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BADLAND EROSION PROCESSES AND THEIR INTERACTIONS WITH VEGETATION: A CASE STUDY FROM PISTICCI, BASILICATA, SOUTHERN ITALY

ABSTRACT: DEL PRETE M., BENTIVENGA M., AMATO M., BASSO F. & TACCONI P., *Badland erosion processes and their interactions with vegetation: a case study from Pisticci, Basilicata, Southern Italy.* (IT ISSN 0391-9838, 1997).

The eastern part of Basilicata (Southern Italy) is characterised by the presence of Plio-Pleistocene clays, which are strongly affected by typical badland erosion forms. These landforms are the outcome of the recent uplift of a region of a clay bedrock and a mediterranean climate. The evolution of such features interacts with native or planted vegetation through several mechanisms. Resulting landforms show signs of more severe degradation on slopes exposed to the S. The geomorphological evolution includes the propagation of erosion process from the S to the N, with the result of the progressive demolition of the hills. Therefore, erosion control programs should focus on the stabilization of south-facing hillsides, a key to the stability of the whole system.

The present work focuses on some of the relations between soil exposure, plant cover and soil vulnerability to erosive processes, through an analysis conducted on 10 sample areas with different exposure and cover: bare, herbaceous, or woods.

The role of vegetation is of great importance for the stability of slopes, because it causes a higher content of organic matter, a lower level of salinity, especially at the soil surface, and a lower swelling of aggregates. Results suggest that the colonization of the south-facing hillsides with plants may be an important process of slope stabilization with regards to surface processes.

KEY WORDS: Erosion, Badlands, Vegetation, Basilicata (Italy).

RIASSUNTO: DEL PRETE M., BENTIVENGA M., AMATO M., BASSO F. & TACCONI P., *Processi di erosione calanchiva e loro interazione con la vegetazione: il caso di Pisticci in Basilicata.* (IT ISSN 0391-9838, 1997).

La parte orientale della Basilicata è caratterizzata dalla presenza di argille plio-pleistoceniche interessate da processi erosivi a calanco. Questi processi sono il risultato del recente sollevamento dell'area e delle attuali condizioni climatiche.

Dopo aver ricostruito i principali meccanismi evolutivi dei calanchi e delle biancane, nella zona collinare di Pisticci sono state individuate dieci aree non interessate da coperture vegetali agricole al fine di esaminare la relazione tra le coperture vegetali e lo sviluppo dei processi erosivi. Le aree indagate sono state distinte in base all'esposizione (settentrionale o meridionale) ed alle coperture vegetali: suoli nudi, con copertura erbacea, con copertura arborea. In ognuna delle dieci aree sono stati prelevati tre campioni per le seguenti determinazioni: contenuto della sostanza organica dei livelli più superficiali, conduttività elettrica, complesso di cationi scambiabili, contenuto di acqua gravifica nella stagione prima e dopo le piogge.

Con il metodo Saran-resin sono state costruite le curve di ritiro degli aggregati campionati alla profondità compresa tra 10 e 15 cm. L'indagine ha fornito complessivamente i seguenti risultati:

- le biancane sono forme residue originatesi alla base dei versanti per dissezione trasversale di preesistenti creste calanchive;
- l'origine e l'approfondimento dei solchi calanchivi deriva da effetti combinati di erosione superficiale e sotterranea;
- il progressivo arretramento delle scarpate calanchive è accelerato da scorrimenti traslazionali per rapida saturazione delle croste superficiali durante i periodi piovosi;
- la vegetazione ha effetti diretti sul contenuto d'acqua dei suoli e sulla riduzione dei sali di sodio e di potassio.

I fronti erosivi si muovono da S verso N con progressivi smantellamenti dei rilievi. Pertanto occorre indirizzare gli interventi sui versanti meridionali tenendo nella giusta considerazione gli effetti di coperture vegetali alofile, adeguatamente selezionate, ai fini del miglioramento delle caratteristiche dei terreni superficiali.

TERMINI CHIAVE: Erosione, Calanchi, Vegetazione, Basilicata.

INTRODUCTION

Badlands are typical landforms of loose and coesive soils characterised by strongly dissected slopes. The prevailing climate of many badland areas is arid or semiarid but similar morphological features are also found in Honk Kong with annual rain amounts of about 2000 mm/yr.

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(Lam, 1977) or in cold continental north-American areas (Bryan & Yair, 1982).

According to Imeson & *alii* (1982), the physical and chemical properties of soil are very important for the development of various types of badlands. Two main morphological features of badlands have been distinguished for many years in Italy as *Calanchi* and *Biancane*. *Calanchi* represent a dense network of gullies deeply carved in steep slopes. *Biancane*, whose name derives from white salt efflorescence, are few meters high dome-shaped forms morphologically well distinguished from *calanchi* (Vittorini, 1977; Guasparri, 1978; Alexander, 1982; Torri & *alii*, 1994). Del Prete & *alii* (1992) and Del Prete (1994) clearly distinguish the *biancane* as residual forms of former *calanchi* ridges.

