

Crop Response to Soil Acidity Factors in Ultisols and Oxisols in Puerto Rico. VI. Grain Sorghum^{1,2}

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ABSTRACT

The effects of various soil acidity factors on yield and foliar composition of sorghum (*Sorghum bicolor* (L.) Moench) were determined. Sorghum responded strongly to liming in yield on two Ultisols and one Oxisol. The response was stronger on the Ultisols than on the Oxisol. On the Ultisols, yields of grain produced by a seed and a ratoon crop decreased as the percent Al saturation of the soil increased, averaging only 861 kg/ha on the Corozal clay, and only 428 kg/ha on the Corozal subsoil at the highest Al saturation percentage, as compared to 5,255 and 3,969 kg/ha with no Al, respectively. On the Oxisol, the yields were not so drastically reduced because the highest Al saturation attained was only 34%. On all soils, yields increased with increasing pH, and decreased as the Al/base ratio increased. The P content of the leaves decreased significantly with increasing soil acidity and was highly correlated with grain yields of the seed crop on the Ultisols. The Ca content of the leaves was not correlated with soil acidity factors, nor was it correlated as closely with yields as has been shown in crops such as soybean and corn.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is an important cereal crop throughout the tropics. It is used mainly as animal feed in many areas, but it is also used for human consumption in East and Central Africa (16). Because of its drought resistance it is also gaining popularity as a substitute for white corn in the dry areas of Nicaragua and Honduras.⁴

The response of sorghum to liming has been studied in many tropical countries, but the effects of the various soil acidity components on foliar composition and nutrient uptake have not been fully evaluated. Soares et al. (13), working with dark-red latosols (Oxisols) at the Brasilia Experiment Station, found that the applications of 5 t of lime/ha increased sorghum yields 140%. The soil had an initial pH of 4.2 and 86% Al saturation. Spain et al. (14), working at Carimagua, Colombia, found that maximum yields of sorghum were obtained by applying 2 t of lime per hectare to an acid Oxisol with 78% Al saturation. Awan (5) found a highly significant increase in sorghum yields when Zamorano soils in Honduras

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⁴ Personal communication, Anibal Palencia, 1977.

were limed to pH 6.5. Hortenstein and Blue (9) reported a positive response of sorghum to lime applications that raised the pH from 5.4 to 6.3 on a fine sandy loam in Honduras. Foster, in Uganda, (8) found that sorghum responded to lime applications in only one out of four trials, even though the soil pH was 5.1. Cabala and Fassbender (6) found that sorghum responded to liming in three out of eight trials carried out on acid soils of Bahia, Brazil, even though pH values were above 5.5 before liming.

In the study reported here, the relationships between the various soil acidity factors were determined. The factors studied were pH, Al saturation and exchangeable Al to exchangeable base ratio, against yield and foliar composition of grain sorghum grown in two field experiments on two Ultisols. On the Oxisol no foliar analysis was performed, and the only relationships studied were those between soil acidity factors and yield.

MATERIALS AND METHODS

The experiments were carried out during the spring of 1974 on a normal Corozal clay, and on a Corozal clay subsoil (topsoil removed) at the Corozal Experiment Substation, located in the mountainous region of Puerto Rico and on a Coto sandy clay (Tropeptic Haplorthox) at the Isabela Experiment Substation, located in the northwestern part of Puerto Rico. There were 30 4m² plots at both Corozal sites, and 40 at the Coto soil site. All plots were surrounded by ditches 10 cm deep, to avoid runoff from one plot into another. Every plot had variable concentrations of exchangeable Ca, Mg, Mn and Al resulting from various lime rates that ranged from 0 to 2.6 t/ha on Coto soil and from 0 to 5.9 on Corozal soils.

The soil in each plot was sampled (1 month after planting the sorghum) by taking 10 borings to a depth of 15 cm. The samples were air dried and extracted with *N* NH₄OAc to determine exchangeable K, Ca, Mg, and Mn in the leachate. Calcium and Mg were determined by the Versenate titration method (7), K by flame photometry, and Mn colorimetrically after reduction with KIO. Exchangeable Al was extracted with *N* KCl and determined by the double titration method (11). Soil reaction was measured with a glass electrode on a 1 to 1.5 soil-water ratio.

