Importance of subsurface soil pockets for plant growth in a karst environment

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Abstract

Northern Yucatan has generally shallow soils (< 30 cm depth) underlain by limestone, and an aquifer at several meters depth. Pockets of soil have accumulated within the limestone bedrock as a consequence of rock dissolution and illuviation of finer materials from topsoil. These soil pockets are thought to be additional sources of water and nutrients for plants but their abundance and properties have been poorly studied. This study was conducted in a limestone quarry, where the aquifer is at 9 m, to determine the abundance and distribution of soil pockets and to compare their physical properties with those of the topsoil. Soil pockets represented about 12 % of area of the vadose zone, whereas topsoil occupies only 3.3%. The volume of the soil contained in soil pockets was twice as much as the volume occupied by topsoil. Deeper and finer roots were regularly associated with soil pockets. Soil pockets had 3 times more clay and 10% less porosity compared with topsoil. Available water was similar in topsoil and soil pockets because field capacity and permanent wilting points were higher in soil pockets. Soil pockets are more abundant than previously thought and have different properties than topsoil.

Key Words

Northern Yucatan, leptosols, shallow soils, rendzinas, soil accumulations, limestone bedrock

Introduction

Karst areas constitute about 10 % of land surface of the world (Ford and Williams, 1989). They are terrains with distinctive characteristics of relief and drainage formed over any kind of soluble rocks such as limestones, dolomites and evaporites (Jennings, 1985). Karst in Yucatan, Mexico, developed on limestone, has no surface streams, and shows different developmental stages (Finch, 1965). In Northern Yucatan, where the youngest stage is present, the vadose zone is composed of a shallow layer of soil, the *laja*, a consolidated rock exposed or immediately underlying soils (Duch, 1988; Espinosa *et al*., 1998; Perry *et al*., 1989); the *sascab*, a subsurface non-indurated softer limestone with high porosity (Duch, 1988; Espinosa *et al*., 1998); and the *coquina*, a highly fossiliferous rock with high void percentage, found above the water table (Espinosa *et al*., 1998). Within the limestone matrix there is a number of dissolution cavities ranging in size from pores (< 0.1 to 1000 mm) to caves (big enough for a person to get in), including soil pockets (cavities filled with soil). Soil pockets start as empty cavities formed by the dissolution of the matrix of the limestone and are filled with soil material afterwards. These soil pockets are thought to be important as additional sources of water and nutrients for plants, but their abundance and properties have been poorly studied. The aim of this study was to investigate the abundance, distribution and physical properties of soil pockets in northern Yucatan, Mexico. Properties of soil pockets were compared with those of the topsoil to discuss their importance for plant growth.

Methods

Study area

The study site was a limestone quarry located approximately 10 km south of Merida city (20°54'18.86"N and 89°37'49.64"W), in the state of Yucatan, Mexico. Vegetation was a 15-year-old deciduous forest. The quarry is currently mined for gravel, lime, and cement leading to daily exposure of fresh walls. Vegetation and soil are removed before blasting the rock. One freshly exposed wall was observed and sampled every month from June 2007 to May 2008 (except for April).

Soil pockets distribution

Ground surveys were conducted with a SIR-3000 system portable Ground Penetrating Radar (GPR) unit (Geophysical Survey Systems, Inc. Salem, NH) with a 400 MHz antenna. A 190-m traverse line was established along a road adjacent to the quarry on the land surface. Soil was not removed. Position markers were inserted into the radar record as landscape features changed. The antenna was pulled manually. Surveys were conducted in May, the end of the dry season, to minimize attenuation of the signal due to a high water content of the soil and rocks.

Abundance of soil pockets

For area assessment of soil pockets, digital photographs of recently exposed walls were taken after blasted rock was removed. A photomosaic was created by joining the individual pictures with the program Photostich v3.1 (Canon, USA). On the photomosaic, empty cavities and soil pockets were drawn using the program CorelDraw v11 (Corel Corporation, USA). A different color was assigned for each different feature (1=rock matrix, 2=cavities and, 3=soil pockets). 24 bits Bitmaps of the photomosaics were imported into IDRISI32 (Clark Labs, USA) where they were cut in three sections; each representing one rock layer. The area of the karst features was calculated by using the tabular option of the module AREA.