An important aspect of genetic processes of badlands is piping or similar processes of sub-surface erosion. This is favoured in silty or varved materials (Slaymaker, 1982) or in presence of surface overconsolidated crust, cracks and gypsum veins (Harvey, 1982).

Badlands on Plio-Calabrian clays are widespread in Italy from Piedmont to Sicily. Rates of erosion in these areas are very high and sediments loads in rivers have been estimated at about 28000 tonnes/km^2/year (Rendell, 1982).

The purpose of this work is to highlight relationships between the exposure of hillsides, plant cover, and soil susceptibility to badlands erosion processes, with the purpose of devising forms of reclamation within the workprogramme of EC «Environment and Climate».

Study sites were selected among a badland regional area of about 2500 km^2 in the area of Pisticci in Basilicata, Southern Italy (fig. 1), along a N-S transect. Different exposure and plant cover were considered: herbaceous or wood vegetation is found on the northern slopes, and herbaceous cover or bare slopes on the southern ones. In each area soil samples were collected at different depths. Samples were used for mineralogical, physical, mechanical, and chemical analyses. Namely, determinations of clay mineral content, index properties, shear strength parameters, swelling properties, soil water content, organic matter and salinity.

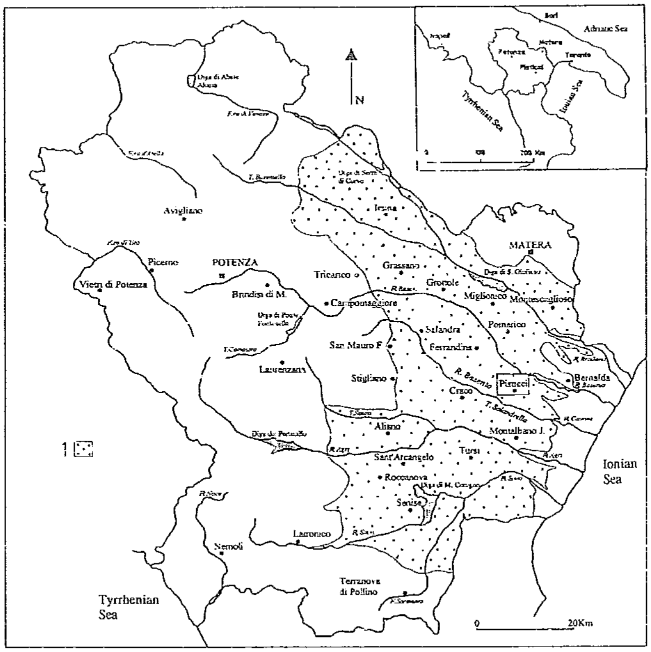

FIG. 1 - Area affected by badlands in Basilicata (1) and location of Pisticci hills.

GEOLOGICAL AND GEOTECHNICAL OUTLINE

The hilly area of Pisticci divides the valleys of Basento river and Salandrella torrent, which are deeply carved in the Upper Pliocene-Calabrian Subapennine Clay formations of the Bradanic Foredeep, covered at the top by marine terrace sediments (figs 2 and 3). The Subapennine Clays are represented by clays and silty clays, sometimes sandy clays, characterized by a typical blue color. The lithological uniformity of the pelitic facies is attenuated by thin sand-silt and by tuffite layers at the centimeter scale. Towards the top of the formation there is an increase in silty-sands and with it the presence of Quaternary macrofossils.

On the ionic (SE) side of the Basilicata region, 8 orders of marine terraces can be found, sloping towards the present coastline (Bruckner, 1980). They represent clear evidence of uplift of the area during the Quaternary. The whole area shows tectonic aspects determined by movements with a prevailing vertical component. This is evident from the attitude of sedimentary layers: from sub-horizontal to gently dipping. In general, the stratification of Subapennine Clays remains poorly distinguished. Nevertheless, where evidence allows it, layer thickness of the order of 10 cm are measured.

The Subappenine clays are the most important formation in processes of erosion and landslides in eastern Basilicata. They have a clay fraction consisting of illite and subordinate kaolinite, smectite and interstratified smectite-illite. The coarser detritic fraction is represented by quartz and carbonates (tab. 1). From a geotechnical point of view, the deposit can be classified as a silty-sandy overconsolidated inorganic clay, with high plasticity. Table 1 reports values of mineralogical composition, property index and shear strengh parameters with peak friction angles belowe 20° and residual friction angles between 13°-18° which are typical of illitic-kaolinitic clay. Colloidal activity is equal to 0.70 on average. The swelling activity of these clays increases with the content of smectites and Sodium, which is often remarkable. Upon wetting these materials swell, and upon drying they shrink and show a network of cracks. This condition makes them easily attacked by rainfall water and runoff, and due to their particle size they easily go into suspension.