Sorghum DeKalb hybrid F-61 was seeded 10 cm apart in rows 60 cm apart. All plots were fertilized at a rate of 112 kg of N/ha from (NH₄)₂SO₄, 84 of P₂O₅ from triple superphosphate and 112 of K₂O as KCl. Half of the fertilizer was applied at seeding time, and the rest 40 days after planting. Overhead irrigation was applied as needed to raise soil humidity to field capacity.

Samples of the third and fourth leaves from plants on the central row of every plot of the Corozal soils were taken at the prebloom stage,

and analyzed for N, P, K, Ca and Mg. No leaf samples were taken at the Coto soil site.

Heads were harvested by hand when less than 10% of grains were green and further dried to 14% moisture.

RESULTS AND DISCUSSION

COROZAL CLAY SOIL

Table 1 shows that the combined yields of a seed and a ratoon crop of sorghum decreased sharply with Al saturation when saturation exceeded 50%. At this level, 74% of maximum yield was attained compared with only 16% when the soil was 68% Al saturated. The effect of the soil acidity factors was more evident on the ratoon than on the seed crop. At the 50% Al saturation level, the seed crop produced 61% of maximum, while the ratoon crop yielded only 32%. The seed and the ratoon crops produced essentially the same yields when Al saturation was less than 8%, but ratoon crop yields were considerably lower than seed crop yields at Al saturation levels higher than 30%.

Table 1 also shows that all leaf components except Mg and Mn decreased with increasing soil acidity. However, the most significant change occurred with P content, which in the seed crop at Corozal decreased from 0.34% when there was no active Al present in the soil to 0.19% when the Al saturation was 68%. Previous work with other crops on these sites (1, 2, 3, 4) showed that Ca content of the leaves was affected most by the soil acidity factors, whereas P content was not affected at all. Lockman (10) reported very little effect of soil acidity factors on the leaf composition of sorghum except that Mn was increased 2 to 5 times at the highest level of soil acidity. This was not the case on Corozal soil. Manganese contents were very low even on the strongly acid plots. Probably the preponderance of active Al in the soil solution inhibited the uptake of Mn (12).

Correlation coefficients in table 2 show that all the soil acidity factors were significantly correlated with yields. The highest correlations were between yield and percent Al saturation, and between yield and the ratio of exchangeable Al to exchangeable bases. Calcium content of the leaves was not correlated with soil acidity factors. Phosphorus content was positively correlated with all acidity factors and with the yield of the seed crop.

COROZAL CLAY SUBSOIL

Table 1 shows that the seed crop produced higher yields than the ratoon crop at all Al saturation levels, except at the 0 saturation level. The reduction in yield between the seed and the ratoon crops ranged

TABLE 1.—Effect of soil acidity factors on yield and foliar composition of grain sorghum grown on two Ultisols and one Oxisol in the uplands of Puerto Rico

Soil acidity factors				Yield Data				Foliar composition ²			
pH	Al ¹ sat.	Exch. Ca + Mg	Exch. Al	Seed crop	Ratoon	N	P	K	Ca	Mg	Mn
			Exch. bases	Grain Yields							
	%	me/100 g		kg/ha							p/m
<i>Corozal clay soil—Aquic Tropudults</i>											
5.55	0	12.93	0	2,500	2,740	3.70	.34	2.31	.65	.17	.10
5.10	8	9.73	.08	2,450	2,340	3.71	.31	2.31	.64	.19	.12
4.80	24	6.43	.32	2,280	1,900	3.68	.30	2.30	.56	.20	.11
4.70	37	6.26	.59	2,000	1,850	3.73	.29	2.09	.58	.18	.12
4.55	50	5.92	1.00	1,550	890	3.57	.25	2.04	.63	.19	.10
4.40	68	4.31	2.12	670	200	2.68	.19	1.92	.55	.19	.10
<i>Corozal clay subsoil—Aquic Tropudults</i>											
5.40	0	8.89	0	2,290	1,680	3.79	.30	2.02	.72	.16	.12
5.00	12	7.78	.14	2,000	1,600	3.72	.28	2.03	.70	.18	.12
4.80	25	6.78	.34	1,710	1,160	3.71	.26	1.99	.73	.14	.12
4.65	38	5.80	.62	1,640	1,160	3.62	.24	1.97	.72	.16	.10
4.50	51	4.71	1.05	1,110	740	3.41	.21	1.83	.66	.18	.12
4.35	64	3.01	1.78	520	130	3.00	.18	1.82	.62	.17	.12
4.20	76	3.00	3.17	210	210	3.31	.18	1.84	.59	.18	.14
<i>Coto sandy clay—Tropetric Haplorthox</i>											
5.20	0	2.89	0	2,630							
4.90	8	2.30	.08	2,390		No ratoon crop harvested			Not determined		
4.70	23	2.23	.30	2,090							
4.50	34	2.00	.51	1,530							

