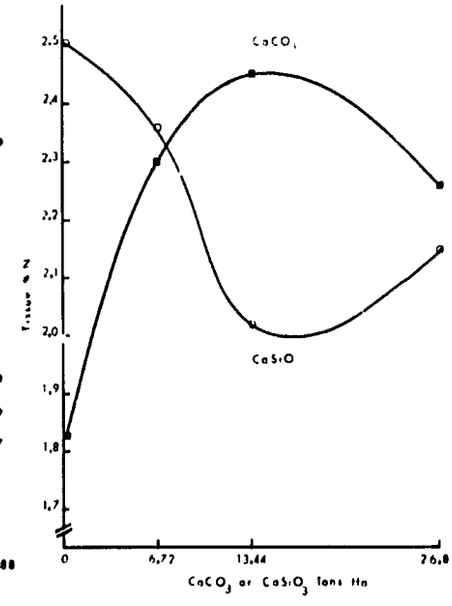

Fig. 2 The Effect of $CaSiO_3$ and $CaCO_3$ Rates on Tissue Nitrogen.

Percent tissue nitrogen was found to decrease with increasing rate of $CaSiO_3$ and to increase with increasing rate of $CaCO_3$ up to the 13.44 T/Ha rate (fig. 2). The decrease in percent N with $CaSiO_3$ treatments may be due to dilution effect in the plant.

Effect of $CaSiO_3$ on tissue percent P did not follow a definite trend, while with increasing $CaCO_3$ there was a significant increase in tissue P (table 2). There was no significant interaction effect between rates of $CaSiO_3$ and $CaCO_3$ on tissue percent P.

Table 2 The effect of $CaSiO_3$ and $CaCO_3$ on tissue P, K, and Ca

T/Ha $CaSiO_3$ or $CaCO_3$	% P		% K		% Ca	
	$CaSiO_3$	$CaCO_3$	$CaSiO_3$	$CaCO_3$	$CaSiO_3$	$CaCO_3$
0	.166	.166 b*	2.44 a*	2.44	0.600 b*	0.600 b*
6.72	.146	.201 ab	1.95 ab	2.37	0.680 ab	0.941 a
13.44	.164	.235 a	1.75 b	2.71	0.661 ab	0.914 a
26.88	.182	.207 ab	1.49 b	2.28	0.927 a	0.774 ab
	N.S.	$P < .05$	$P < .05$	N.S.	$P < .05$	$P < .05$

* Means followed by different letters are significantly different at $P < .05$.

Tissue percent K was significantly reduced with increasing rates of $CaSiO_3$, while with $CaCO_3$ there was no specific trend (table 2). Increasing rates of $CaSiO_3$ and $CaCO_3$ significantly increased tissue percent Ca (table 2). Magnesium in the plant tissue was drastically lowered by increasing rates of $CaCO_3$, while this decrease was not statistically significant as pertaining to application of $CaSiO_3$ (table 3). $CaSiO_3$ seems to have a « stabilizing » effect on Mg uptake. This may be noted from averages of tissue percent Mg under different rates of $CaSiO_3$ over all rates of $CaCO_3$ (table 3).

Table 3 The effect of $CaSiO_3$ and $CaCO_3$ on tissue percent Mg

$CaCO_3$, T/Ha	$CaSiO_3$ T/Ha				
	0	6.72	13.44	26.88	Ave.
0	.159	.146	.141	.137	.146 a*
6.72	.155	.145	.152	.131	.146 a
13.44	.134	.129	.124	.127	.129 b
26.88	.086	.109	.096	.119	.103 c
Average	.134	.132	.128	.129	

* Means followed by different letters are significantly different at $P < .05$.

There was a considerable increase in tissue silicon with increasing rate of $CaSiO_3$ (table 4). Over all $CaSiO_3$ rates, there was a significant decrease in tissue percent Si as rates of $CaCO_3$ increased up to 13.44 T/Ha. At 26.88 T/Ha $CaCO_3$ an increase in Si percent occurred.

Table 4 The effect of $CaSiO_3$ and $CaCO_3$ on tissue percent silicon

$CaCO_3$ T/Ha	$CaSiO_3$ T/Ha				
	0	6.72	13.44	26.88	Ave.
0	.14	.61	.89	1.00	.66 a*
6.72	.12	.52	.75	1.10	.62 ab
13.44	.11	.54	.59	.93	.54 c
26.88	.15	.51	.76	1.02	.61 b
Average	.13 d*	.55 c	.75 b	1.01 a	

Means followed by different letters are significantly different at $P < .05$.