CLIMATE AND MORPHOLOGICAL FEATURES

The selected area ranges from 27 m a.s.l. along the Basento valley, to 392 m a.s.l. corresponding to the hilltop oc-

FIG. 2 - Geological map of the Pisticci area: 1) Slipped blocks of sands and conglomerates derived from the marine terraces; 2) Current and recent alluvial deposits; 3) Fluvial terraces of Salandrella torrent; 4) Marine terrace (VIII° order - 650 x 10^3 years); 5) Marine terrace (VII° order - 600 x 10^3 years); 6) Marine terrace (VI° order - 500-600 x 10^3 years); 7) Subapennine clays (Upper Pliocene-Calabrian); 8) Attitude of beds; 9) Sampled areas; 10) Geological section; 11) Altitude in m. a.s.l.

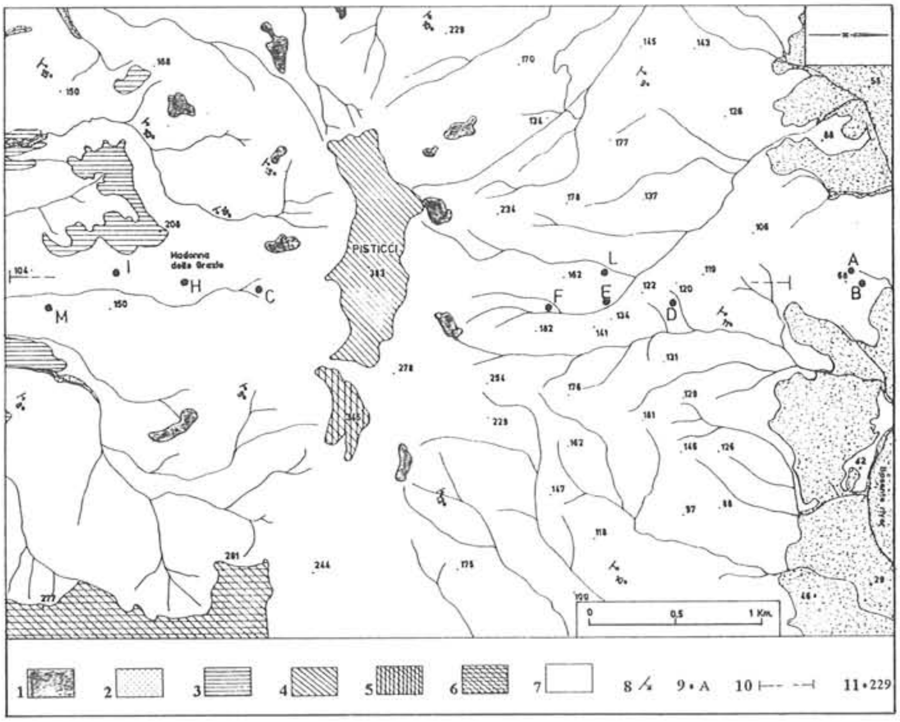

TABLE 1 - Mean values of mineralogical composition, property index and shear strength parameters of Subappennine clays in Bradanic Foredeep (Del Prete, 1994). For location of the sites see fig. 1

Locality	Mineralogical composition									Property index				Shear strength parameters				
	N. Sample	Int. (%)	Smec. (%)	Verm. (%)	Clor. (%)	Ill. (%)	Kaol. (%)	Quarz. (%)	Carb. (%)	<2μ	LL%	LP%	IP%	N. Sample	ϕ' (°)	C' (KPa)	ϕ'r (°)	C'r (KPa)
Miglionico	18									44	52	25	27	3 ds	–	–	14	0
Pomarico	31									41	50	23	27	1 ds	17.7	–	14	0
Ferrandina	9	5	tr	–	–	33	12	13	21	56	49	21	28	4 ds 3 tx	– 20	– 56	13 –	0 –
Grassano	6	tr	5	–	tr	30	10	15	20	6	50	23	27	6 ds	22.3	33.3	13	0
Montalbano J.	25										30	37	22	25	12 ds	22.8	–	–
Pisticci	20	5	14	–	tr	27	6	18	20	32	44	20	24	20 ds 5 tx	25.2 22.5	23.5 48	15 –	0 –

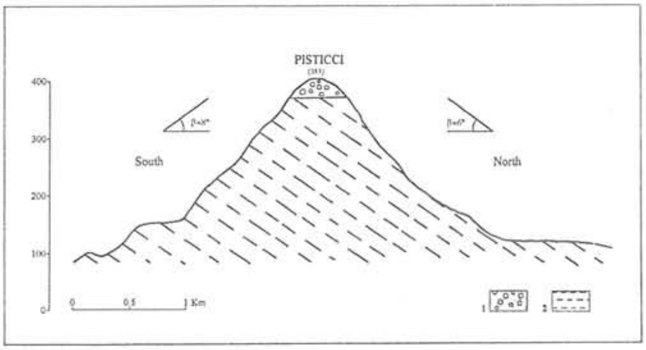

FIG. 3 - Geological section of Pisticci hill (exaggerated scale): 1) Marine terrace (conglomerates and sands); 2) Subapennine Clay.

