INFLUENCE OF MANAGEMENT WITH SALIC MULCH ON SOIL TEMPERATURE

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The use of salic pyroclasts as soil mulch is a common management practice in arid conditions in southern and south-eastern parts of the island of Tenerife (Canary Islands, Spain). It forms the basis for a traditional farming technique, which is known locally as 'jable'. In its various forms the practice, used at heights of 300-1500 metres, covers an area of 3,850 hectares. The present work examines its influence on soil temperature and particularly on the estimation of Classes of Soil Temperature (Soil Survey Staff, 1999). Soil temperature was measured monthly at 50 cm depth in six covered plots and in adjacent uncovered plots, all located at different altitudes: 325-375, 600, 825 and 1275 m. In each season, measurements were also taken at 0, 10, 20, 30, 40 and 50 cm. The thickness of the mulch covering varied between 23 cm and 43 cm. The natural altitudinal soils sequence was as follows: aridisols, vertisols and vertic inceptisols, and inceptisols. The covered soil is currently used to grow grapes and/or potatoes while the natural soil has natural vegetation. The results evidence the buffering effect of the system, which is more marked at the lower heights of the sequence. Whereas the natural soils have a hyperthermic temperature regime (annual soil temperature, mean ≥ 22ºC, and a difference between mean summer temperature, mst, and mean winter temperature, mwt, > 6ºC) the soils under the pumice are isohyperthermic (mean ≥ 22ºC and mst-mwt < 6ºC). At approximately 600 m, the natural soils are thermic (15≤mean<22ºC and mst-mwt >6ºC) and the covered soils are isothermic (mst-mwt < 6ºC). This situation is maintained up to 800/900 m, where the buffering effect of the pumice is less pronounced. The temperature profiles are also influenced by the system. In the natural soils, temperature decreases with depth, while in the covered soils this occurs only in summer. The management system helps prevent high temperatures and enables the soil to be used for farming.

INTRODUCTION

Arid regions are characterised by their lack of water and their daily and seasonal temperature fluctuations, particularly in the top layers of the soil. Inorganic mulch is commonly used to conserve the moisture and control the temperature of the soil.

Regarding soil temperature control, while many articles report the use of plastics as mulch (Bowers, 1968; Maher et al. 1984; Guttormsen, 1992; Larrea and Suzuki, 1997; Li et al., 2003), fewer describe the use of lithic materials (Othieno and Ahn,1980; Nachtergaele et al., 1998; Woldeab et al., 1994; Tejedor et al., 2000; Díaz, 2004). In Kenya, Othieno and Ahn, 1980, found the temperature in soils covered with ground volcanic rock to be higher than in unmulched soils. A similar conclusion was reached by Nachtergaele et al., 1998, in studies conducted in Chamoson (Switzerland), in soils covered with gravel. Conversely, Woldeab et al., 1994, in Ethiopia, noted lower temperatures in soils covered with a layer of pumice, as well as in others covered with basaltic scoria. Díaz, 2004, reached similar conclusions in studies carried out on the island of Lanzarote in Spain, in soils covered with basaltic pyroclasts. Few references exist in the literature concerning how soil temperature changes caused by mulch affect the definition of Classes of Soil Temperature (Soil Survey Staff, 1999).

A farming system, known locally as 'jable' and involving the use of a surface layer of pumice, has been developed in very arid conditions in southern and southeastern Tenerife (Canary Islands, Spain). While the system has been described in the literature (Martín et al., 1993; Rodríguez Brito, 1988, 1996; Álvarez, 1997; Sabaté, 1997; Morales and Pérez, 2000), there have been no studies to date on the influence this lithic mulch exerts on the properties of the soil underneath.