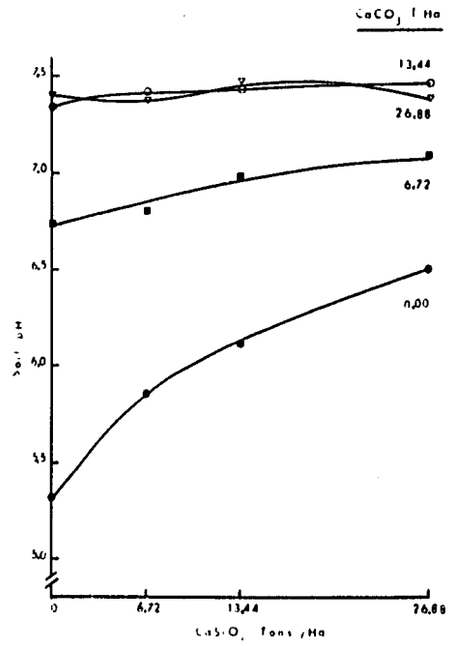

Fig. 3 The Effect of $CaSiO_3$ and $CaCo_3$ on Soil pH.

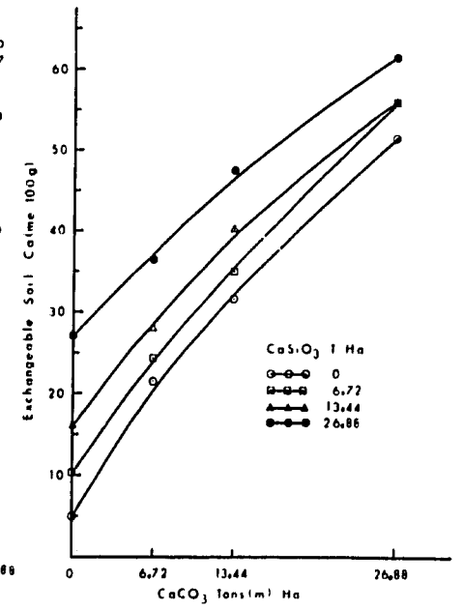

Fig. 4 The Effect of $CaSiO_3$ and $CaCO_3$ on Soil Exchangeable Calcium.

The soil

Soil analysis shows $CaCO_3$ to be more effective in raising soil pH than $CaSiO_3$ (fig. 3). This is due to the higher content of Ca in $CaCO_3$ than $CaSiO_3$ (table 1). The effect of added increments of $CaCO_3$ or $CaSiO_3$ after the application of 13.44 T/Ha $CaCO_3$ had no significant effect on raising soil pH (fig. 3), even though the pH of saturated paste for $CaCO_3$ was 8.45 and for $CaSiO_3$ 8.90. This may be due to saturation of the cation exchange sites in the soil with Ca, or to a reduction in solubility of both $CaCO_3$ and $CaSiO_3$ due to the common ion effect.

Soil extractable phosphorus was reduced significantly with application of 26.88 T/Ha of $CaCO_3$ (table 5). At these pH levels and Ca concentrations, reversion of Ca $(H_2PO_4)_2$ and $CaHPO_4$ to $Ca_3(PO_4)_2$ may possibly be a reason for this decrease in extractable phosphorus. Increasing rates of $CaSiO_3$ (without $CaCO_3$) had a slight effect on the extractable phosphorus level in the soil (table 5). This may be due to the dominance of Ca $(H_2PO_4)_2$ and $CaHPO_4$ forms of phosphorus rather than the $Ca_3(PO_4)_2$ form at the corresponding soil pH levels.

Table 5 The effect of $CaSiO_3$ and $CaCO_3$ on soil phosphorus and potassium

$CaSiO_3$ or $CaCO_3$ T/Ha	Soil P, ppm		Soil K, ppm	
	$CaSiO_3$	$CaCO_3$	$CaSiO_3$	$CaCO_3$
0	27.9 a*	29.3 a	545 ab	207 c
6.72	26.7 ab	28.2 a	548 a	565 ab
13.44	25.2 b	28.5 a	424 c	667 a
26.88	25.1 b	19.0 b	498 ab	577 ab
	$P < .05$	$P < .05$	$P < .05$	$P < .05$

* Means followed by different letters are significantly different at $P < .05$.

