SOILS OF THE EXPERIMENTAL FIELDS OF UEM-ESUDER, VILANKULO, MOZAMBIQUE

I.D. Ngungulo, C.B. Chutumia, C.J. Maite, F.A. Manjate, F.E.O. Remane, P.N. Vine[a]

Universidade Eduardo Mondlane—Escola Superior de Desenvolvimento Rural (UEM-ESUDER), Vilankulo, Moçambique

[a] Correspondence: vineesucessores@gmail.com (current affiliation: Vine E Sucessores, E.I., Vilankulo, Mozambique)

Submitted for publication 06 November 2023

SUMMARY: It is necessary to know the characteristics of the soils on experiment sites in order to plan and interpret experiments appropriately. It is also necessary in attempting to extrapolate results of the experiments to other locations. Five different soils were identified and delineated in the experimental lands of UEM-ESUDER. Parameters measured at depths 0-2.0 m or more in representative soil pits were: colour, horizon boundaries, pore morphology, biological phenomena, cementation, consistence, structure, texture, density, porosity, *p*H, and salinity. Around each soil pit were measured: infiltration velocity of water, saturated soil hydraulic conductivity (K_s), field capacity water content (ϑ_{FC}), permanent wilting point water content (ϑ_{PWP}), available-water holding capacity (*AWHC*), and penetration resistance at field capacity water content (PR_{FC}). Topsoil texture differed between soils, distributed amongst sandy loam, sandy clay loam, and loamy sand; ultimate infiltration velocity ranged between soils from 210 mm.h^{-1} to 1660 mm.h^{-1}; *p*H (1:2.5 soil:distilled water) in the topmost horizon ranged between soils from 6.1 to 8.0. Salinity was notably high near the river (Rio Govuro). Density, ϑ_{FC}, ϑ_{PWP}, *AWHC*, and PR_{FC} tended to increase with depth. Consistence varied greatly with depth from loose to hard on the faces of the profile pits. The whole of the university Campus consisted of what we designated as ESUDER Soil 1 (well drained; deep). Land at Pambarra-1 consisted of: ESUDER Soil 2 (hydromorphic; incipient saline) in the floodplain of the River Govuro, ESUDER Soil 3 (calcareous subsoil) on the escarpment that bordered the floodplain, and ESUDER Soil 4 (well drained; deep) on the upper plain. The whole of the land at Pambarra-2 consisted of ESUDER Soil 5 (well drained; deep; with Oxisol characteristics).

Keywords: Soil properties; Vilankulo; Mozambique

RESUMO: É necessário saber as características dos solos nos sitios de experiências para planificar e interpretar apropriadamente as experiências. É necessario tambem em tentar extrapolação dos resultados das experiências para outros lugares. Cinco diferentes solos foram identificados e delineados nos terrenos experimentais da UEM-ESUDER. Os parâmetros analisados nas profundidades 0-2.0 m ou mais em trincheiras representativas foram para cada horizonte: cor, transição de horizonte, morfologia de poros, fenómenos biológicos, cimentação, consistência, estrutura, textura, densidade, porosidade, *p*H, e salinidade. Ao redor de cada trincheira foram medidos: velocidade de infiltração, conductividade hidráulica do solo saturado (K_s), capacidade do campo a reter água (ϑ_{FC}), ponto de murchamento permanente (ϑ_{PWP}), capacidade de reter água disponível (*AWHC*), e resistência do solo a penetração na condição de humidade igual a ϑ_{FC} (PR_{FC}). Textura no horizonte o mais alto diferiu entre os solos, distribuida entre franco arenoso, franco argiloso arenoso, e areia francosa; velocidade da infiltração ultima diferiu entre solos entre 210 mm.h^{-1} e 1660 mm.h^{-1}; *p*H (1:2.5 solo:H_2O destilada) no horizonte o mais alto diferiu entre solos entre 6.1 a 8.0. O teor de salinidade foi notavelmente elevado perto do rio (Rio Govuro). Densidade, ϑ_{FC}, ϑ_{PWP}, *AWHC*, e PR_{FC} tinham tendência de aumento nas camadas as mais profundas. A consistência quanto à dureza apresentou uma grande variação com a profundidade de solta a dura na face do perfil. Todo o Campus universitario foi de o que designamos ESUDER Solo 1 (bem drenado, profundo). A terra em Pambarra-1 foi de ESUDER Solo 2 (hidromorfico, incipiente salino) na planície de inundação do Rio Govuro, ESUDER Solo 3 (calcário no subsolo) no escarpamento contiguo dessa planicie, e ESUDER Solo 4 (bem drenado, profundo) no planalto. Toda a terra da UEM-ESUDER em Pambarra-2 foi de ESUDER Solo 5 (bem drenado, profundo, com características de um Oxissolo).

***Palavras-chave*:** Solo, propriedades; Vilankulo; Moçambique

INTRODUCTION

In experimental lands researchers need to know the soil conditions and appreciate the differences amongst the soils. This is in order to design and interpret experiments and to facilitate attempts to extrapolate the results of the experiments to other locations.

The 1:1 000 000 soil map (INIA/DTA, 1994) for Inhambane Province, in which Vilankulo is located, indicates that the experimental lands of UEM-ESUDER lie within the areas which INIA/DTA label as dA (location of ESUDER Soil 1 of the present article), Ah (location of ESUDER Soil 2), and WV (location of ESUDER Soils 3, 4, and 5). Of necessity at a scale of 1:1 000 000 those areas will include considerable variation of soil properties but in the map's *nota explicativa* INIA/DTA attempted to ascribe formal classifications in the FAO classification as follows, respectively: dAA [*sic*], Ferralic Arenosol; Ah, Gleyic Arenosol; WV, Chromic Luvisol, Haplic Lixosol [*sic*]. In the USDA classification they ascribed the following: dAA, Ustic Torripsamment; Ah, Mollic Psammaquent; WV, Haplargid. INIA/DTA also gave in the *nota explicativa* general properties which are probably applicable over each soil area mapped.

We report detailed measurements of properties of the five distinct soils of the experimental lands of UEM-ESUDER, which we designated as ESUDER Soils 1, 2, 3, 4, and 5. The measurements provide more information for each soil in the lands of UEM-ESUDER than a 1:1 000 000 map or an FAO or USDA name can convey. Formal classification of the five soils in the FAO or USDA systems was neither feasible nor necessary for the purposes of the investigation.

We do not give land management recommendations because, almost by definition, the purpose of experiments done on the land is to generate innovations in management. Available nutrient levels were not measured: these levels will vary from point to point and the variation has been confounded by the fact that the different sequences of recent experimental treatments on individual areas have largely been unrecorded despite the efforts of FOLIGE (2021).

We suggest that in reporting experiments done on the UEM-ESUDER lands the identity of the soil used may be given as ESUDER Soil 1, 2, 3, 4, or 5 of this article, and reports may also reference the FAO or USDA names which were given for the wider areas dA, Ah, and WV by INIA/DTA (1994).

MATERIALS AND METHODS

Study area

Vilankulo District is situated in the north of Inhambane Province and is bounded in the east by the Indian Ocean. In a review by Governo do Distrito de Vilankulo (GDV) (2017) the climate is categorized as dry tropical in the interior of the District and humid tropical in the coastal area; both areas have two seasons: a warm, wet season from October to March and a cool, dry season from April to September. The review indicates that the relief in the interior is undulating to gently undulating and the soils are clayey sand, reddish, brownish, and calcareous whereas the coastal area consists of dunes intercalated by depressions, with variable and permeable soils including, in the depressions, hydromorphic soils of sandy texture. Fig. 1 illustrates the interior relief and the coastal relief, spanned by ESUDER experimental sites.