cupied by the town of Pisticci (fig. 4). A climate diagram (Walter & Lieth 1960), based on precipitation and atmospheric temperature data collected at Pisticci meteorological station (364 m a.s.l.) between 1921 and 1984 (fig. 5), shows a dry period starting mid May, through September. The temperature is superior to 10° for 10 months per year, in the dry period it shows values ranging between 20° and 25°. The annual total precipitation is 683 mm. The climate is typically mediterranean, characterized by dry wather at the time when temperatures are more favourable for plant growth and by precipitations associated with low temperatures.

The area can be divided into two main morphological environments, characterized by a different distribution of erosion forms:

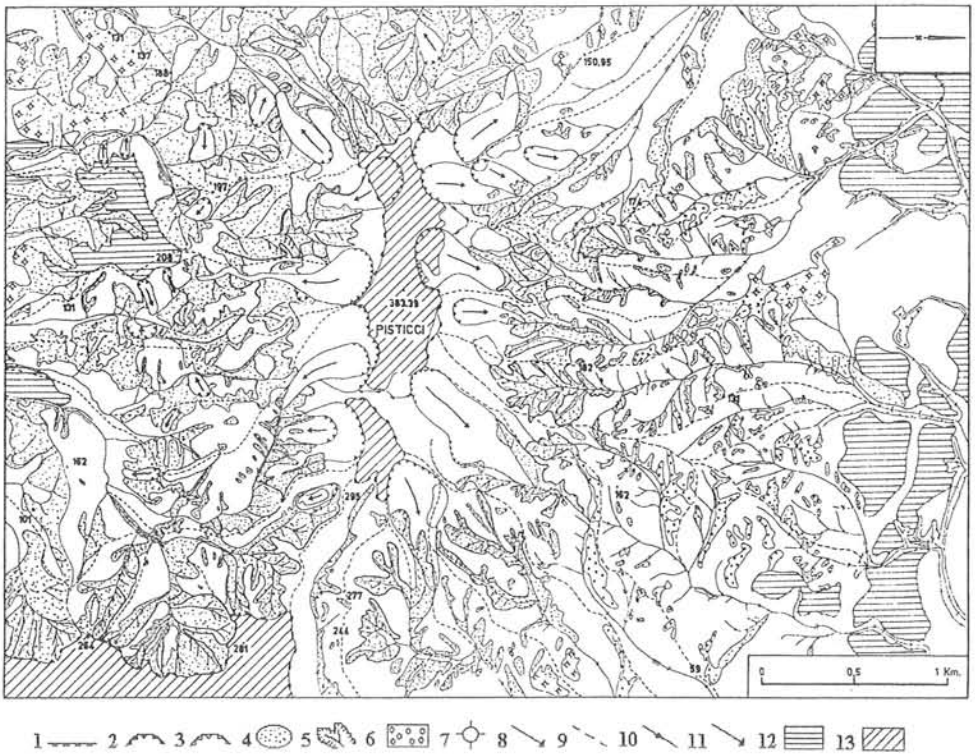

FIG. 4 - Geomorphological map of Pisticci area: 1) Marine terrace scarps; 2) Landslide degraded scarps; 3) Landslide intact scarps; 4) *Calanchi* active network; 5) Concentrated rill erosion; 6) Hummocky areas; 7) *Biancana* areas; 8) Mass movement direction; 9) Ridges; 10) V-shaped valleys; 11) Flat valleys; 12) Fluvial terraces; 13) Flat marine terrace surface.

a) high energy relief, including the upper slope, connected with marine terrace sand-conglomerate sequences on top, with a spectacular landscape of *Calanchi* which constitute a drainage system deeply carved in the blue clays, extremely hierarchic, with narrow interfluvial *knife-ridges* (fig. 6);
b) low energy relief, extending between altitude 200 m a.s.l. and valley bottom, characterized by shallower slopes with typical rounded forms of *biancane*. These can be defined as features derived from the transverse dissection of former *calanchi* ridges (fig. 7). In fact the following conditions have been verified:

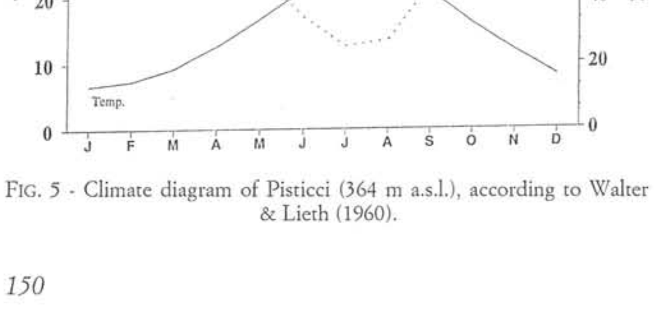

FIG. 5 - Climate diagram of Pisticci (364 m a.s.l.), according to Walter & Lieth (1960).