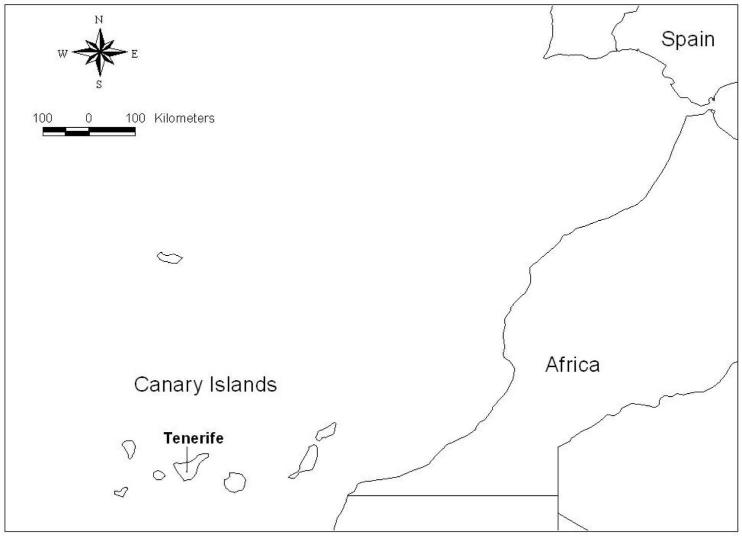
The objective of the present paper is to examine the effect of the pumice covering on the soil temperature and on the classes of soil temperature. To this end we conducted a comparative study of covered and uncovered soils and also studied the relationship between the soil temperature and the main properties of the material used as mulch.

MATERIALS AND METHODS

Description of the Study Area

The island of Tenerife, which covers an area of 2,057 km^2 and has a maximum height of 3,718 m, is the largest and highest of the Canary Islands (Spain). It is situated near the Tropic of Cancer, at 28º 15' north latitude and 16º 30' west longitude (figure 1) and is influenced by the trade winds that affect the northern side of the island. Together with other factors, (height, altitude, orientation, cold sea current of the Canaries, etc) this circumstance makes for a wide variety of microclimates. The north is much wetter than the south or southeast, both of which are extremely arid. The island is of volcanic origin, with basalts and phonolitic materials predominating.

Figure 1
Location of the study area



The study zone is located on the south side of the island, at between 300 and 1300 m. Annual rainfall varies depending on height: from below 200 mm at heights of up to 500 m to 400 mm at the highest points in the study zone. The mean annual air temperature varies between 21ºC and 14ºC. Lithology is mainly with acidic materials, pumice deposits, agglomerates of lapilli and pumice tuff (Hausen, 1956), occasionally on top of basaltic formations. The altitudinal sequence of the soils is aridisols, vertisols and vertic inceptisols, and inceptisols.

System Description

In the arid conditions described above a traditional farming system has been developed, known locally as 'jable' and consisting of the placing of a 20-60 cm layer of pumice on the soil as mulch. Although many of the crops grow directly in the soil (vegetables, grapes), others -potatoes for example- grow in the layer of pyroclasts. Where this occurs, the ground is usually ploughed every two years to mix the pumice with the soil. The variety of uses of the system is reflected in plot selection. More than 3,800 ha are currently used for the practice.

Six representative sites were chosen to reflect the different soil types and different plot uses. At each site, in addition to the mulched plot, a natural soil plot nearby was selected also. Table 1 gives, for each site, the altitude, size of the mulched plot, average mulch layer thickness, type of use, soil type, and the natural vegetation in the plots not used for farming.