Whereas surface water in the interior zone is sparse, there is a surface hydrographic network in the coastal zone consisting of rivers, streams, and permanent and intermittent lakes. Rio Govuro is the main river in the District; it begins near Mapinhane in Vilankulo District and reaches the sea in Govuro District to the North. The lakes are important in fish production and their margins are important for agriculture (GDV, 2017).

Vegetation, where not removed for agriculture or other purposes, consists in the interior zone of both closed and open forest, and in the coastal zone consists of both closed and open dunal forest gathered principally on the upper parts of the dunes (GDV, 2017) whereas the vegetation we observed in the depressions in the coastal zone was principally grasses and reeds with occasional trees.

The parent material of the soils of the interior is reported to be (GDV, 2017) wind-blown deposits on top of various underlying sediments whereas the soils of the coastal zone are wind-blown deposits so deep that the underlying material seems irrelevant.

The five soils in the experimental lands of UEM-ESUDER do not include some important soils farther west that are mentioned in the GDV (2017) review of Vilankulo District.

Distinction of the different soils of UEM-ESUDER and selection of representative locations

Tube auger and Dutch auger were used for initial reconnaissance of soil profiles within the UEM-ESUDER lands. For each of the five distinct soils identified, a representative location was selected for detailed measurements: **ESUDER Soil 1** 21°59´31.1´´S 35°16´16.1´´E, **ESUDER Soil 2** 21°56´22.8´´S 35°07´30.0´´E, **ESUDER Soil 3** 21°56´23.9´´S 35°07´29.7´´E, **ESUDER Soil 4** 21°56´23.3´´S 35°07´23.9´´E, **ESUDER Soil 5** 21°56´03.5´´S 35°06´20.5´´E (GPS instrument Garmin Etrex 10). These locations are indicated with arrows bearing the corresponding numbers (1, 2, 3, 4, 5) on the topographic model in Fig. 1 (upper). The physiography observed by satellite is shown in Fig. 1 (middle). The scale and orientation of Fig. 1 (upper) and of Fig. 1 (middle) are indicated in Fig. 1 (lower).

Soil pits

For the description of each profile a soil pit was dug 2 m in depth, 1 m in width, and 2 m in length. Direct observation and bulk density sampling (see below) were done on the face of the profile and a composite sample was taken in each layer for subsequent analyses.

Colour

Colour was analyzed on moist soil outdoors but shaded from the direct rays of the sun. A fragment of soil was compared with Munsell soil colour charts. Munsell colour charts printed from the Internet were used to obtain preliminary colour identifications, which were later matched with the REVISED STANDARD SOIL COLOR CHARTS (1967). The purpose of first comparing with charts printed from the Internet was to avoid contamination of the standard charts.

Texture by feel

The guideline of THIEN (1979) was used as given in modified form by USDA-NRCS (2014).

Structure

The method of INIA/UEM (1995) was used.

***p*H**

*p*H was measured in the mixture 1:2.5 (by volume) soil:0.01 M $CaCl_2$ and in the mixture 1:2.5 (by volume) soil:distilled water. The 0.01 M $CaCl_2$ method is more appropriate (TROEH & THOMPSON, 2007, p232) although the distilled water result is commonly reported. The volumes—3.2 mL of soil and 8.0 mL of liquid—were measured in medical syringes that had been cut to size. The mixtures were shaken in new 110 x 210 mm polythene bags for 10 minutes and then rested for 5 minutes before inserting the *p*H probe of a digital meter (Extech Exstick II) whose calibration was checked every few weeks in standard *p*H 4.01 and *p*H 7.00 solutions. *p*H values reported are those when readings were steady or after 2 minutes, whichever was sooner. As stated by EXTECH (2008) the meter readings were internally corrected for temperature.

Salinity

Electrical conductivity of the saturated-soil extract (EC_e) is a standard measure of soil salinity (CARTER & GREGOVICH, 2007).

In our study, the first stage consisted of measuring $EC_{1:5}$, the electrical conductivity of the mixture 1:5 (by volume) soil:distilled water—4 mL soil and 20 mL of liquid—shaken in new polythene bags (10 minutes) and rested (5 minutes) before inserting the conductivity probe of a digital meter (Extech Exstick II) whose calibration was infrequently checked in standard solutions. The second stage consisted of conversion of $EC_{1:5}$ values to EC_e values using the following correlation (EUDOXIE & CARTER, 2006) which was based on a range of soils of Trinidad -Tobago. The correlation obtained by those authors was used because it gave a close and very reasonable relation between EC_e values thus derived for Soil 2 and the EC (electrical conductivity) of the adjacent River Govuro:

$$\boldsymbol{EC_e = -0.1893 + (3.031 \times EC_{1:5})}$$

where EC_e and $EC_{1:5}$ have the unit $mS.cm^{-1}$.

For ESUDER Soil 2 a study was carried out on the spatial distribution of salinity at a time when the river level was at its low stage, Sampling was done by auger from 0 to 2.20 m depth in intervals of 0.20 m thickness at locations separated by horizontal distance of 50 m along a line parallel to the Rio Govuro. Sampling was also done at locations separated by horizontal distance of 5 m along a line perpendicular to the Rio Govuro. The parallel line was approximately 15 m from the bottom of the escarpment that marks the edge of the river floodplain. The examination pit of ESUDER Soil 2 was at the middle of this line. The perpendicular line passed through the examination pit. (The layout is also indicated below, under Results).

Another study was done of salinity in the same (floodplain) area when the river was at its low stage in December 2013, approximately 12 months before the rest of the characterization of ESUDER Soil 2. Salinity was measured at 0-0.15 and 0.15-0.30 m depths in blocks parallel to Rio Govuro, each block lying at a different distance from the river. Measurement in each block was made on a composite sample taken from 10 points in the block. (The layout is also indicated below, under Results).

Infiltration velocity

The double-ring method as outlined by USDA-NRCS (2014) was used, with an outer ring of 0.58 m diameter and an inner ring of 0.29 m diameter, both having 0.24 m height and inserted with 0.12 m inside the soil and 0.12 m above the soil, in three locations around each soil pit. Vegetation was cut without disturbing the soil. In our method the rings were inserted vertically using the weight of several persons on the rings. Grass cuttings were placed inside to avoid damage to the soil structure from the impact of the initial application of water, after which the grass was removed. At each location the water used was from a well in the hydrographic vicinity or from the nearby river. Fall in water level was timed from one fixed mark to another mark 20 mm below the first mark before refilling and repeating. The head of water above the soil during measurements was approximately 0.10 m. Readings continued until the time of 20 mm fall, t, tended to a constant value designated as the ultimate infiltration velocity. Infiltration velocity in $mm.hr^{-1}$ was $20/t$ where t was expressed in hours.

Penetration resistance at field capacity water content (PR_{FC})

We used a manually-driven penetrometer (awaiting publication) of shaft length 1 m with a cone having half-angle 15^o and basal diameter 12.77 mm. The penetration force was read at different depths while maintaining approximately constant velocity of penetration. Readings were made at five different places within the location of each inner infiltration ring approximately 24 hours after the infiltration measurements were made and just before auger samples were taken for ϑ_{FC} measurement.