– the clays forming biancane have granulometric composition and physical-mechanical characters very similar to those costituting calanchi;
– in some points has been observed the in situ situation of clays forming biancane and their continuous stratigraphic sequence with those constituting over hill calanchi;
– there are hummocky intermediate forms between calanchi and biancane where can be noticed initial transversal erosion of the ridges which bring to their progressive splitting up.

In figure 8 is shown a model of *Calanchi* passing to *Biancane* through an *hummocky* area.

Rotational landslides, often of remarkable size, are frequently found at the top of the hills, influenced by a fractured sandy conglomeratic cap (Del Prete, 1994). Small first-time slides take place during rainy periods, and involve only the weathered yellow clay surface crust, which exhibits a network of shrinkage cracks during the dry period (fig. 9). The succession of relief is assymetrical and characterized by southern slopes steeper than the northern slopes (fig. 3). Badlands are seldom found on the northern side and translational slides occur in very limited areas. The weathered clay and detrital cover are thicker than on the southern side ranging from between 0.2 and 0.6 m.

The greatest development of badland erosion on Southern slope agrees with authors which maintain the importance of microclimatic conditions and of sun exposure (Passerini, 1937).

On the other hand, considering a light immersion of strata towards N-E, the observation of a possible incidence

FIG. 6 - Badlands drainage system deeply carved in the blue clays, with narrow interfluvial *Knife* ridges.

FIG. 7 - Typical rounded forms, called *biancane*; residual dissection of *calanchi* ridges.

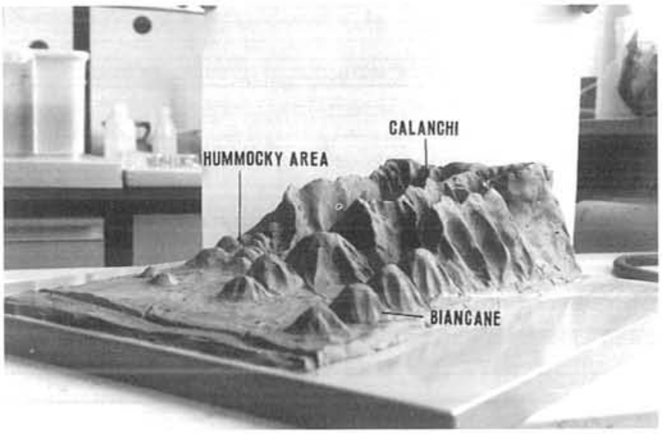

FIG. 8 - Model of badland morphology.

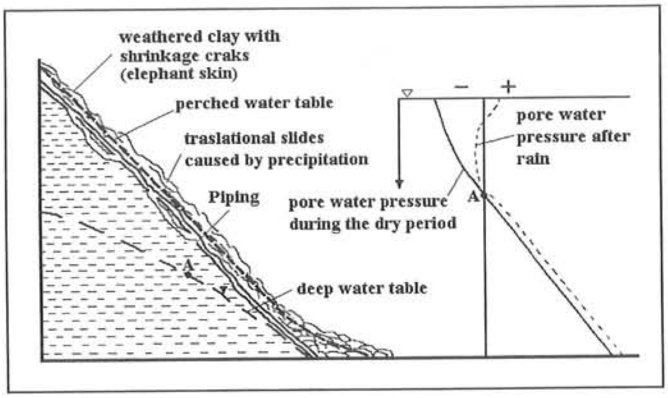

FIG. 9 - Evolution model of a *calanchi* slope side in relation of underground water (after Del Prete,1994).

of the structural condition (Castiglioni, 1935) cannot be neglected also.

As it will be specified better afterwards, it is considered that the exposure towards South is the major responsible for the formation of the weathered material and of salty crusts subjected to erosion and shallow slides which control the development of badlands.

The badland network evolution along the S side has been reconstructed through the following main processes shrinkage cracks, surface erosion including the effect of rain splashes (figg. 10-11), underground erosion and pi-

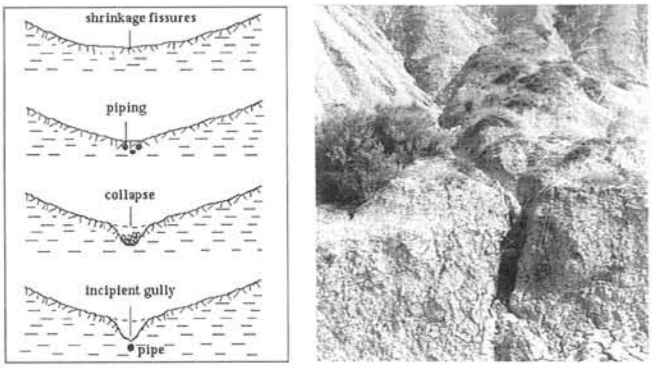

FIG. 10 - Origin of gullies after shrinkage, piping and collapse.