Soil exchangeable K increased with applications of 6.72 and 13.44 T/Ha of $CaCO_3$, and decreased at 26.88 T/Ha rate. This may be due to an increase in soil C.E.C. with increase in pH (C.E.C. being pH dependent) up to the 13.44 T/Ha rate and after that the excessive Ca^{++} present at 26.88 T/Ha rate may have caused K^+ to be displaced by Ca thus rendering K more susceptible to leaching. Generally speaking, increasing rates of $CaSiO_3$ was associated with decrease in soil K (table 5). It is to be noted here that 200 ppm of K was applied every 2 weeks, thus maintaining a continuous supply for the growth period of the plants.

Both $CaSiO_3$ and $CaCO_3$ increased soil Ca significantly (fig. 4). By virtue of its higher Ca analysis, $CaCO_3$ at equal weights contributed greater amounts of Ca to the soil than $CaSiO_3$. Extractable Ca contributed to the soil from $CaSiO_3$

seems to decrease with increasing rates of $CaCO_3$ (fig 4). This may be due to a lower solubility of this material at these pH levels and/or due to the common ion effect. This decrease in solubility is obvious from figure 4 where all lines converge and the slope of the curves is reduced with increasing rates of $CaCO_3$.

Soil exchangeable Mg was significantly higher in treatments with increasing rates of $CaSiO_3$ (at the zero T/Ha $CaCO_3$ rate) (fig. 5). When $CaCO_3$ rates were increased, soil Mg was found to decrease greatly to the point that it is suspected to be in deficient amount for plant requirement. This may be in part a major factor contributing to the depressed yield of sorghum when $CaCO_3$ was applied. Higher soil Mg with $CaSiO_3$ treatments may be due to a lower degree of competition between Ca^{++} and Mg^{++} ions in this system than in the $CaCO_3$ system. Thus, greater degree of leaching of Mg may prevail where $CaCO_3$ was applied. Soil extractable Si (with 1 N neutral NH_4OAc) increased from 24 ppm at zero T/Ha $CaSiO_3$ to 138 ppm at 26.88 T/Ha rate of $CaSiO_3$ (fig. 6). There was a significant reduction in extractable silicon with increasing rate of $CaCO_3$ (fig. 6). It is obvious that increasing rates of $CaCO_3$ and/or soil pH seems to render $CaSiO_3$ less soluble. This may be due to the common ion effect and/or to the pH level, with common ion effect being more plausible.

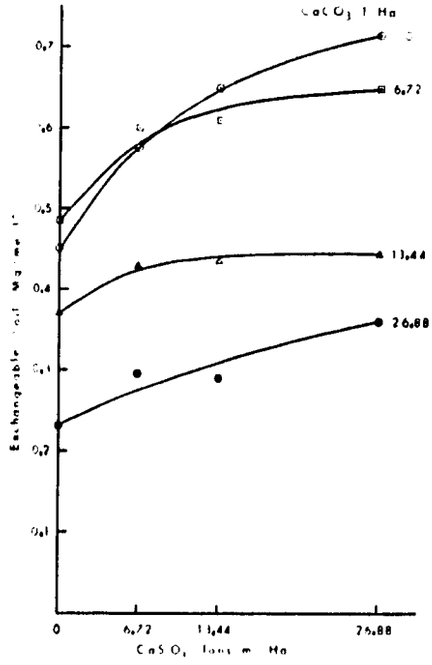

Fig. 5 The Effect of $CaSiO_3$ and $CaCO_3$ on Soil Exchangeable Magnesium.

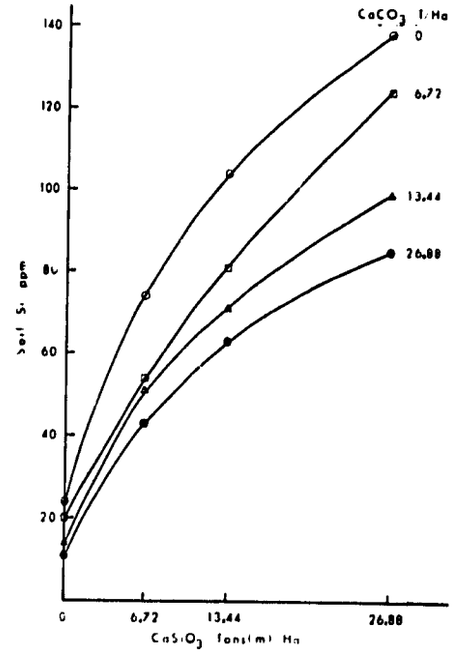

Fig. 6 The Effect of $CaSiO_3$ and $CaCO_3$ on Soil Extractable Silicon.