Root distribution

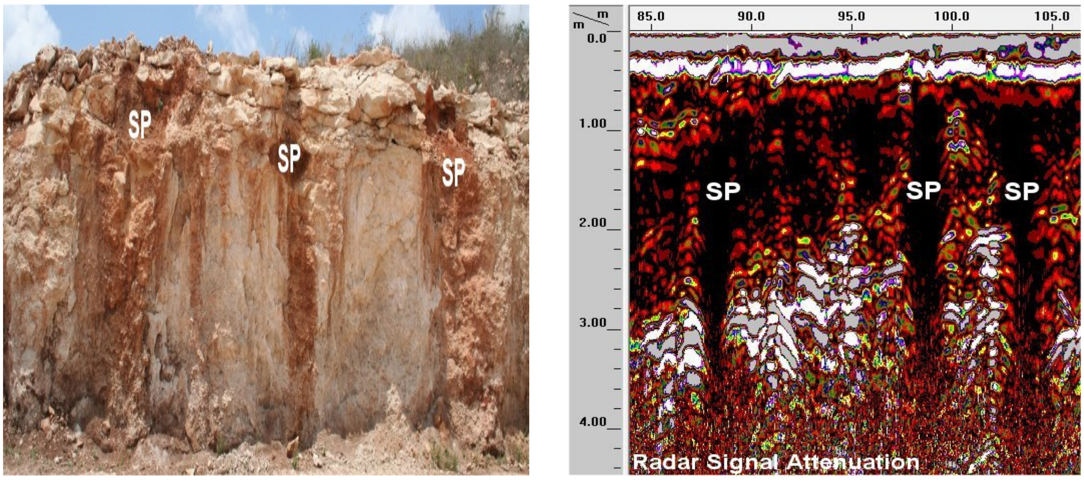
For assessment of root distribution, one 40 m width X 7.5 m height wall was sampled monthly. Walls were gridded into 1.25-m X 1-m sections. The first 1.25 m of the upper rock layer was not sampled to avoid most shrub and herbaceous roots. In every section root tips > 1 mm in diameter were counted. The root percentage was calculated for the rock matrix, soil pockets and empty cavities.

Soil analyses

Soil physical properties were analyzed for samples from three representative soil profiles and six soil pockets. Properties analyzed were particle and bulk density, particle-size distribution, porosity, and volumetric water contents at field capacity (FC) and permanent wilting point (PWP). Particle density was analyzed with a gas pycnometer (Accupyc 1330; Micromeretics Instrument Corporation, Georgia, USA). Bulk density was measured using the core method (Blake and Hartge, 1986). Particle-size distribution was determined by the hydrometer method (Gee and Bauder, 1986). Porosity was calculated as 1- (bulk density / particle density) X 100. Water contents at field capacity and permanent wilting point were obtained using the pressure plate extractor method (Dane and Hopmans, 2002).

Results

A great number of soil pockets of different sizes and shapes were observed in the field. Large soil pockets, similar to the ones observed in Figure 1a, were detected with GPR (Figure 1b)**.** The large number of potential soil pockets observed along the GPR traverse line suggests that, at least in some areas, they may be a more common occurrence in this landscape than originally thought. Most of these pockets are located in the middle part of the vadose zone where the limestone bedrock is softer.



(a) (b)

Figure 1. Soil pockets a) soil pockets in the field, b) soil pockets as recorded by using a GPR

Soil pockets represented about 12 % of area of the vadose zone (9m), whereas topsoil only 3.3% (Figure 2). This proportion is relatively constant during the year although areas with no soil pockets and areas with more than 12 % were also observed.