FIG. 11 - Rain splash effects.

ping processes, shallow mass movements including collapses and translational slides, linear erosion processes on the resulting grooves (fig. 10). With these processes the influence of slope exposure to the sun and the prevailing direction of the rain associated with the dominant southern winds is evident, causing a definite enhancement of all abovementioned processes (Dramis & *alii*, 1982, Calvo-Cases & *alii*, 1991).

VEGETATION

In a 19 km^2 area around Pisticci there is a remarkable variation in soil chemical and physical conditions, related to variations in exposure and the recent history of plant cover. Summarizing, the following situations can be found:

- bare soils or areas with herbaceous plant cover on southern hillsides;
- bare soils, areas with herbaceous cover, or areas with woody plant cover on northern hillsides.

It is interesting to compare conditions of bare soils with the different exposure, and the evolution related to soil cover type. Vegetation in the area is characterized by the presence of native species ascribed to different plant associations, species introduced recently through reforestation, and agricultural species.

Researchers (Fascetti & *alii*, 1990; Corbetta & *alii*, 1991) have identified in this study area natural vegetational groups closely related to the physical characteristics of the soil. In areas with moderate slope there is herbaceous vegetation with prevalence of *Lygeum spartum* (L.) and *Camphorosma monospeliaca* (L.), even in halomorphic soils. With an increase in salt content *Sueda fruticosa* (L.) becomes prevalent. Areas with mediterranean scrub with dominance of *Pistacia lentiscus* (Corbetta & *alii*, 1991), and bare areas are present in the southern hillsides. The northern sides present degraded woods of *Quercus pubescens* and bushes of *Spartium junceum*. The vegetation characterized by *Lygeum* shows variations due to the origin (perennial or post-cropping swards) and to the soil properties.

MATERIALS AND METHODS

Ten areas with non-agricultural vegetation were sampled (fig. 2), for the purpose of characterizing some of the relations between plant cover and soil vulnerability to erosion. Areas were classified based on the prevalent hillside exposure (S or N), and based on three levels of plant cover: bare, with herbaceous cover, with woody cover (tab. 2).

The following soil properties were measured in the 10 areas, on three replicate samples per determination: the organic matter content of the surface layer (0-10 cm), using the potassium bichromate method, the electrical conductivity of saturated paste as a measure of salinity at the depths of 0-10 and 30-40 cm. On three representative areas (bare, with plant cover, and bare with leached material), the exchangeable cations Na$^+$, K$^+$, and Ca^{++} were measured in the layers at 0-5, 10-15, 20-25, 35-40, 65-70, and >100 cm from the soil surface, the gravimetric water content at 0-10 and 30-40 cm of depth, on two dates: October 7, 1994, and January 19, 1995, the shrinkage curve of aggregates collected at the depth of 0-10 cm from the soil surface, with the Saran-resin method (McGarry & Daniells, 1987).

TABLE 2 - Soil properties

area (fig. 2)	exposure	cover	% O.M.	electrical conductivity (mS/m) depth 0-10 cm	electrical conductivity (mS/m) depth 30-40cm
A	North	woody	4.10 A	274	308 D
B	North	herbaceous	4.13 A	426	253 D
C	South	bare	0.61 D	5590	2500 B
D	North	herbaceous	1.90 C	299	417 D
E	North	herbaceous	3.69 A	229	578 D
F	North	bare	0.94 D	3577	1405 C
H	South	herbaceous	2.40 BC	267	545 D
I	South	bare	0.76 D	7280	8010 A
L	North	herbaceous	1.75 C	245	235 D
M	South	bare	0.80 D	4140	4205 B

RESULTS

The levels of organic matter (tab. 2), were higher in areas with plant cover compared to those of bare soils (1% significance), but the differences between vegetation types were not statistically significant.

Electrical conductivity (tab. 2) was quite high in all cases, and especially in bare soils (1% significance), although more so in those from hillsides with a southern exposure (1% significance). The difference of exchangeable Na between bare and covered soils amounted to two orders of magnitude up to 65 cm of depth (tab. 3). The results show a buildup of salts at the surface of bare soils, which is probably due to increased evaporation. In vegetated areas plant shading reduced water loss. The work does not provide direct measurements of the soil water balance, but the soil water content data (fig. 12) show higher values in areas