Table 1
Site description

Site	Altitude m	Area m^2	Thickness of pumice layer (cm)	Crop*	Soil	Natural vegetation ***
1	375	2700	33	potatoes	Haplocambids	Periploco laevigatae- Euphorbietum canariensis
2	350	1150	25	grapes	Haplocambids	Ceropegio fuscae-Euphorbietum balsamiferae
3	325	950	23	potatoes**	Haplocambids	Ceropegio fuscae-Euphorbietum balsamiferae
4	600	1100	34	grapes, potatoes	Calcitorrerts	Junipero canariensis-Oleetum cerasiformis
5	825	850	31	grapes	Haploxererts	Artemisia thusculae-Rumicetum lunariae
6	1275	1750	23	grapes	Haploxererts	Micromerio hyssopifoliae-Cistion monspeliensis

* in plots covered with pumice. ** currently abandoned. *** in non-covered plots

Sampling and Physical Methods

In order to characterise the pumice layer, samples were taken at two depths: in the top 10 cm (representative of the less degraded zone) and deeper down near the soil, a zone which is usually more altered and mixed with the soil. Moisture retention at tensions of 33 and 1500 kPa was determined by Richards pressure membrane. Bulk density was determined by calculating the weight presented by a given volume of sample in a 500 ml test-tube, with five replications. Total porosity was then calculated from bulk density and particle density (2.65 Mg m^{-3}). Average diameter size was estimated by mechanical sieving using an array of sieve-sizes (16, 8, 4, 2, 1 and 0.5 mm) for 10 minutes at 5 r.p.m.

Soil temperature measurements were taken monthly for one year at 50 cm (Soil Survey Staff, 1999) both in the mulched plots and also in the adjacent uncovered plots. On each date and for each plot 4 replications were carried out and the average value taken. When the difference between them exceeded 1ºC, two further measurements were taken and the highest and lowest values were eliminated. On one day in each season, temperature measurements were taken every 10 cm to 50 cm. Geo-thermometers of the T-Bar Digital Multi-Stem Thermometer type were used.

Results were analysed statistically using SPSS version 11.0.1 (SPSS Inc. 2001).

RESULTS AND DISCUSSION

Characterisation of the pumice mulch

Table 2 gives a selection of physical properties of the pumice layer near the surface and at deeper zones. Although all the properties conform to those of pumice pyroclasts (Díaz, 2004) - high water retention capacity, low bulk density, high porosity and high average particle diameter - the properties of the surface zone are more characteristic. The mixing with the soil that occurs deeper down is reflected in the variation in properties, namely, lower water retention capacity (at both 33 kPa and 1500 kPa), lower total porosity and smaller particle diameter, but greater bulk density.

Based on these properties, the systems can also be classified depending on the extent of mixing. The extremes are systems 6 and 3, where the degradation of the pumice layer is evident, and system 5, where the deterioration is lower. The other systems lie somewhere in between, with system 4 closer to the first pair and 1 and 2 to system 5. The grouping is confirmed by cluster analysis.

Table 2
Physical characteristics of the pumice layer

Site	Pumice layer	% Water Retention 33 kPa	% Water Retention 1500 kPa	B.D. (Mg m^{-3})	Total Porosity (%)	A. Diameter (mm)
1	surface	55.40	38.70	0.31	88.30	7.81
	bottom	38.00	37.60	0.35	86.79	4.61
2	surface	56.00	36.70	0.35	86.79	5.50
	bottom	50.40	16.70	0.50	81.13	2.98
3	surface	54.60	31.50	0.36	86.42	3.47
	bottom	44.90	14.00	0.53	80.00	2.71
4	surface	61.70	36.40	0.33	87.55	4.61
	bottom	45.60	17.50	0.59	77.74	2.20
5	surface	63.30	43.00	0.30	88.68	6.51

	bottom	46,90	23.10	0.45	83.02	2.48
6	surface	40.40	13.50	0.42	84.15	2.11
	bottom	34.30	12.90	0.67	74.72	1.85

B.D. = Bulk density. A.Diameter = Average particle diameter.

Soil temperature

Table 3 gives the mean annual temperature at 50 cm in the soils with and without the pumice cover, together with the difference between the two soil types both as regards the annual mean and the summer and winter means. Also shown is the difference between the mean summer and the mean winter temperatures in the mulched and unmulched soils.