Saturated soil hydraulic conductivity (K_s)

We used the pump-in method (outlined by LANDON, 1991) at three locations near each soil pit. The soil was pre-saturated to a depth greater than the depth for which K_s was to be measured. A tube auger of 28 mm external diameter was used to make a hole of that diameter in the soil to 0.30 m depth and another hole to 0.90 m depth. For K_s of the soil of 0-0.30 m depth, water was maintained level with the top of the hole while measuring the time for successive litres of water to be added, until the addition tended to a constant rate. For K_s of the soil of 0.30-0.90 m depth, water was added through a tube while keeping the water level 0.30 m below the ground surface as monitored by an air manometer of our design. K_s was calculated using the final steady water entry rate Q (volume per unit of time) divided by the wetted area of the hole:

$$K_s = Q/(\pi d^2/4 + \pi dh) \qquad \text{(FAEF, 1998)}$$

where *d* is the hole diameter and *h* is the wetted length of the hole.

Field capacity water content (ϑ_{FC})

Soil was sampled by tube auger at the centre of each infiltration location to a maximum of 2 m depth in intervals of 0.20 m depth approximately 24 h after termination of infiltration. Soil sample water content was measured gravimetrically (105 ^oC to constant mass with a balance of 0.01 g sensitivity).

Permanent wilting point water content (ϑ_{PWP})

ϑ_{PWP} was measured with the following procedure adapted at UEM-ESUDER from VEIHMEYER and HENDRICKSON (1949) that provided sharp and consistent end-points. After taking samples for ϑ_{FC}, larger samples were taken within each infiltration location and filled into cylindrical 175-mL sardine cans, avoiding compaction. In each can were planted two pregerminated maize (*Zea mays*) seeds. Cans were kept on a verandah and each day received direct sunlight for about one hour. Each received 5 mL of distilled water every morning and evening until the two plants attained 0.10 to 0.15 m height with the third leaf open. At this stage, at sunset the last 5 mL of water was applied, each plant was collared with thin cardboard at the soil surface, and semi-molten wax was used to seal the soil surface except within the collar. The gap within the collar was filled with tissue paper allowing some oxygen to pass. At sunset on the following days, if the two plants were wilted, showing no turgidity, the can was placed in a covered outdoor barrel thoroughly wetted on the inside surfaces to maintain 100% relative air humidity overnight. At dawn, any can in this humidity chamber having a plant that had recovered some turgidity overnight was defined as not having reached permanent wilting point and was returned to the verandah. Otherwise each plant was pulled out, the resulting hole filled with semi-solid wax, and the can kept in shade to prevent change of soil water content. Subsequently cans were emptied, wax was separated from soil, and soil water content was measured gravimetrically ($\vartheta_{PWP,g}$).

Bulk density

At each depth in the soil pit were taken four undeformed samples using a steel cylinder of mean internal diameter 67.905 mm and mean length 67.545 mm, aided by a driving cylinder of the same diameter to avoid compaction of the sample, and hammer, wooden cover on the driving cylinder to distribute hammer impact evenly, machete to cut the filled cylinder out of the soil, and knife to cut the two ends of the sample level with the cylinder. Bulk density was taken as the dried (105 ^oC) mass of the sample divided by the calculated internal volume of the cylinder.

Porosity

Porosity is the space not occupied by solids:

$$\textbf{Porosity (\%)} = [1 - \textbf{bulk density}/2.65] \cdot 100\%$$

where bulk density is in $g.mL^{-1}$ or $Mg.m^{-3}$ and 2.65 $Mg.m^{-3}$ is the mean particle density assumed for most of the world's soils (FAEF, 1998).

Authors have differed as to how macro-, meso-, and micro-porosity are defined for soil (LANDON, 1991). Macro-porosity could be defined as the porosity filled by air at field capacity water content but this would only be appropriate in cases where drainage to field capacity (by gravity) is not impeded by a high water table or by impermeable underlying layer. Then in soils with unimpeded drainage meso-porosity could be defined as equal to the available-water holding capacity (see below). Micro-porosity could be defined in all soils as the porosity equal to the permanent wilting point water content. So defined, macro-, meso-, and micro-porosity may be deduced from the values of total porosity, volumetric ϑ_{FC}, and volumetric ϑ_{PWP} reported below except in ESUDER Soil 2 which appeared (see below) to have only limited drainage outlets.

Available-water holding capacity (*AWHC*)

This is the amount of water the soil can hold between field capacity and permanent wilting point.

$$\boldsymbol{AWHC = (\vartheta_{FC,g} - \vartheta_{PWP,g}) \cdot (\text{bulk density})}$$

where *AWHC* is in mm available water/mm soil, $\vartheta_{FC,g}$ and $\vartheta_{PWP,g}$ are in g water/g soil, and bulk density is in $g.mL^{-1}$ or $Mg.m^{-3}$.

Mapping

The boundary between ESUDER Soil 2 and ESUDER Soil 3 at Pambarra-1 was taken as the topographically distinct base of the escarpment bounding the lowland; the lowland occurs at the side of the river and in the wet season is often observed to be flooded. To determine the boundary between ESUDER Soil 3 and ESUDER Soil 4, augering was done to 0.40 m depth between termite mounds of different colours (grey *versus* orange). The colour of each mound was the colour of the subsoil. The boundary was regarded as where augering revealed a mixture of the two subsoil colours.

RESULTS AND DISCUSSION

Delineation of the five soils

The observations on the five soils agreed approximately with the 1:1 000 000 soil map (INIA/DTA, 1994) for Inhambane Province and with the map's *nota explicativa*. But in the present study we obtained more specific details.

Sampling at 0-0.20 and 0.20-0.40 m depths at 27 points on a 100 m x 100 m grid all over the university Campus (12 ha), and to 4 m depth in intervals of 0.20 m depth at the two ends of the Campus and in the representative soil pit near the middle, indicated that the whole Campus had one and the same soil even at the most specific level of classification. Continuing to auger in the soil pit to 6 m below the ground surface revealed no further horizon differentiation.

Augering all over the Pambarra-1 land to a maximum of 2 m depth in intervals of 0.15 m depth, revealed three different soils within the 12 ha (Fig. 2). ESUDER Soil 2 occupied the lowland. ESUDER Soil 3 occupied most of the escarpment. ESUDER Soil 4 occupied the upper plain and part of the top of the escarpment. There was notably little variation amongst profiles at different locations within the area of ESUDER Soil 2 and within the area of ESUDER Soil 4. ESUDER Soil 3 was also notably uniform except that its whitish calcareous horizon and/or whitish boulders started at various depths ranging from 0.0 m to >1.5 m. For Soil 3 we avoided making the examination pit at a location having relatively shallow whitish horizon; this was done in order to facilitate study of all the horizons above the whitish horizon.

At Pambarra-2, augering to 2 m depth at nine locations uniformly distributed within the 30-ha UEM-ESUDER land showed notable similarity of soil amongst all locations. Whitish calcareous material was only found in a few locations where sparse fragments occurred at about 2 m depth, differing from the information in the *nota explicativa* of the 1:1 000 000 map (INIA/DTA, 1994) which indicated a greater quantity of calcareous material. For Pambarra-2 the representative soil pit was approximately 300 m west of the UEM-ESUDER land in soil indistinguishable from that of the UEM-ESUDER area. This location of the pit was near a source of water (a well) which was necessary for tests on the soil. The soil in the UEM-ESUDER land and in the pit was also morphologically indistinguishable from the soil visible in the various excavations throughout the 300 ha that was designated by the local council for community use around the UEM-ESUDER land.