¹ Percent Al saturation = $\frac{\text{Exchangeable Al}}{(\text{Exchangeable Ca} + \text{Mg} + \text{K}, \text{Al} + \text{H})}$
² Foliar composition data for seed crop only.

from 36% at 0 Al saturation percentage to 75% at the 64% Al saturation level.

(The topsoil of Corozal soil was removed many years ago). Yields on Corozal subsoil were considerably lower than those on the normal Corozal soil at all Al saturation levels with both seed and ratoon crops. In the seed crop, the yield differences between soils ranged from 10% at 0 Al saturation to 39% at 50% saturation. In the ratoon crop yields were about

TABLE 2.—Correlation coefficients between soil acidity factors, yield and foliar composition of sorghum grown in two Ultisols and one Oxisol

Independent variable (X)	Yield (Y)			Foliar (Y) composition (%)	
	Seed crop	Ratoon crop	Total	Ca	P
<i>Corozal clay—Topsoil</i>					
pH	.78** ¹	.81**	.83**	Non sig.	.74**
% Al saturation	.84**	.83**	.86**	do	.77**
Al/bases	.84**	.81**	.86**	do	.77**
Exch. Ca + Mg	.69**	.65**	.69**	do	.64**
% Ca in leaves	.54**	—	—	—	—
% P in leaves	.83**	—	—	—	—
<i>Corozal clay—Subsoil</i>					
pH	.89**	.83**	.88**	Non sig.	.79**
% Al saturation	.88**	.82**	.87**	do	.68**
Al/bases	.86**	.81**	.85**	do	.68**
Exch. Ca + Mg	.87**	.81**	.86**	do	.69**
% Ca in leaves	.56**	—	—	—	—
% P in leaves	.90**	—	—	—	—
<i>Coto sandy clay²</i>					
pH	.79**	—	—	—	—
% Al saturation	.77**	—	—	—	—
Al/bases	.76**	—	—	—	—
Exch. Ca + Mg	.67**	—	—	—	—
% Ca in leaves	—	—	—	—	—
% P in leaves	—	—	—	—	—

¹ Significant at 1% level (Duncan multiple range).

² Only a seed crop was harvested and no foliar analysis was performed.

60% lower on the normal Corozal soil than on the Corozal subsoil at comparable Al saturation levels, except at the 76% saturation level.

As on the normal Corozal clay soil, the P content in the leaves was affected most by variations in the intensity of the soil acidity factors. The P content of the leaves from plants grown on the subsoil was around 13% lower than in those grown on the normal soil. This might partly explain the significantly lower yields produced by sorghum on the subsoil as compared to the yields on normal soil.

Table 2 shows that the correlation coefficients obtained between yields and soil acidity factors on the Corozal subsoil were similar to those obtained in the normal Corozal soil. Correlations between yield and the soil acidity factors in the subsoil were closer than in the normal soil.

As in the Corozal soil, Ca content of the leaves was not correlated with any of the soil acidity factors. On the other hand, P contents of the leaves and yields were very closely correlated. The P content of the leaves was correlated with all soil acidity factors. A closer correlation between P content of the leaves and percent Al saturation would be expected since the level of exchangeable Al at a given pH should reflect reactivity of the aluminous surfaces which in turn govern the solubility of P as shown by Summer (15).

COTO SANDY CLAY

Table 1 shows that sorghum yields of the seed crop on the Coto soil were similar to those obtained on the normal Corozal clay soil. Although the response to soil acidity factors was of the same magnitude as that on the other soils at low acidity levels, at 34% Al saturation sorghum produced only 60% of maximum yield as compared with 81 and 71% on normal Corozal soil and Corozal subsoil, respectively.