Throughout the year the temperature is lower in the soils covered with pumice (figure 2), except in site 6 where it is slightly higher in November and December. In all the sites the mean annual temperature is also lower in the mulched soils, by an average of 2.8ºC, a reduction which is statistically significant ($p<0.01$) at all plot heights (table 3). The reduction is even more pronounced in the summer months (5.6ºC), whereas in winter the average reduction is 1.4ºC. In both seasons the differences are also statistically significant ($p<0.05$). The data highlight the buffering effect of the pumice on the soil temperature in all cases, although differences can be seen depending on the characteristics of the system. Statistical (cluster) analysis enables two groups to be differentiated according to effectiveness and these groups coincide largely with those identified when the types of pumice covering were classified.

The greatest differences between the mulched and unmulched soils were seen in sites 5 and 2, where the soils are covered by a relatively well-conserved layer of pumice. The behaviour of systems 1 and 4 was similar. The reduction in the mean annual temperature in the mulched soils compared to the naked soils is equal to or greater than 3.0ºC and this difference increases in summer to between 7.0ºC and 5.9ºC. In systems 6 and 3, where the layer of pumice was more deteriorated, a different pattern was seen compared to the others. The mean annual temperature reduction was lower (2.0ºC and 2.4ºC respectively) as were the differences in summer (3.9ºC and 3.6ºC). It can thus be concluded that the better-conserved layers of pumice, i.e. those that mix less with the soil, influence soil temperature to a greater extent.

Table 3

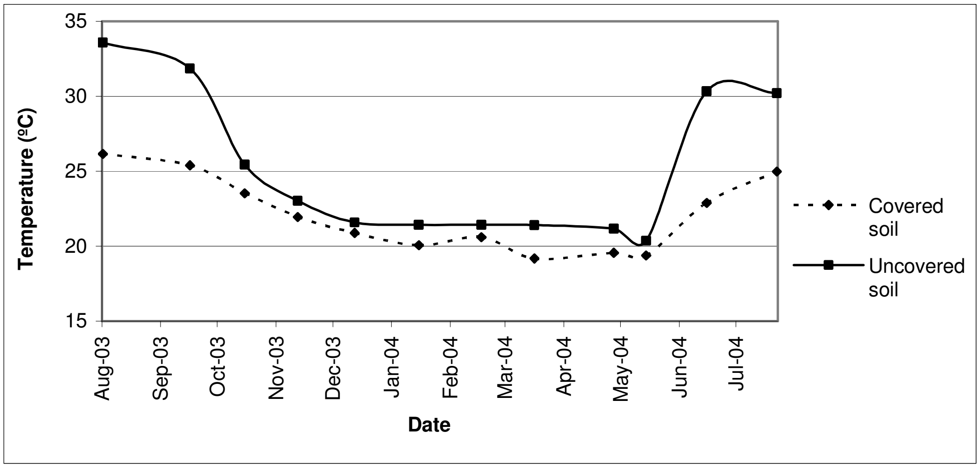
Influence of pumice layer on soil temperature variations and the resulting temperature regimes

Site	Soil	M	M^{unc} - M^{cov}	MST^{unc} - MST^{cov}	MWT^{unc} - MWT^{cov}	MST- MWT	S.T.R.
1	Covered	20.8	3.1	6.3	1.5	2.9	Isothermic
	Uncovered	23.9				7.8	Hyperthermic
2	Covered	22.0	3.1	6.7	1.0	4.2	Isohyperthermic
	Uncovered	25.1				9.9	Hyperthermic
3	Covered	22.0	2.4	3.6	2.0	4.8	Isohyperthermic
	Uncovered	24.4				6.4	Hyperthermic
4	Covered	19.8	3.0	5.9	1.6	4.2	Isothermic
	Uncovered	22.8				8.5	Hyperthermic
5	Covered	18.2	3.0	7.0	1.2	5.5	Isothermic
	Uncovered	21.2				11.2	Thermic
6	Covered	16.9	2.0	3.9	0.9	6.8	Thermic
	Uncovered	18.9				9.9	Thermic