Relation of the soils to parent material and topography

The uniformity of the soil within the university Campus (the Campus only had ESUDER Soil 1) was associated with uniformity of topography and of parent material (an old dune (INIA/DTA, 1994)). The uniformity of the soil at Pambarra-2 (which had only ESUDER Soil 5) was associated with uniformity of topography and parent material in the area.

At Pambarra-1, ESUDER Soil 2 was on the lowland adjacent to Rio Govuro, ESUDER Soil 3 was on the escarpment alongside the lowland, and ESUDER Soil 4 was on the upper plain. But ESUDER Soil 4 extended to the escarpment in a small area (Fig. 2), indicating that at Pambarra-1 there did not exist an exact relation amongst soil, topography, and parent material.

Our descriptions of ESUDER Soils 1, 2, 3, 4, and 5 are probably closely applicable to soils on corresponding topography and parent material in the neighbourhood beyond UEM-ESUDER's boundaries including the proviso that on upper parts of the escarpment ESUDER Soil 4 may occasionally be found instead of ESUDER Soil 3.

Profile formation

The profile images (Fig. 3) show that in ESUDER Soils 1, 4, and 5 there was steady gradation of soil development in relation to depth. In ESUDER Soils 2 and 3 there was an abrupt transition to a dark, undulating, and relatively hard layer below the paler upper horizons. In Fig. 3 there is a supplementary whole-trench view of ESUDER Soil 3 to show that the abrupt transition in ESUDER Soil 3 appeared similar to that in ESUDER Soil 2. Explanation of this discontinuity requires further investigation.

General description of the soils

Morphology of the soils (Fig. 3) showed that ESUDER Soil 1 was deep and well drained, ESUDER Soil 2 was hydromorphic in the subsoil due to the water table associated with Rio Govuro, ESUDER Soil 3 was calcareous, ESUDER Soil 4 was well drained, and ESUDER Soil 5 was well drained and had characteristics of an Oxisol.

Descriptions of each soil

ESUDER SOIL 1

ESUDER Soil 1 was deep and well drained, with accumulation of organic matter in the topmost horizon (Tables 1, 2; Fig. 3). Analysis by feel showed that the 0-0.17 m layer was sandy loam and the rest of the layers to at least 6 m depth were loam (Table 3). Structure, consistence, bulk density, and porosity (Table 3) were consistent with the texture and with the distribution of organic matter. There were many (as defined by INIA & UEM, 1995) visible tunnels and cavities of apparently biological origin in the two uppermost horizons; such were common between 0.30 and 0.85 m depth, and few from thereon to the bottom of the pit at 2.0 m depth.

In ESUDER Soil 1, ultimate infiltration velocity (*UIV*) (Table 4) was much faster than the maximum expected intensity of rain. K_S (Table 5) was in the INIA & UEM (1995) class 'rapid', with all its consequences. The high internal drainage capacity indicated by this value of K_S in conjunction with the high *UIV* and the morphological evidence of neither temporary nor permanent water table within 6 m of the ground surface puts ESUDER Soil 1 within the USDA-NRCS (2007) hydrologic soil group A, hence having 'low runoff potential when thoroughly wet'. Runoff is not expected unless the current soil structure (and hence *UIV*) deteriorates greatly; but splash- and wind-erosion are possible if soil is bare.

ϑ_{FC}, ϑ_{PWP}, and AWHC were clearly low (Table 6; Fig. 4). Correspondingly, macro-porosity was high relative to meso- and micro-porosity.

At field capacity water content ESUDER Soil 1 was relatively low in penetrometer resistance (and therefore in resistance to penetration by roots (BENGOUGH *et al*., 2011)) to at least 0.9 m depth (Fig. 5).

ESUDER Soil 1 was slightly acid in the topsoil (*p*H in distilled water, 6.1; *p*H in 0.01 M $CaCl_2$, 4.7), increasing slightly in acidity to approximately 1.0 m depth (*p*H 4.2 in 0.01 M $CaCl_2$) and then increasing no further to at least 6.0 m depth (Table 7).

ESUDER Soil 1 salinity was very low from the surface to at least 6.0 m depth ($EC_{1:5} < 0.015$ mS.cm^{-1}; EC_e approximately zero)(data not tabulated).

ESUDER SOIL 2

At Pambarra-1, between Rio Govuro and the escarpment, augering to 2 m depth in lines parallel and lines perpendicular to the river indicated one and the same soil even at the most specific level of classification.

This soil, ESUDER Soil 2, had horizons in the sequence dark-light-light-dark in colour from the top downwards (Fig. 3; Table 8). There was evident accumulation of organic matter in the topmost horizon. Each horizon had different texture (Table 9). There was a distinct and abrupt colour and texture boundary between the third and fourth horizons. Colours and mottles indicated chemical reduction from Fe^{3+} to Fe^{2+} (hydromorphism) in all horizons except possibly the topmost horizon. The reduction may be ascribed to a high water table and seasonal flooding in most years.

Structure, bulk density, porosity, and penetrometer resistance were only favourable to plant roots in the topmost horizon and worsened greatly and continuously with increased depth (Table 9; Fig, 5).

UIV was much less than in the other four soils (Table 4) but nevertheless was faster than the maximum reasonably expected rainfall intensity or overhead irrigation rate. Internal drainage capacity (Table 5) was rapid, at least to 0.90 m depth, so that runoff is not expected until the water table becomes very high or structure deteriorates greatly. The water table is indeed seasonally very high in ESUDER Soil 2, reaching as high as the soil surface or above, with appreciable standing water and/or runoff. Around the time of measuring K_s in ESUDER Soil 2 the water table depth was measured at three locations around the pit as 0.92, 1.14, and 0.86 m. The high surface infiltration rate and high K_s in soil depths 0-0.30 m and 0.30-0.90 m with simultaneous impeded drainage caused by high water table and/or by relatively impermeable deeper soil, put ESUDER Soil 2 in the USDA-NRCS (2007) hydrologic soil category B, i.e. there is a moderate potential for runoff when thoroughly wet. This contrasts with the category A (low potential for runoff when thoroughly wet) which our observations ascribed to ESUDER Soils 1, 3, 4, and 5.

The values of water retention at field capacity (ϑ_{FC}) in ESUDER Soil 2-were higher than would have been predicted on the basis of texture, suggesting that drainage of water after saturation was delayed in the presence of a relatively high water table; meanwhile values of water retention at permanent wilting point (ϑ_{PWP}) were consistent with texture (Tables 9, 10; Fig. 4); hence values of available-water holding capacity ($AWHC = \vartheta_{FC} - \vartheta_{PWP}$), were higher than would have otherwise been predicted on the basis of texture. The observations on this soil affirmed the rationale for sampling ϑ_{FC} in the field on the natural profile rather than in a laboratory. From a depth of 0.80 m downwards air-filled porosity at field capacity water content, *i.e.* total porosity minus ϑ_{FC}, was <10% (normally an anaerobic condition: LANDON, 1991, p83); for reasons described earlier for soils with paucity of outlets for drainage this did not necessarily mean there was a shortage of large pores. On another note, in the topmost horizon the values of ϑ_{FC}, ϑ_{PWP}, and *AWHC* were high compared with the other horizons, in concordance with the texture of the topmost horizon.

PR_{FC} in this soil indicated great resistance to development of roots below the topmost horizon, the resistance worsening with increased depth (Fig. 5) to values of *PR* which are expected to reduce root elongation by 90-100% (BENGOUGH *et al*., 2011).

