EFFECT OF SUGAR FOAM WASTE AND PHOSPHOGYPSUM ON A MEDITERRANEAN ULTISOL UNDER FORAGE CROPPING

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1 INTRODUCTION

Raña formations are a common occurrence in the landscape of SW Spain, where they span wide areas hundreds of square kilometers in size, which act as watershed divides. They were formed in the Middle-Upper Pliocene and support very old and highly weathered soils, whose properties have resulted mostly from the action of a pre-Quaternary climate with subtropical features (Espejo, 1987). Agriculturally, *raña* soils are very poor and subjected to a number of severe constraints as regards exploitation due to the effect of their poor Ca, Mg, K and P availability, and high Al contents in the exchange complex (Espejo, 1987; Peregrina et al., 2006).

In the 1930’s and 1940’s, most of the natural vegetation on these surfaces was cleared for agricultural use. Tillage of these virgin soils increased the mineralization rate of the organic matter (SOM) and, as a result, after several decades of crop production, the soils evolved from Palehumults to Palexerults (Soil Survey Staff, 2003).

The loss of SOM , and the extraction of bases by crops further reduced the already low productivity of these soils, reducing nutrient bioavailability and the Ca/Al ratio, with the latter causing an increase in Al toxicity (Mariscal-Sancho et al., 2009). This led to most of the tilled fields being abandoned within 20-50 years of clearing.

Any regeneration or rehabilitation measure to be adopted for these degraded soils should consider preliminary liming, in order to increase base saturation in the exchange complex, raise the Ca/Al ratio, and encourage the success of conservative management practices, which promote the accumulation of OM and the storage base capacity.

The objective of this work was to evaluate the incidence on the exchange complex of the application of lime amendments in the form of sugar foam waste (sugar-manufacturing residue), alone or accompanied by another industrial bye product like phosphogypsum, the latter with the aim of supplying Ca to the subsurface horizons as gypsum is more soluble than lime. The effect on the biomass production was studied through the yield of a forage crop.

2 MATERIALS AND METHODS

2.1 Study zone

The study was conducted at the Cañamero *raña* (SW Spain). The longitudinal slope of the zone is about 0.5% and the average height of the study sites was 615 m a.s.l. The mean annual precipitation of this surface is 869 mm, the mean annual evapotranspiration (Penman-Monteith) is 1248 mm, and the mean daily temperature is 15.0ºC. The soil moisture regime for this *raña* surface is Xeric I (Espejo, 1987).

2.2 Experiment field

In 2002 an experiment field was designed by the random block system with four replications. The individual plots measured 6x12 $m^{2.}$

2.3 Treatments

The treatments applied to the plot soil were: Control; sugar foam waste (SFW), and SFW + phosphogypsum (PG). Table 1 gives the composition of the two amendment products.

The amendments were applied manually. In the case of the foam, this was applied at a dose equivalent to 3.9 t/ha, needed to raise the pH of the horizon Ap from 5.1 to 6.2; the dose was determined in the laboratory by incubating, at a field capacity and 25ºC for one month, 100 g samples of the horizon Ap which had received increasing amounts of sugar foam equivalent to 2, 3, 5 and 7 t/ha; the pH curve permitted the determination of the dose necessary for reaching the desired pH. The phosphogypsum dose was fixed so that it supplied the same amount of Ca as that of the Ca + Mg contained in the sugar foam waste, resulting in a dose of 6,800 kg/ha.

TABLE 1 **SFW and PG composition according to Peregrina, (2006).**

Component	SFW (g / kg)	PG (g / kg)
CaO	437	287
SO_4^{2-}	5,1	515
SiO_2	17,3	3,9
P_2O_5	8,1	8,6
MgO	47,3	<0,1
F^-	nd	12,3
Al_2O_3	24,2	5,8
K_2O	1,95	<0,5
Fe_2O_3	1,9	0,35
Na_2O	1,05	1,2
TiO_2	nd	0,2
MnO	47,3	<0,1
Mat. Org	86,7	nd
caliza	765	nd
caliza activa	213	nd
PI*	467,6	178

Element	SFW (mg/kg)	PG (mg/kg)
Ni	<0.5	<2
Ba	19,7	30,8
Zn	24,7	6,1
Cu	4,7	3,3
Cd	nd	1,45
Pb	<0,5	1,75
Mo	0,2	0,2
Cr	nd	2,12

PI*.- ignition lost (100-1000 ºC). nd.- not detected

2.4 Crops used

The plots were sown with a mixture of cereals and winter legumes. Table 2 shows the crops sown each year and the fertilizer dose employed.

TABLE 2 **Crop data for the period between 2003 and -2007 .**

Year	Crop	pre-growing (kg/ha)	fertilization	
		N	P_2O_5	K_2O
2003-2004	Triticale + rye+Vetch	70	70	70
2004-2005	Triticale + Vetch	35	70	70
2005-2006	Oat + Vetch	35	70	70
2006-2007	Oat+Triticale+Vetch	35	70	70

2.5 Laboratory methods

pH was measured in 1:2.5 soil/distilled water and soil/0.01 M KCl suspensions. Exchangeable bases were extracted with 1 N NH_4Ac at a soil/solution ratio of 1:10 (Thomas, 1982), the extracts being used to quantify Ca and Mg by "atomic absorption spectrophotometry", and Na and K by "atomic emission spectrophotometry". Aluminum was extracted with a 1 N KCl solution (Barnishel and Bertsch, 1982) and determined by titration with NaF (Yuan, 1959). Electric conductivity (EC) was measured in 1:2.5 soil/distilled water suspensions with a CM 2202 conductivimeter