M= Mean annual temperature. MST= Mean summer temperature. MWT= Mean winter temperature. ^{unc} = Uncovered soil. ^{cov} = Covered soil. S.T.R= Soil temperature regime

Figure 2

Monthly evolution of the temperature at 50 cm in a covered soil and a uncovered adjacent soil (site 2)



Classes of Soil Temperature Regimes

The Soil Taxonomy (Soil Survey Staff, 1999) defines classes of soil temperature regimes according to the mean annual soil temperature (M) at 50 cm, or up to certain contacts if less deep, and to the difference between the mean summer and winter temperature. The prefix *iso* is used where the seasonal difference is below 6ºC. Tejedor et al. (2003) have defined the following altitudinal sequence of soil temperature regimes for natural soils on the south side of Tenerife: hyperthermic (M>22ºC) up to 800 m and thermic (15ºC<M<22ºC) at higher elevations.

The use of pumice as mulch produces important alterations in the soil temperature regimes (table 3). Given that seasonal fluctuations are reduced, the *iso* element - which is not present in the natural soils- becomes more marked. Three different situations can be seen, depending on altitude (table 3):

- At altitudes below 600 m. (sites 1, 2 and 3) all the mulched soils become *iso* and their soil temperature regime changes, or is on the verge of changing, not just due to the difference between summer and winter but also the mean annual temperature. The soils under pumice have an isohyperthermic regime, bordering on isothermic, and even -in one case- is actually isothermic; the natural soils, however, are hyperthermic, with average temperatures a long way from a thermic regime.
- Between 600 m and 800 m (site 4) the natural soils, although still having a hyperthermic soil temperature regime, are bordering on thermic. The soils under pumice are already clearly isothermic between these heights.

- Around 800 m, the soil temperature regime in the natural soils changes from hyperthermic to thermic (sites 5 and 6). This is also the regime of the mulched soils, although site 5, with a temperature difference between summer and winter of 5.5ºC, is on the limit. At this height the pumice soils lose their *iso* nature, although the seasonal fluctuations are still considerably lower than in the natural soils.

The above data underline the importance of altitude in soil temperature and reveal that, as of a certain height, the pumice layer does not alter the class of soil temperature regime.

Thermic profiles

Figures 3 and 4 show the thermic profiles in the four seasons for the soils (pumiced and without pumice) in site 1, which has been taken as being representative of the studied set.

The thermic profile is also influenced by the layer of surface pumice. In the natural soils the temperature always falls throughout the profile and the lowest differences between the surface and deeper zones occur in winter, where temperature inversion is even seen. The greatest temperature difference throughout the profile is found in summer in site 3 (21ºC).

Conversely, in the pumice soils the temperature always increases with depth, except in August when a slight fall is seen. The temperature variations throughout the profile are very small here, never exceeding 2ºC except in summer in systems 3, 4 and 5, where the differences are 7ºC, 5ºC and 3ºC respectively.

As for the temperature of the layer of pumice itself, an important difference is seen between the top few centimetres and the part nearest the soil. In all cases the highest values reached in the study are found in site 3 in summer, where the top section of pumice reaches 45ºC and the top few centimetres of natural soil and the mulched soil reach 52ºC and 33ºC respectively.

Figure 3
Thermic profile of a uncovered soil (site 1)