*p*H of ESUDER Soil 2 was alkaline and did not change appreciably down the profile (0-1.60 m depth) (Table 11). Values obtained were in 0.01M $CaCl_2$; values measured in distilled water would probably be farther on the alkaline side by half to one unit of *p*H (WILD, 1988).

Profiles of salinity (EC_e) from 0 to 2.20 m depth in ESUDER Soil 2 are shown in Fig. 6 for sampling done in 2014 at the low stage of river level. Near the river, salinity was highest in the topmost layer and approximately uniform below, or was low and approximately uniform at all depths. At the two sampling positions farthest from the river, salinity was least near the ground surface and increased with depth. Values in the topmost layer nearer the river approached 4 $mS.cm^{-1}$, which is the level above which soil is classified as saline (TROEH & THOMPSON, 2007).

For sampling between 0 and 0.30 m depth in December 2013 (approximately 12 months before the rest of the characterization of ESUDER Soil 2), salinity was higher nearer the river than farther away and higher nearer the ground surface than deeper down (Fig. 7). Some topsoil salinity values exceeded 4 $mS.cm^{-1}$. The salinity of Rio Govuro was measured as approximately 2.0 $mS.cm^{-1}$. These results suggested salinization of the soil by evaporation of water rising from a shallow water table connected to the river.

The observations on salinity in ESUDER Soil 2 in this study were consistent with the study of MUANDO (2018) in the same location, which indicated that, at least in a dry period, the water forming the water table moved in a direction away from the slightly saline Rio Govuro, and that at the lesser distances from the river the water table was nearer to the ground surface. The observations on salinity profiles in the present article were also consistent with the results on salinity profiles in the same area (floodplain) in relation to the use of mulching to reduce evaporation (DANISSE, 2015) and in relation to the use of leaching (MUENDANE, 2015).

ESUDER Soil 3

ESUDER Soil 3 was on the escarpment bounding Rio Govuro. The lower part of the profile was whitish calcareous material. Depth to the whitish horizon varied from 0 to >1.5 m amongst different locations. The profile had a dark discontinuity between two of the subsoil horizons (Fig. 3) similar to the discontinuity in ESUDER Soil 2 but slightly less distinct. The reddish and brownish colours above the whitish horizon indicated good drainage (absence of chemically reducing conditions) except possibly in small mottles (Table 12). Like ESUDER Soil 2 but unlike ESUDER Soils 1, 4, and 5 air space at field capacity in the lower part of the profile was <10% (a value normally found to be anaerobic): in ESUDER Soil 3 this may be due to low macro-porosity in the lower part of the profile rather than being due to scarcity of drainage outlets. There was apparent accumulation of organic matter in the topmost horizon (Fig. 3). Texture varied amongst horizons from sandy loam to loam to sandy clay loam. In the top three horizons structure and consistence accorded with texture and level of organic matter (Table 13) but in the deeper horizons consistence and bulk density were more severe than the observed texture would have suggested.

Visible pores were rare below the second horizon; roots were rare below the topmost horizon. PR_{FC} was favourably low from 0 to 0.30 m depth, corresponding to the two topmost horizons, but increased rapidly with depth from 0.40 m, corresponding to the third and subsequent horizons (Fig. 5).

UIV (Table 4) and internal drainage capacity (Table 5) were rapid.

ϑ_{FC} and ϑ_{PWP} increased with depth. *AWHC* was not high in the topsoil but increased continuously to a maximum value of 14.3 mm available-water capacity/100 mm soil in the last horizon before the whitish layer (Table 14; Fig. 4).

ESUDER Soil 3 was slightly alkaline in the topmost horizons but the alkalinity increased with depth reaching *p*H 8.4 (1:2.5 0.01M $CaCl_2$) and 9.7 (1:2.5 distilled water) in the whitish horizon (Table 15). Salinity was measured as 0.0 $mS.cm^{-1}$ throughout the profile.

ESUDER Soil 4

ESUDER Soil 4 was deep and well drained (Table 16; Fig. 3). Texture was sandy loam to loam (Table 17); structure was angular blocky, medium in size, weak, in all horizons except the topmost, in which there was probably an effect of accumulation of organic matter. Consistence (moist) changed from very friable and loose in the topmost horizon to firm in the subsoil. Bulk density increased with depth; below 0.34 m depth were observed values of bulk density which normally indicate excessive resistance to penetration by crop roots. Visible pores were few, and roots were rare, below 0.56 m depth. PR_{FC} (Fig. 5) was relatively low between 0 and 0.30 m depth (better than ESUDER Soil 1, for example) but increased continuously reaching relatively high values by 0.90 m depth.

UIV and drainage capacity were rapid (Tables 4, 5).

ϑ_{FC}, ϑ_{PWP}, and *AWHC* had low values typical of a soil of coarse texture, but had a tendency to increase in value with depths more than 1.2 m (Table 18; Fig. 4); *AWHC* in ESUDER Soil 4 was better than in ESUDER Soil 1 which was a somewhat similar soil in other respects.

*p*H was approximately neutral (Table 19) in all horizons observed. Salinity was measured as 0.0 $mS.cm^{-1}$ throughout the profile.

ESUDER Soil 5

ESUDER Soil 5 was deep, well drained, and had characteristics of an Oxisol (Table 20; Fig. 3). The profile was reddish brown in the topsoil with continuous increase in the intensity of red with increased depth to 0.88 m and from thereon was simply red. These colours indicated a high level of Fe^{3+}. The topmost horizon was very dark, which indicated accumulation of organic matter, and was of texture (by feel) silty loam, of consistence (air-dry) loose, and of crumb structure (Table 21). The rest of the profile was sandy loam, slightly hard, and of weak very fine angular blocky structure. Bulk density was slightly more than ESUDER Soil 1whose structure as seen at x4 magnification was single-grained with much interstitial pore space maintained by sesquioxide bridging from grain to grain, whereas bulk density of the red ESUDER Soil 5 was much less than ESUDER Soil 4 in accordance with the proposition that ESUDER Soil 5 was an Oxisol evidenced by its low bulk density and high Fe^{3+} content.

Table 22 and Fig. 4 show the values of ϑ_{FC}, ϑ_{PWP}, and *AWHC*, which were relatively uniform with depth.

Visible pores were few in ESUDER Soil 5 between 0 and 0.50 m depth and rare below 0.50 m depth; roots were rare throughout the profile. But macroporosity (calculated as total porosity minus volumetric ϑ_{FC}) (equivalent to air space at field capacity water content) was >32% in all horizons. PR_{FC} was relatively high in the topmost part of the profile but did not exceed 1.8 MPa to at least 0.70 m depth (Fig. 5).

UIV and internal drainage capacity were rapid (Tables 4, 5).

*p*H in the profile of ESUDER Soil 5 was generally slightly alkaline but in one of three locations of measurement the *p*H below 1.0 m depth was slightly acid for unknown reasons (Table 23). Salinity was measured as 0.0 $mS.cm^{-1}$ throughout the profile.

Various experiments in mechanized production have already started on the ESUDER Soil 5 at Pambarra-2; hence, to facilitate interpretation of the extensive trials we have tried to give a tentative classification of ESUDER Soil 5 as follows without as yet having confirmatory chemical and mineralogical analyses: all the observations reported above on ESUDER Soil 5 were consistent with a tentative classification as a Typic Eutrustox (SOIL SURVEY STAFF, 1999). This classification is also consistent with subsequent micro-morphological studies by GULAMO (2018).