TABLE 3 - Concentration of exchangeable ions in three representative areas

area	depth (cm)	Na$^+$ (ppm)	K$^+$ (ppm)	Ca^{++} (ppm)
bare soil	0-5	174.0	12.0	435.0
	10-15	206.0	16.5	411.0
	20-25	179.0	14.0	470.0
	35-40	138.0	18.0	362.0
	65-70	119.0	15.0	377.0
soil with plant cover	0-5	1.5	9.0	395.0
	10-15	2.0	6.5	374.0
	20-25	1.5	3.5	345.0
	35-40	1.0	2.5	374.0
	65-70	1.5	2.0	305.0
	>100	22.0	7.5	305.0
leached soil bare	0-5	40.0	7.5	345.0
	10-15	77.5	13.5	414.0
	20-25	81.0	15.0	325.0
	40-50	61.0	14.0	374.0

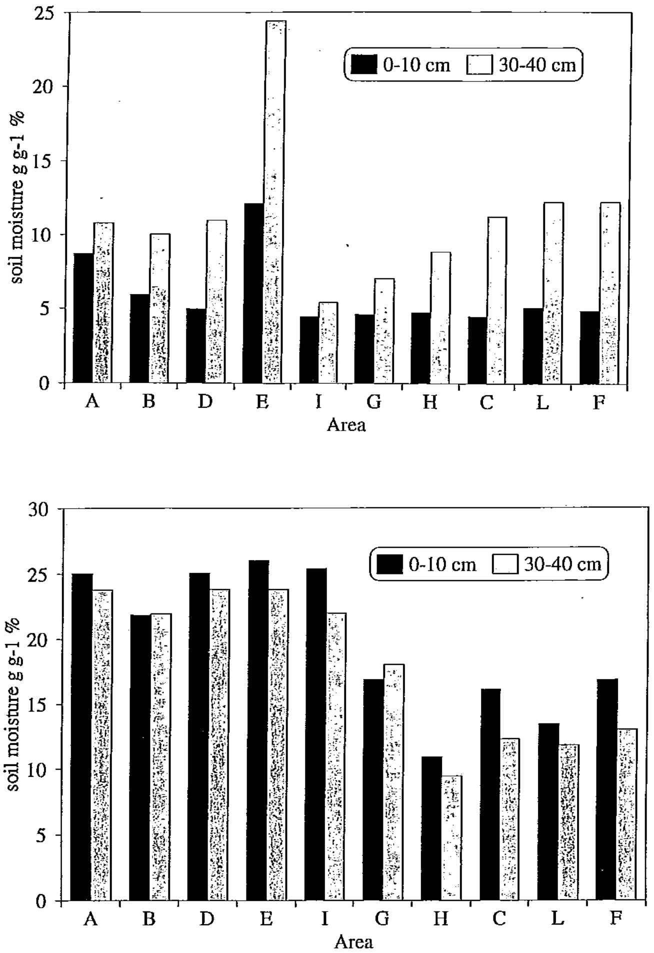

FIG. 12 -Gravimetric soil water content in 10 sampled areas on October 7, 1994 and January 19, 1995. Letters as in table 2.

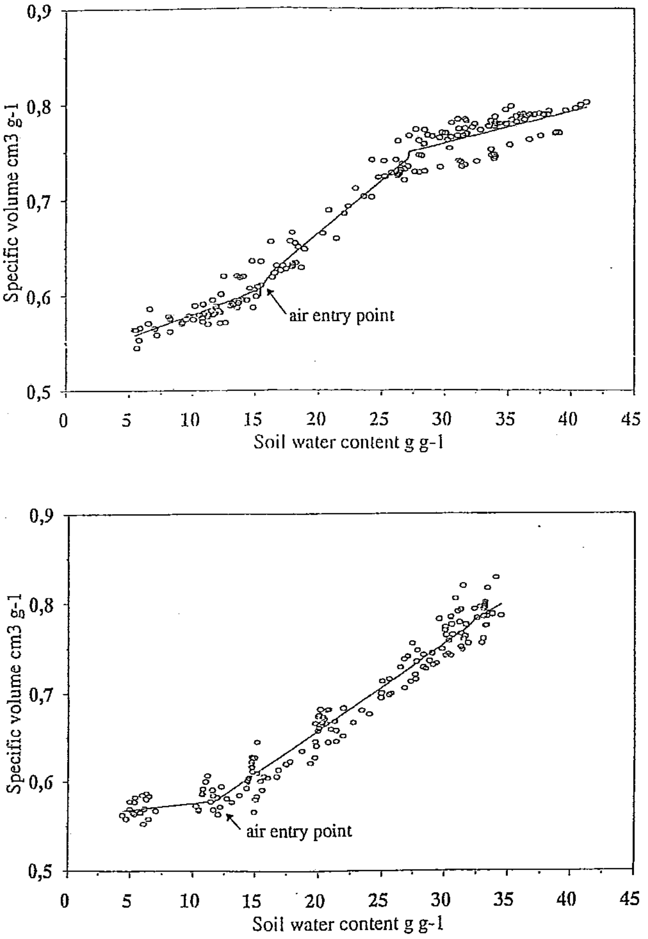

FIG. 13 - Shrinkage curve for soil aggregates sampled from bare and vegetated areas.

with plant cover. figure 13 show shrinkage curves for the 10 areas considered. The curves represent specific soil volume (the ratio of bulk volume and weight of soil aggreagates) as a function of water content in swelling soils. Curves typically show three zones with different slopes (McGarry & Malafant, 1987):

– at low water content, a zone with slope <1: an increase of water volume leads to a partial increase in soil volume, because water partially substitutes for air in pores.