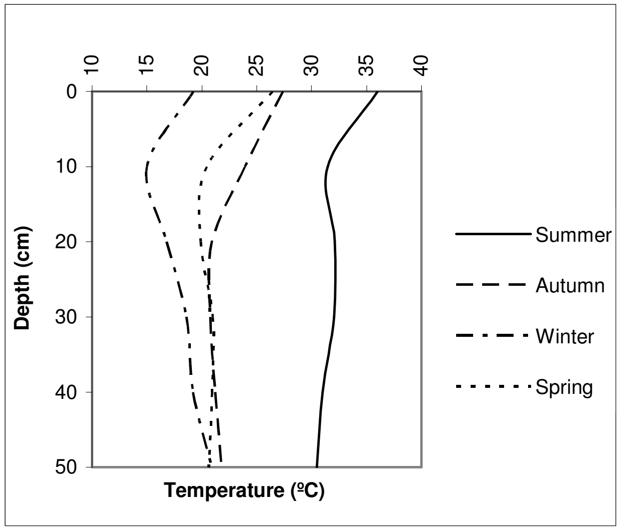
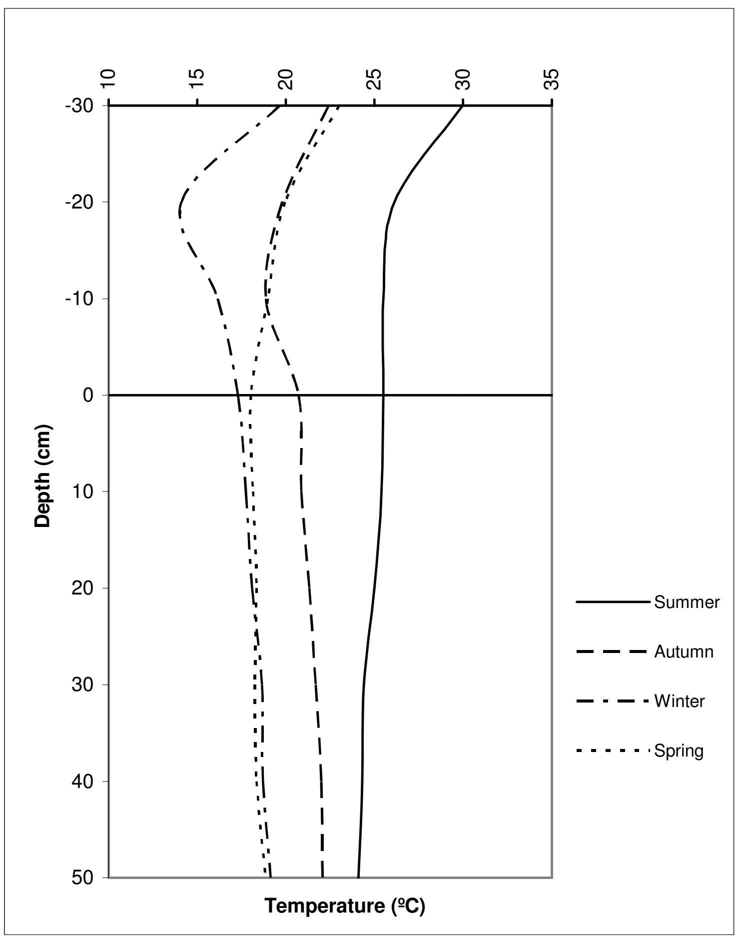


Figure 4
Thermic profile of a pumice covered soil (site 1)



CONCLUSIONS

The above results show that, on account of its properties, mulch consisting of pumice pyroclasts plays an important insulation role, reflected in a homogenisation of the soil temperature. Seasonal fluctuations and variations in temperature through the profile are reduced considerably and extreme temperatures are prevented. The degree of conservation of the pumice layer and the effectiveness of the system are related to a certain extent. The less the pumice mixes with the soil below, the greater the differences between the mulched soil and the uncovered soil.

The soil temperature modifications caused by the pumice mulch are reflected in the changes noted in the soil temperature regime at heights of up to approximately 800 m. Below this height the regimes are prefixed by *iso*. At greater heights, however, in spite of the buffering effect exerted by the pumice on the soil temperature, the reduction in seasonal differences is not so important as to lead the soils to become *iso*.

In view of the importance of temperature for crop development, the use of this farming practice produces beneficial effects which, along with others such as soil water conservation, contribute to improved productivity.

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