Summary and conclusions

Application of $CaSiO_3$ to a Hydric Dystrandept Soil increased dry matter yield of sorghum . Calcium carbonate caused a great decrease in yield. When $CaSiO_3$ was applied with $CaCO_3$, it had a tendency to reduce the « harmful » effect of $CaCO_3$ on growth of sorghum. Tissue percent N was generally increased with increasing rate of $CaCO_3$ and decreased with increasing rate of $CaSiO_3$. $CaCO_3$ significantly increased tissue phosphorus, while CaSiO did not have any significant effect. Plant tissue K was found to decrease with increasing $CaSiO_3$, while $CaCO_3$ had no significant effect. An increase in tissue Ca was associated with increasing rates of $CaSiO_3$ as well as $CaCO_3$. Reduction in tissue Mg was very considerable with increasing rate of $CaCO_3$, while with increasing rates of $CaSiO_3$ this reduction was non significant. It seems that $CaSiO_3$ has a « stabilizing » effect on Mg uptake. This in general agrees with results reported by Bonischot [2]. Tissue percent Si consistently increased with increasing $CaSiO_3$ applications while $CaCO_3$ at intermediate levels reduced tissue percent Si.

Both $CaCO_3$ and $CaSiO_3$ increased soil pH significantly to a rate of 13.44 T/Ha of $CaCO_3$. Above that rate there was no significant increase in soil pH. This may be due to the common ion effect (Ca) or due to lower solubilities of these compounds at the soil pH levels achieved. This phenomenon also seems to apply to soil exchangeable Ca as well as to soil extractable silicon.

Increasing rates of $CaSiO_3$ were found to enhance Mg retention by the soil, while with increasing rates of $CaCO_3$ soil exchangeable Mg was signifcantly reduced. The reduction in sorghum yield due to applications of $CaCO_3$ may be due to low levels of soil Mg that were associated with the $CaCO_3$ treatments.

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Résumé : Action du silicate et du carbonate de calcium sur la croissance du sorgho — Y.N. Tamimi et D.T. Matsuyama

Dans un essai en vases réalisé avec du sorgho dans un sol limono-argileux humide, il a été constaté que le rendement du sorgho était augmenté par une application de silicate de calcium et diminué par une application de carbonate de calcium. Celui-ci a provoqué une diminution de la teneur du sorgho en magnésium ainsi que de la teneur du sol en Mg échangeable. Par contre, le silicate de calcium a augmenté cette dernière et n'a pas donné lieu à une diminution significative de la teneur en Mg du sorgho. Cette constatation expliquerait l'effet favorable du silicate de calcium sur le rendement.

L'influence du $CaCO_3$ et du $CaSiO_3$ sur le pH du sol et sur les teneurs du sorgho en N, P, Ca et Si a également été étudiée dans cet essai.

Resúmen : Acción del silicato y del carbonato de calcio en el crecimiento del sorgo — Y.N. Tamimi y D.T. Matsuyama

En un ensayo en macetas realizado con sorgo, en suelo limo-arcilloso húmedo, se ha observado que el rendimiento del sorgo aumentaba debido a una applicación de silicato de calcio y disminuia debido a una aplicación de carbonato de calcio. Este ha producido una disminución del contenido del sorgo en magnesio, asi como del contenido del suelo en Mg cambiable. Por el contrario, el silicato de calcio ha aumentado ésta última y no ha dado lugar a una disminución significativa del contenido en Mg del sorgo. Esta observación explicaria el efecto favorable del silicato de calcio en el rendimiento.

La influencia del $CaCO_3$ y del $CaSiO_3$ en el pH del suelo y en los contenidos del sorgo en N, P, Ca y Si ha sido igualmente estudiada en este ensayo.

Zusammenfassung : Wirkung des Calziumsilikats und -Karbonats auf das Wachstum der Sorghumhirse — Y.N. Tamimi und D.T. Matsuyama

Aus einem Gefässversuch zu Sorghumhirse auf feuchter lehmiger Tonerde ging hervor, dass der Ertrag der Sorghumhirse durch eine Zufuhr von Calziumsilikat erhöht aber mit Calziumkarbonat vermindert wurde. Calziumkarbonat führte zu einer Abnahme des Magnesiumgehalts bei der Sorghumhirse sowie des Gehalts an Austauschmagnesium im Boden. Dagegen wurde letzterer durch Calziumsilikat erhöht und keine bedeutsame Abnahme des Mg-Gehalts wurde bei der Sorghumhirse festgestellt. Daher soll das Calziumsilikat sich auf den Ertrag günstig auswirken.

Der Einfluss des $CaCO_3$ und $CaSiO_3$ auf den Boden-pH und die N-, P-, Ca- und Si-Gehalte der Sorghumhirse wurde auch untersucht.