Table 2 also shows that although yields were significantly correlated with soil acidity factors, the correlation coefficients were generally lower in most cases, than those in the Ultisols. Other crops tested, e.g., soybean, corn, green beans and sweet potato, have also been less responsive to liming in Oxisols than in Ultisols (1, 2, 4). Apparently, at comparable pH values, the Al activity of the soil solution is less in Oxisols than in Ultisols. On the other hand, the Coto soil has an abundance of easily reducible Mn, and when the soil is acid, the exchangeable Mn is very high. Pearson et al. (12) have shown that Mn activity in the soil solution of Coto soil is many times greater than in Ultisols, while Al activity is the reverse. Response to liming of Mn-sensitive crops such as tobacco, has been partly attributed to Mn toxicity (3). Although no data were obtained on Mn content of the sorghum leaves, Mn toxicity could have contributed to the lower yields. Lockman (10) has reported high Mn contents in the leaves when sorghum was grown on very acid soils.

ALL SOILS COMBINED

Figures 1 to 3 show that when data for all three soils were combined on the basis of relative yields, very close correlations were obtained between soil acidity factors (pH, percent Al saturation and the exchangeable Al to exchangeable bases ratio) and yields.

Figure 1 shows that maximum yield was attained around pH 5.2, which

corresponds to the point at which all active Al^{3+} precipitates, while essentially no yield was produced when pH dropped to around 4.2.

Figure 2 shows that when the soil was 80% saturated with exchangeable Al, no yield was produced. In terms of sensitivity to Al toxicity, sorghum seems to be similar to corn (2), more tolerant than soybean (1) and considerably more sensitive than sweet potato (4).

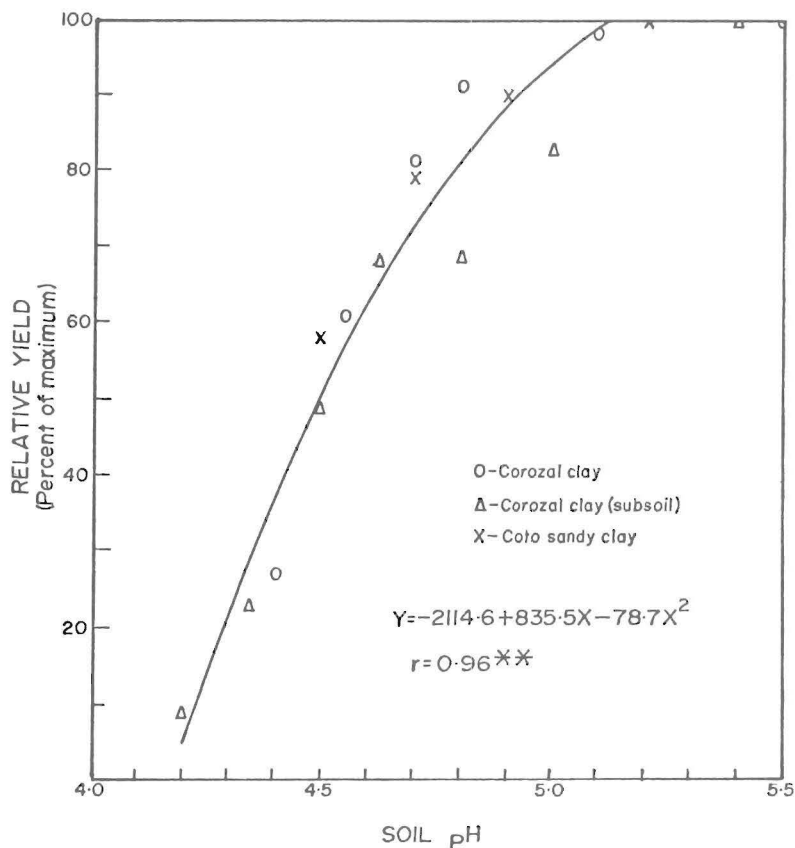


FIG. 1.—Relationship between soil pH and the relative yield produced by grain sorghum grown on two Ultisols (the Corozal soils) and one Oxisol (the Coto soil).

Figure 3 shows that when the ratio of exchangeable Al to exchangeable bases is greater than 1, yields are drastically reduced.