CONCLUSIONS

There were five distinguishable soils on the experimental lands of UEM-ESUDER. All the university Campus was on ESUDER Soil 1 (well drained; deep). The UEM-ESUDER experimental land at Pambarra-1 had ESUDER Soil 2 (hydromorphic; incipient saline) in the floodplain of Rio Govuro; ESUDER Soil 3 (white calcareous material dominating the subsoil) on the escarpment bordering the Rio Govuro floodplain; and ESUDER Soil 4 (well drained; deep) on the neighbouring upper plain and on part of the top of the scarp. All the experimental land of UEM-ESUDER at Pambarra-2 had ESUDER Soil 5 (well drained; deep; with characteristics of an Oxisol). Details were reported in the Results and Discussion to help researchers design and interpret experiments done on the lands of UEM-ESUDER, and to help to identify similar lands where experimental results may be applicable outside of the UEM-ESUDER experimental lands.

ROLES OF AUTHORS

ESUDER Soils 1, 2, 3, 4, and 5 were investigated by Maite, Remane, Chutumia, Ngungulo, and Matano for their respective Trabalhos de Culminação de Curso of the Licenciatura degree. Ngungulo also assisted the other four of these five investigators. Vine supervised these five investigators and did the 2013 salinity survey and produced the topographic base map of Pambarra-1. Ngungulo and Vine wrote the present article and the earlier (Portuguese) version which is located at https://www.academia.edu/40669260. In the present article slight technical updates have been made of the Portuguese article.

BIBLIOGRAPHIC REFERENCES

BENGOUGH, A.G. *et al*. Root elongation, water stress, and mechanical impedance: a review of limiting stresses and beneficial root tip traits. Journal of Environmental Botany v.62, p.59-68. 2011.

CARTER, M.R.; GREGOVICH, E.G. Soil Sampling and Methods of Analysis. 2nd edn. Baton Rouge, USA: CRC Press. 2007.

DANISSE, B.A. Maneio de salinidade do solo para uma agricultura sustentável no campo experimental de Escola Superior de Desenvolvimento Rural no Distrito de Vilankulo, localidade de Pambarra. 45p. Trabalho de Culminação de Curso, Universidade Eduardo Mondlane—Escola Superior de Desenvolvimento Rural. 2015.

EUDOXIE, G. D.; CARTER, N. Evaluation of a direct field method of soil salinity appraisal. In: Proceedings of the 15th meeting of the Caribbean Academy of Sciences, 2006, Guadeloupe, p. 127–130.

EXTECH INSTRUMENTS. ExStik EC500 User's Guide. www.extech.com. 2008.

FAEF (FACULDADE DE AGRONOMIA E ENGENHARIA FLORESTAL). Rega e Drenagem. Maputo: Universidade Eduardo Mondlane. 1998.

FOLIGE, A.F.E. Criação de mapa actualizável de uso histórico do terreno da ESUDER. 58p. Trabalho de Culminação de Curso, Universidade Eduardo Mondlane—Escola Superior de Desenvolvimento Rural. 2021.

GDV (GOVERNO DO DISTRITO DE VILANKULO) (Ed.). Plano Estratégico de Desenvolvimento do Distrito (2016-2025). Vilankulo, Mozambique. 2017.

GOOGLE EARTH (2018). Accessed on 20 January 2019.

GULAMO, A.N. Agregação num oxissolo arenoso e efeitos da remoção de matéria orgânica e de óxidos de ferro no solo do campo experimental da ESUDER-Pambarra II. 80p. Trabalho de Culminação de Curso, Universidade Eduardo Mondlane—Escola Superior de Desenvolvimento Rural. 2018.

INIA/DTA (INSTITUTO NACIONAL DE INVESTIGAÇÃO AGRONÓMICA / DEPARTAMENTO DE TERRA E ÁGUA). Província de Inhambane: carta de solos. Maputo: INIA/DTA. 1994.

INIA (INSTITUTO NACIONAL DE INVESTIGAÇÃO AGRONÓMICA); UEM (UNIVERSIDADE EDUARDO MONDLANE). Manual Para a Descrição do Solo e Codificação para o Banco de Dados. Maputo: INIA. 1995.

LANDON, J.R. (Ed.). Booker Tropical Soil Manual. Harlow, UK: Longman, paperback edition. 1991.

MUANDO, D.J. Medição da água subterranea na baixa do Rio Govuro no povoado de Pambarra: caso campo experimental da ESUDER. 38p. Trabalho de Culminação de Curso, Universidade Eduardo Mondlane—Escola Superior de Desenvolvimento Rural. 2018.

MUENDANE, H.R. Estudo da salinidade do solo na machamba da ESUDER – Pambarra (Distrito de Vilankulo). 40p. Trabalho de Culminação de Curso, Universidade Eduardo Mondlane—Escola Superior de Desenvolvimento Rural. 2015.

REVISED STANDARD SOIL COLOR CHARTS. Tokyo: Research Council for Agriculture, Forestry and Fisheries. 1967.

SOIL SURVEY STAFF. Soil Taxonomy. USDA-NRCS (United States Department of Agriculture - Natural Resources Conservation Service) Handbook 436, 2nd ed. 1999.

THIEN, S.J. A flow diagram for teaching texture by feel analysis. Journal of Agronomic Education, v. 8, p. 54-55. 1979.

TROEH, F.R.; THOMPSON, L.M. Solos e Fertilidade do Solo. 6th edn. Sao Paulo, Brazil: Organização Andrei Editora. 2007.

USDA-NRCS (United States Department of Agriculture - Natural Resources Conservation Service). National Engineering Handbook Part 630 (Hydrology). USDA-NRCS. 2007.

USDA-NRCS (United States Department of Agriculture - Natural Resources Conservation Service). Soil Survey Field and Laboratory Methods Manual. USDA-NRCS. 2014.

VEIHMEYER, F.J., HENDRICKSON, A.H. Methods of measuring field capacity and permanent wilting percentage of soils. Soil Sci., v. 68, p.75-94. 1949.

WILD, A. (ed.). Russell's Soil Conditions and Plant Growth. 11th edn. London: Longman. 1988.