This zone ends at a point called *air entry*, which is characteristic for each soil and depends on pore-size distribution. For the samples collected in soils with plant cover, this point corresponds to a lower water content compared to bare soils, indicating a higher proportion of micropores; at intermediate water content, there is a zone with slope 1: an increase in water content results in an equal increase in soil volume; at high water content, another zone with slope<1. In this zone, incoming water partly fills voids corresponding to inter-aggreagate cracks. This zone is not well-developed in samples from areas with plant cover, indicating a lower presence of cracks. This is presumably related to both the lower content of Na ions – responsible for clay deflocculation – and the higher content of soil organic matter, a key to aggregate stabilization. This stabilizing action of vegetation on soil aggregates results in a lower exposure of surfaces to factors of further degradation.

DISCUSSION AND CONCLUSIONS

The hill of Pisticci, in Basilicata, is an important sample area to study badlands. This area presents the known *calanchi* and *biancane* forms illustrating their origin. The origin and deepening of *calanchi* gullies comes about through the combined effects of superficial and underground erosion favoured by the silty-clay and by the presence of thin fine grained sand layers. Collapses of the underground tunnels assume particular importance in the deepening of the gullies.

The progressive parallel backing of the escarpments is accelerated by shallow translational slides after quick saturation of the superficial crusts during the rainy periods.

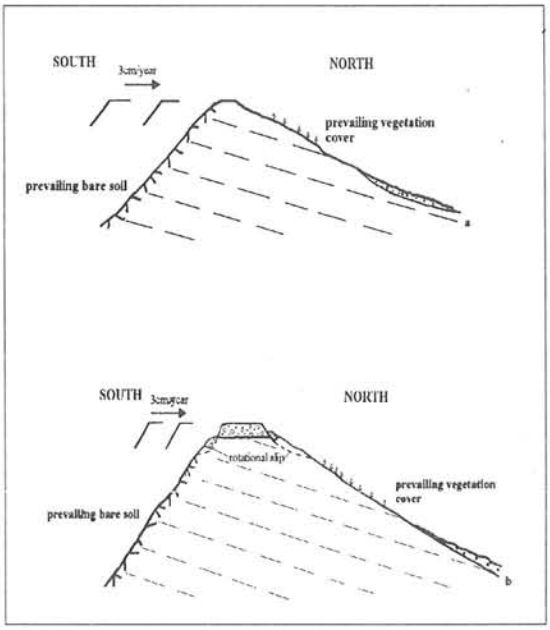

FIG. 14 - Progressive erosion of hills: a) clay relief; b) clay with sand-conglomerate cap and rotational slips at the top.

The *biancane*, residual forms present along the lower hillside and valley bottom, derive from the trasverse dissection of old *calanchi* ridges.

Results of this work identify factors that reduce the vulnerability of soil to degradation in areas affected by badland erosion forms. They are important for both N and S hillsides.

On bare soils of Southern slopes the degradeted crust for swelling and cracks forms and the processes of deepening of gullies occur through piping, falls and backing of slopes by shallow translational slides.

The N hillsides, less exposed to solar radiation and less steep, are in general less vulnerable to erosion.

FIG. 15 - View of bare southern slope and woody northern slope in badland Pisticci area.

Among the mechanisms highlighted by the results are:

- vegetation has an effect on soil water balance, which causes a reduction of Na and K salts; this has a double effect: a) the soil becomes suitable for secondary plant species, less salt-tolerant, and b) a reduction of Na content causes a lower dispersion of clays;
- there is a presence of organic matter content, that stabilizes clays against swelling;
- as a result, aggregates show reduced swelling and crack formation, and therefore a reduced exposure of surfaces to further degragation.

In the studied area in fact, erosive fronts move from the S to the N, progressively eroding the hills with a rate of movement of about 3cm/year, measured from January 1993 to September 1994 in Serra Pizzuta place, a hill located 3 km S of Pisticci (figs. 14 and 15).

Present soil conservation projects concentrate on the northern slopes, with different approaches ranging from slope shaping, to barrage works. Intervention on these sides is apparently more successful, but is not sufficient to control the whole phenomenon; indeed any erosion control program has to keep the geomorphological evolution into account and focus on stabilization of the S sides. In this context, the effect of plant cover can be exploited, selecting salt-tolerant types with root characteristics that increase soil strength with the purpose of controlling erosion and shallow slides.

Further study is needed to asses the effectiveness of the remedial works and on the selection of the characteristics of the plant cover to be used in each case.

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