Figure 4 shows that a P content of around 0.3% was associated with maximum yield, and that when this content dropped to around 0.15%, essentially no yield was produced.

RESUMEN

Se estudió el efecto de los factores de acidez de dos Ultisols y un Oxisol sobre la producción de granos por sorgo (*Sorghum bicolor* (L) Moench). Todos los factores de acidez se correlacionaron íntimamente con los rendimientos, pero se lograron coeficientes de correlación más

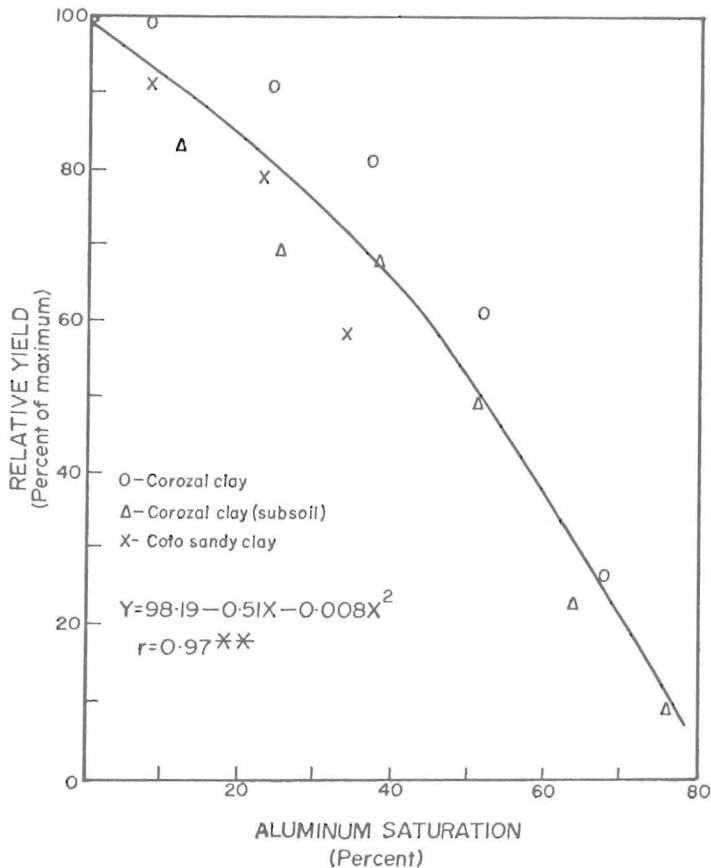


FIG. 2.—Effect of Al saturation of two Ultisols (the Corozal soils) and one Oxisol (the Coto soil) on grain sorghum yields.

altos con el porcentaje de saturación con Al y la razón Al/bases en el caso del suelo Corozal arcilloso y con el pH y el porcentaje de saturación con Al en el caso del subsuelo. En el suelo Coto, aunque también se lograron coeficientes de correlación altamente significativos, los mismos

no fueron tan altos como los obtenidos en el suelo Corozal y en su subsuelo.

Aunque casi todos los contenidos de los constituyentes químicos de las hojas se redujeron notablemente a extremos de acidez, el fósforo mostró las variaciones más notables. La correlación de éste con la producción fue significativa en el suelo y el subsuelo Corozal. Esto también fue cierto con respecto al P y los factores de acidez de dichos