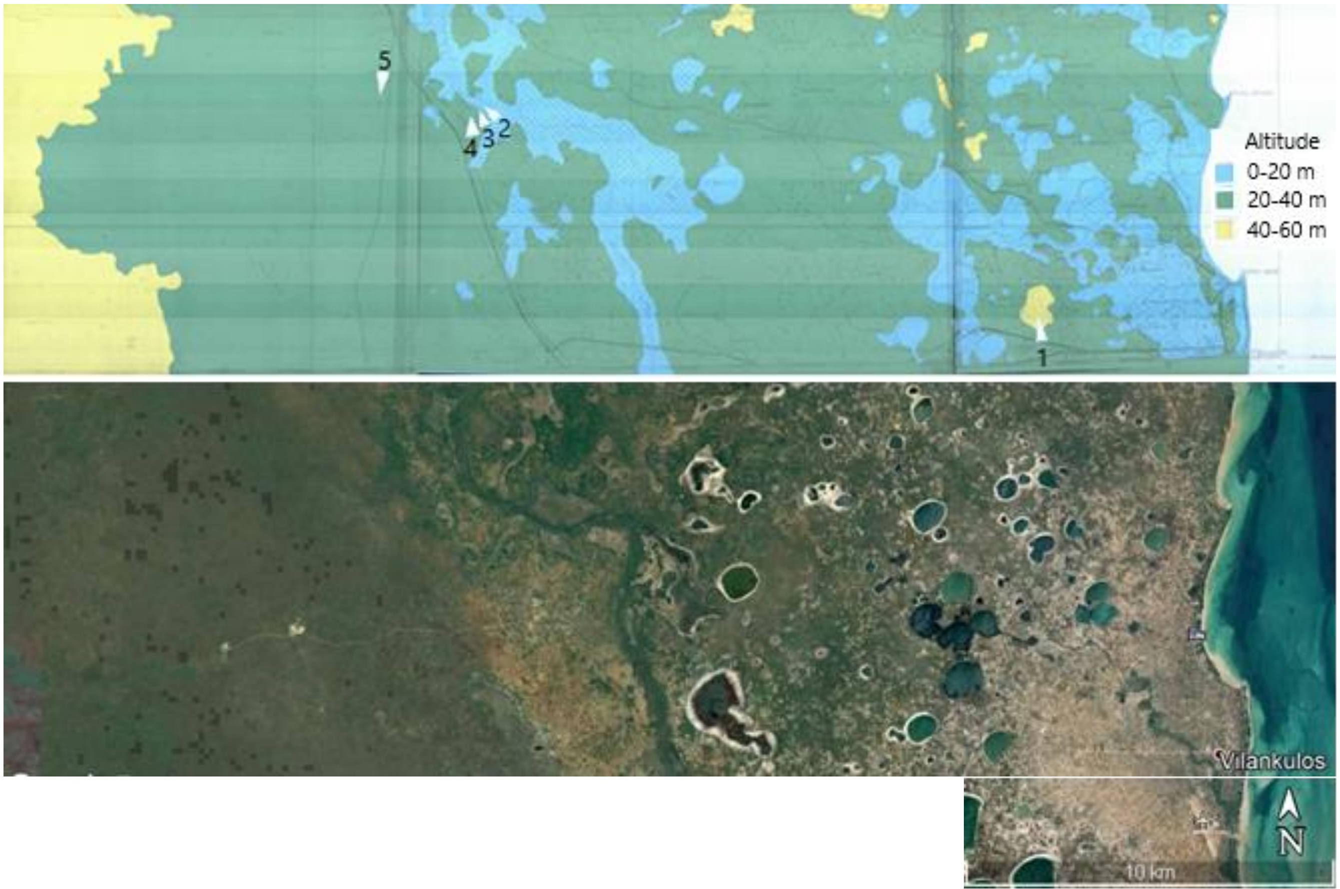

FIG. 1: (top) Topographic model of the area using as base the 1:50 000 national topographic map: locations of the soil pits are indicated by arrows bearing numbers which indicate ESUDER Soils 1, 2, 3, 4, 5: model made by J. KHOSSA; (middle) physiography of the area by GOOGLE EARTH (2018); (bottom) scale and orientation of both top and middle diagrams by GOOGLE EARTH (2018).

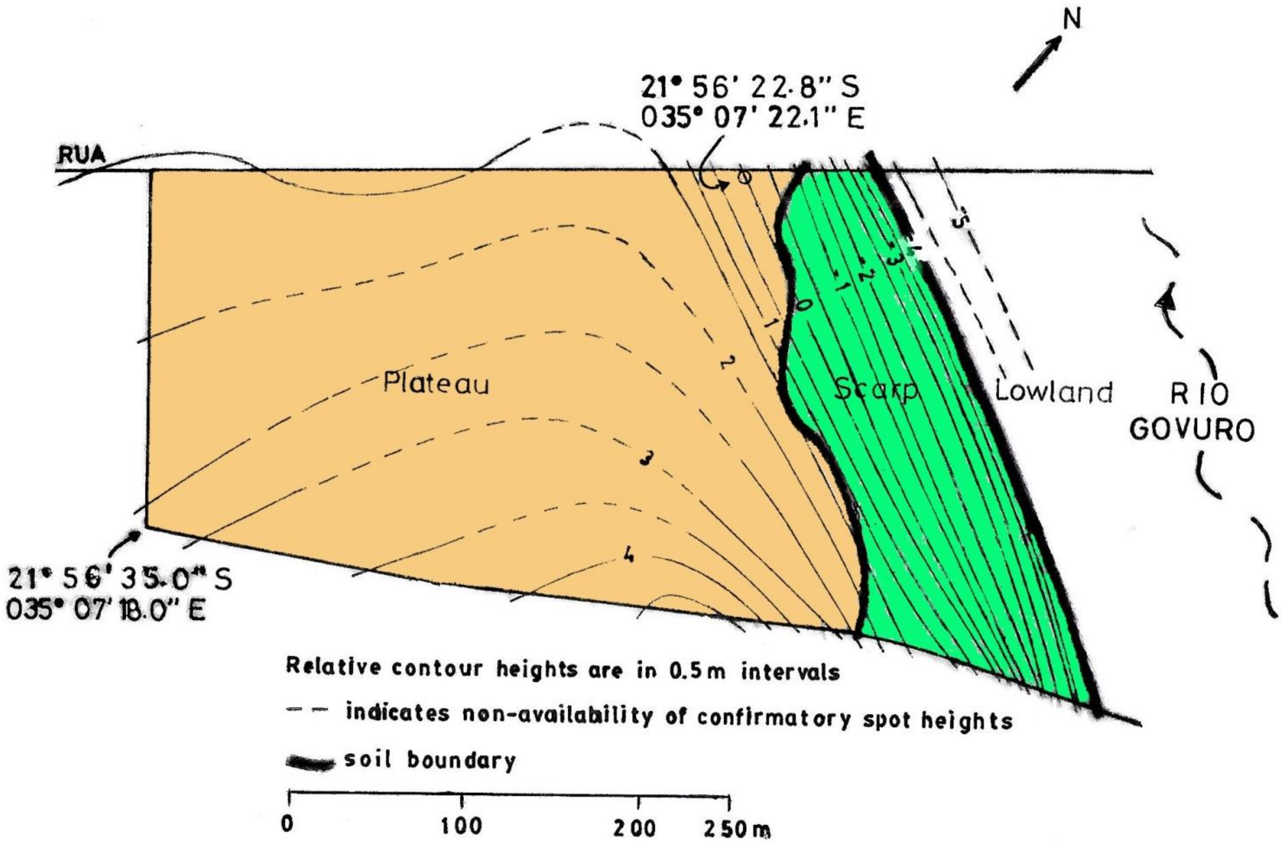

FIG. 2: Soil map of Pambarra-1. Lowland: ESUDER Soil 2; scarp: ESUDER Soil 3 and, near the top, some ESUDER Soil 4; plateau: ESUDER Soil 4.

FIG. 3: Profiles of the five ESUDER soils. Each photograph has the same scale: the profiles shown for ESUDER Soils 1, 2, 3, 4, and 5 are of depth intervals 0-1.7, 0-1.6, 0-2.0, 0-1.8, and 0-2.0 m respectively. The Mozambique national flag photographed in each pit provides three primary colours for any necessary colour adjustment of the images.