3 RESULTS

3.1 Incidence on the exchange complex

Table 3 shows the data of the evolution of the pH, the content in base-exchanges and KCl extractable Al 4.5 years after the application of the amendment. In general, both amendments induced positive changes in the pH and Ca content by increasing both. Concomitantly, the Al content declined in the Ap and AB horizons, therefore increasing the ratio Ca/Al. In the deepest layer, the SFW+PG treatment showed itself to be more effective with respect to Ca and Al. Mg decreased significantly in the Ap horizons of the soils amended with SFW+PG. This effect previously observed in acid soils amended with gypsum (O'Brien, and Sumner, 1988; Ritchey and Snuffer 2002). In our case, the Mg in the Ap horizon of the soils amended with SFW+PG represented 1.7% of the ECEC, which is largely below the response threshold of 7% established by Hailes *et al.* (1997). In the SFW+PG treatment the Mg content of 3.13% did not meet this threshold either. Na followed a similar trend as observed forMg..

TABLE 3 **pH, electric conductivity, exchangeable bases and Al in Ap, AB and Bt horizons after 4.5 years of amendments application.**

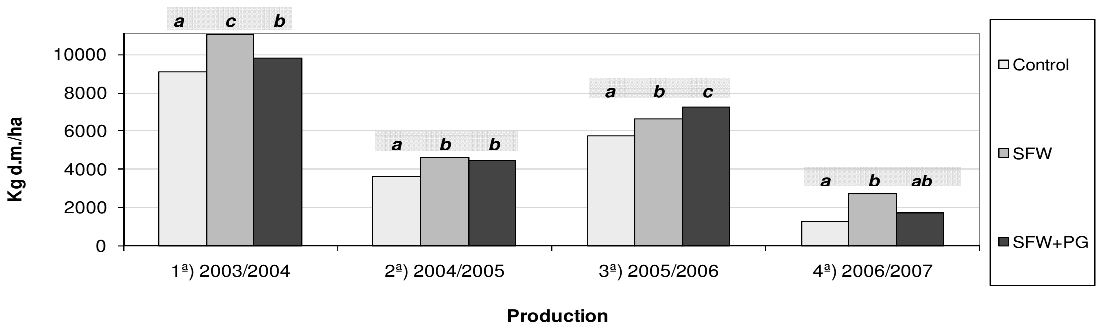
	pH 1:2,5H$_2$0	pH KCl	CE µS/cm	Ca (cmol$_{(+)}$kg^{-1})	Mg	K	Na	Al	ECEC	Ca/Al	% Mg
	Ap horizon (0-20 cmdepth)										
CONTROL	5.26a	4.64a	67.0a	1.64a	0.17b	0.185a	0.068b	0.67b	2.06a	2.45	7.83c
SFW	6.31b	5.87b	95.3b	6.12c	0.21b	0.193a	0.058b	0.00a	6.58b	>100	3.13b
SFW + PG	6.25b	5.83b	120.4c	5.67b	0.10a	0.205a	0.040a	0.00a	6.02b	>100	1.69a
	AB horizon (20-35 cmdepth)										
CONTROL	5.17a	3.94a	36.08a	1.05a	0.10a	0.085a	0.058a	1.47b	1.29a	0.71a	3.45a
SFW	5.52b	4.22a	40.23a	1.25b	0.10a	0.103b	0.058a	1.27a	1.51a	0.98b	3.68a
SFW + PG	5.41b	4.35a	61.93b	1.26b	0.09a	0.100b	0.063b	1.14a	1.51a	1.11c	3.22a
	Bt1 horizon (muestreado de 35-50 cm depth)										
CONTROL	4.83a	3.8a	25.3a	0.85a	0.1a	0.09a	0.07a	1.48b	1.11a	0.57a	3.88a
SFW	4.84a	3.89a	40.9a	0.99b	0.1a	0.085a	0.065a	1.51b	1.24a	0.66a	3.65a
SFW + PG	4.76a	4.14b	71.1b	1.17b	0.11a	0.08a	0.075a	1.27a	1.43a	0.93b	3.90a

Different letters indicate significant differences according to LSD (P<0.05) within a column and a soil depth µ.- Effective cation exchange capacity: Echangeable bases + Al. nd.- No determinado.

3.2 Biomass production

Figure 1 shows the yields obtained from different crops during the period of 2003-2007. In all period, the treatment with SFW and the treatment SFW combined with PG, increased the production of biomass (the yield is in kg of aerial dry matter per ha). In all the seasons there was a positive response in both treatments. The low yields reached in the seasons of 2004-2005 and 2006-2007 were due to lack of rain throughout the spring and beginning of summer.

FIGURE 1 **Biomass production along in kg of aerial dry matter (d.m) per ha between 2003 and 2007**



4 CONCLUSIONS

The application of SFW alone or combined with PG improved the agronomic characteristics of the degraded Palexerults of the *raña* of Cañamero. After 4.5 years of applying an amendment, the pH and Ca content increased and the Al declined in the exchange complex in the upper 35 cm of the soil. The PG induced a decrease in the exchange Mg. This dynamics was accompanied by an increase in the production of biomass of diverse forage crops.

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