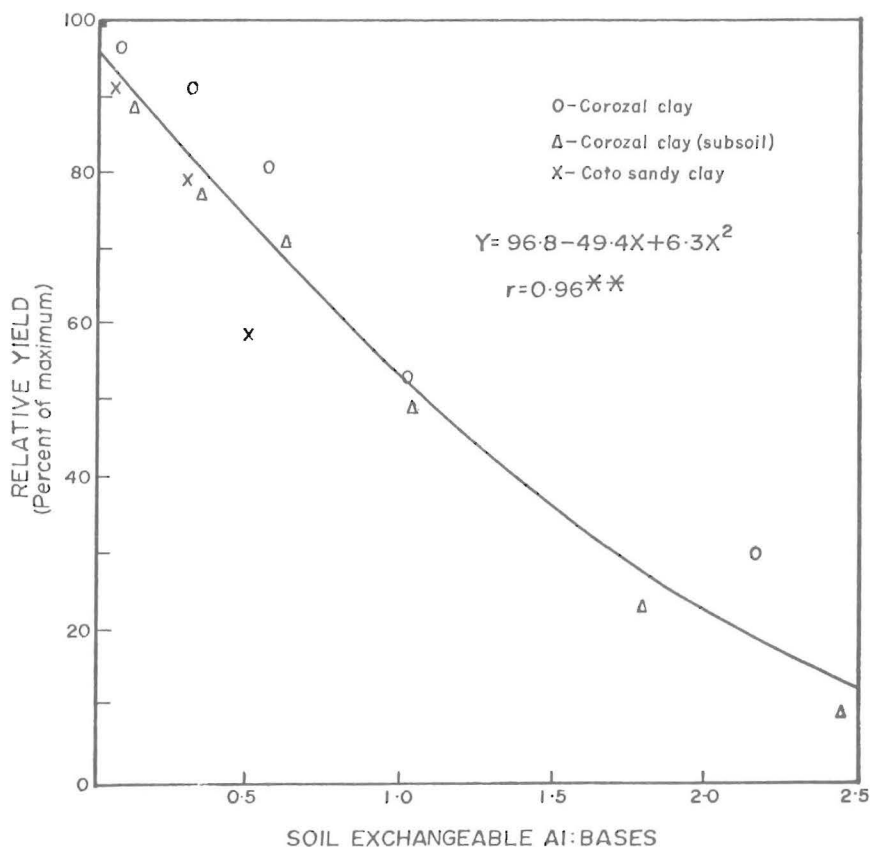


FIG. 3.—Relationship between the ratio of exchangeable aluminum to exchangeable bases of two Ultisols (the Corozal soils) and one Oxisol (the Coto soil), and grain sorghum yields.

suelos. Las correlaciones fueron más altas en el caso del subsuelo. El contenido de Ca en las hojas no estuvo correlacionado con los factores de acidez, como en el caso de otros cultivos, tales como sojas y maíz.

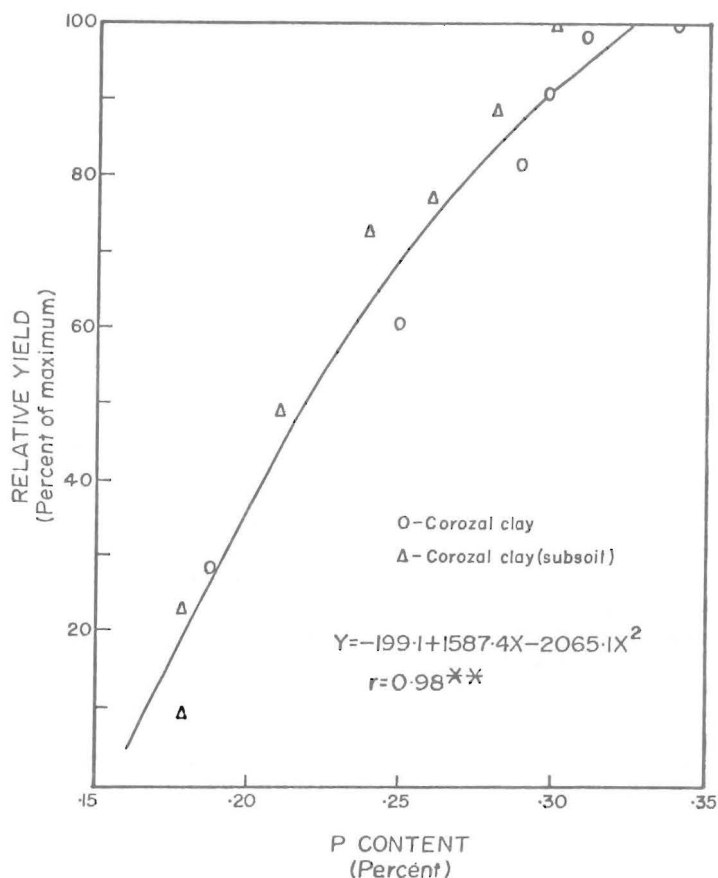


FIG. 4.—Correlation between the P content of the leaves and grain yield produced by sorghum grown on two Ultisols.

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