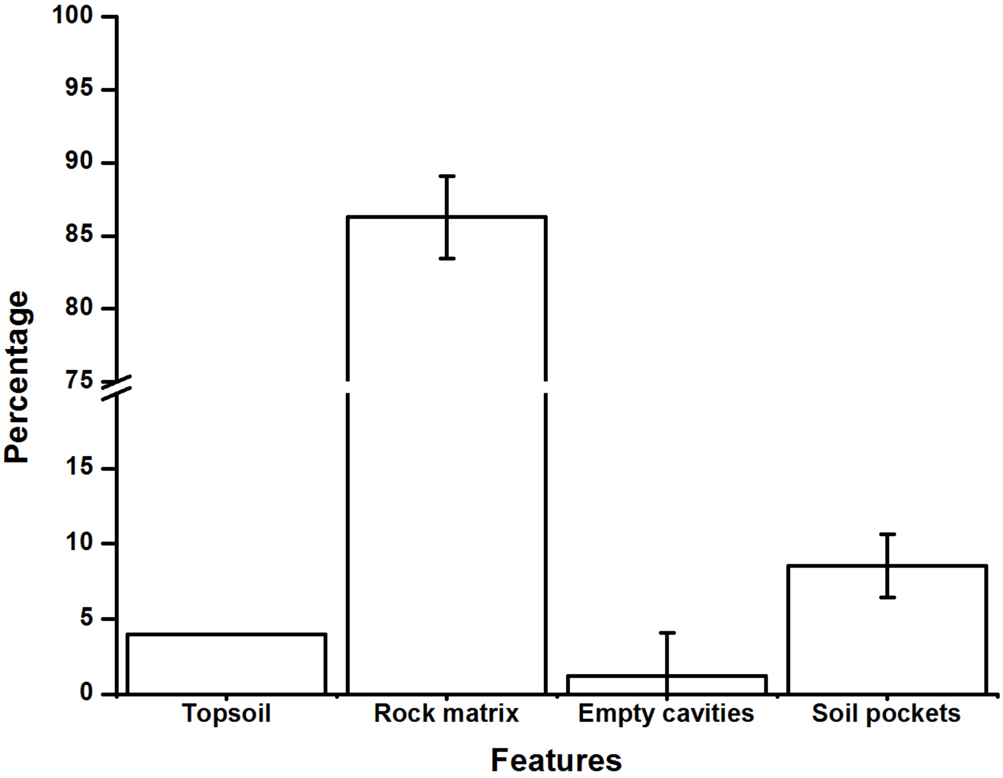


Figure 2. Soil pocket abundance in the vadose zone of northern Yucatan

Although most of the roots are confined to the topsoil (data not shown), there are a large number of roots growing in the rest of the vadose zone (Figure 3). Regardless of their location, soil pockets always contained roots. Finer roots were more abundant than coarse roots in these features. Deeper roots were always associated with soil pockets.

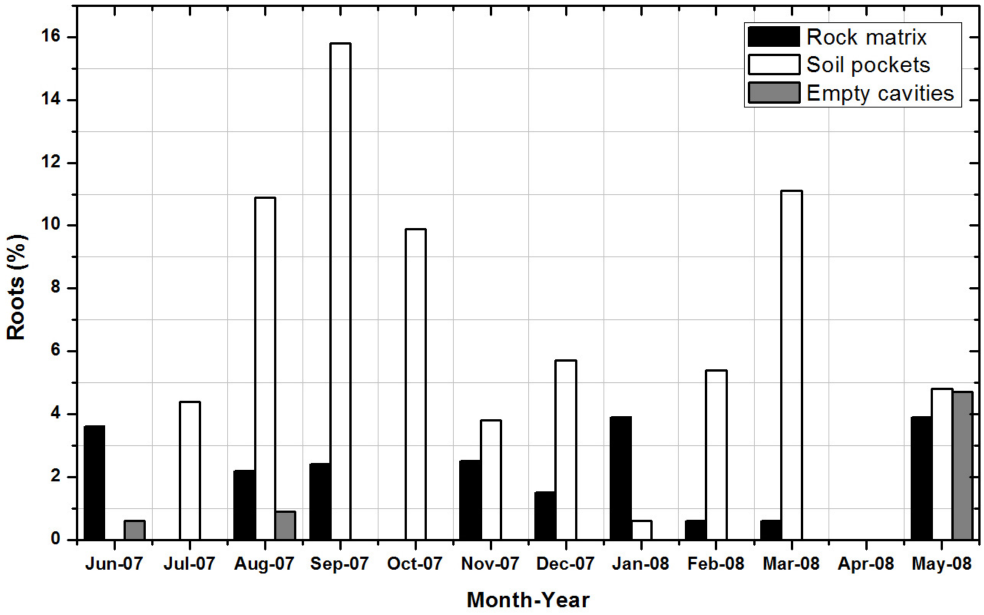


Figure 3. Root abundance in the subsurface karst features of northern Yucatan.

Soil pockets had 3 times more clay and 10% less porosity than topsoil (Table 1). Available water was similar in both topsoil and soil pockets but field capacity and permanent wilting points were higher in soil pockets. Bulk density in topsoil is lower than that of the soil pockets due to the high density of roots in the shallow soils.

Table 1. Selected physical properties of topsoil and soil from pockets.

Sample depth (cm)	Particle density (g cm^{-3})	Bulk density (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	Porosity (%)	FC (%)	PWP (%)	AW (%)
Topsoil (n=3)									
0-30	2.56	0.815	66.5	16.3	17.2	68	25.1	13.2	11.9
	(0.015)	(0.015)	(4.2)	(6.15)	(1.6)		(1.35)	(2.0)	
Soil pockets (n=6)									
30-300	2.58	1.09	21.5	12	66.5	59	32.1	21.0	11.1
	(0.001)	(0.045)	(0.6)	(0.6)	(0.85)		(2.0)	(1.3)	

FC= volumetric field capacity; PWP= volumetric permanent wilting point; AW= available water. Numbers on parentheses are standard deviations.

Soil pockets occupy more volume than topsoil in the vadose zone of northern Yucatan. Consequently, there is more water held in soil pockets than topsoil (Table 2).

Table 2. Volume occupied in the field vs Available Water (AW) of topsoil and soil pockets.

	Volume (m^3 ha^{-1})	AW (m^3 m^{-3})	AW (m^3 ha^{-1})
Topsoil 0-30 cm	3000	97.2	291,600
Soil pockets 30-300 cm	6640	121.0	803,440

Conclusions

Abundance of soil pockets is greater than previously thought; they occupy a greater volume than topsoil. Soil pockets represent pathways for roots, places for avoiding shallow rooted competitors, and additional sources of water, especially during the dry season when water at topsoil is limiting. Water is better preserved in soil pockets because they are not exposed to solar radiation. Properties of soil pockets are different from those of topsoil. Clay content in soil pockets supports the idea that empty cavities are filled by illuviation of fine soil materials from topsoil. Thus, roots growing in soil pockets could have different growth adaptations compared with those roots growing in topsoil.

Acknowledgments

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