1 m

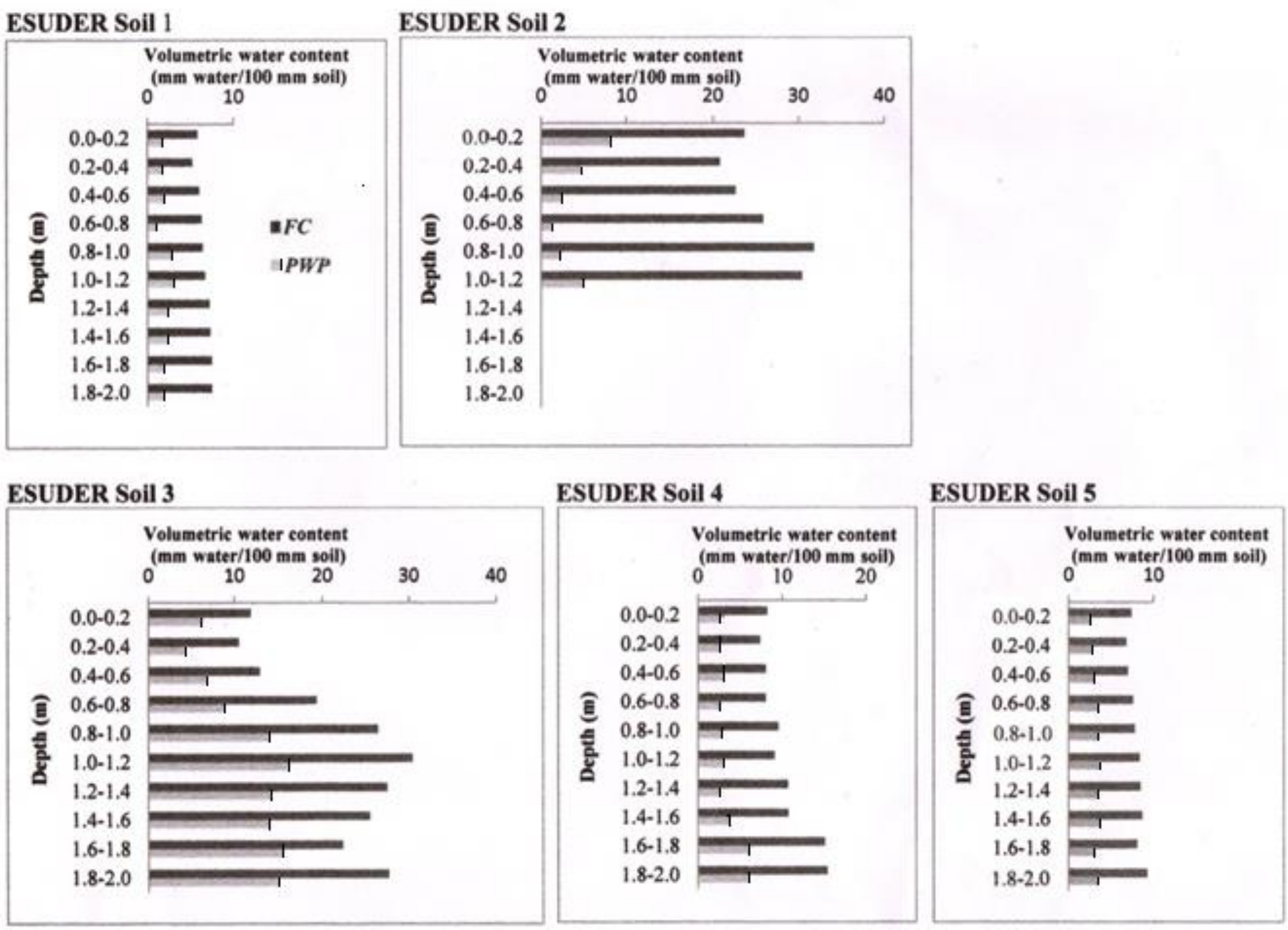

FIG. 4 Field capacity water content (*FC*) and permanent wilting point water content (*PWP*) *versus* depth.

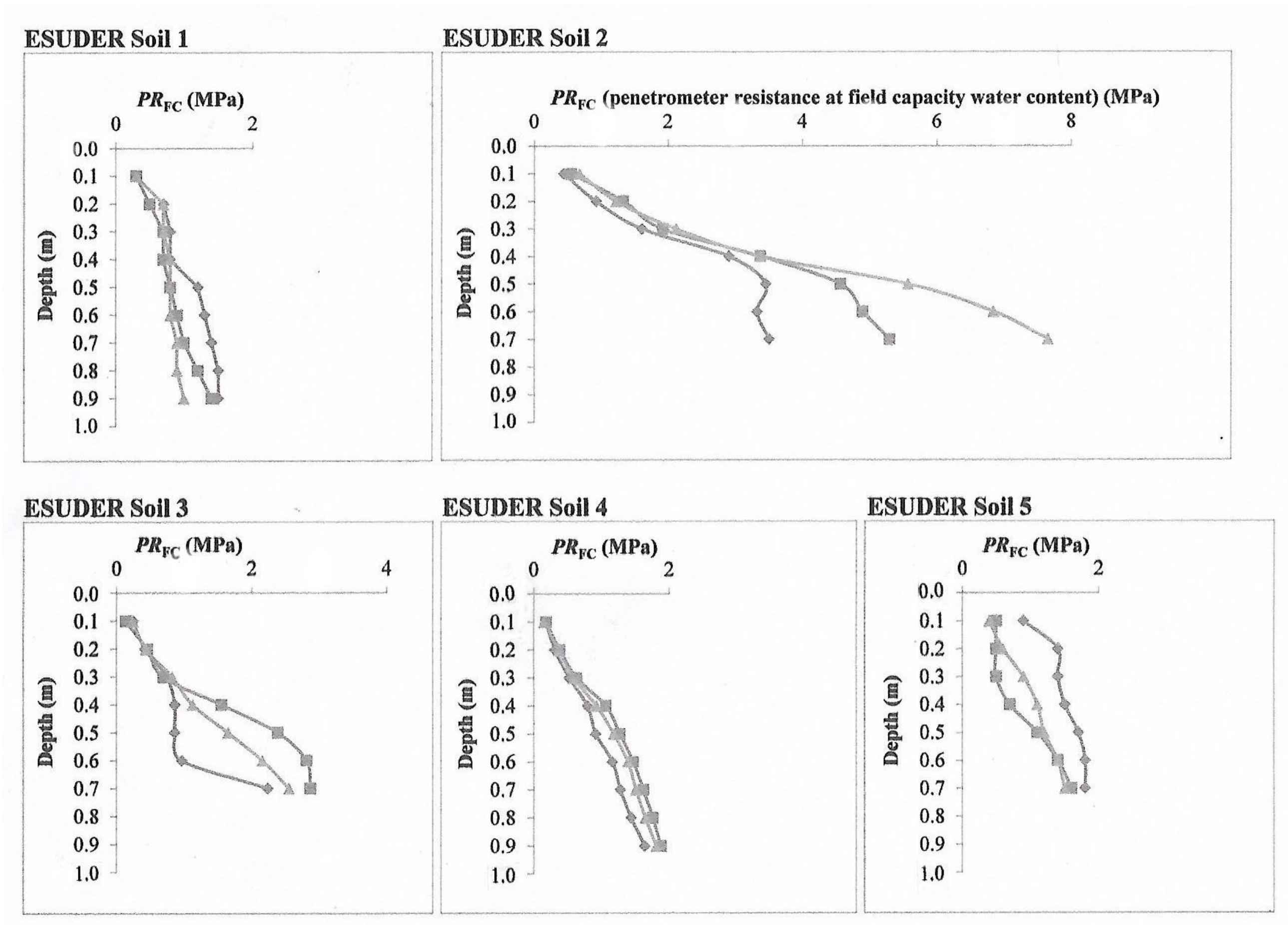

FIG. 5: Penetrometer resistance at field capacity water content (PR_{FC}) *versus* depth at three positions around soil pit.

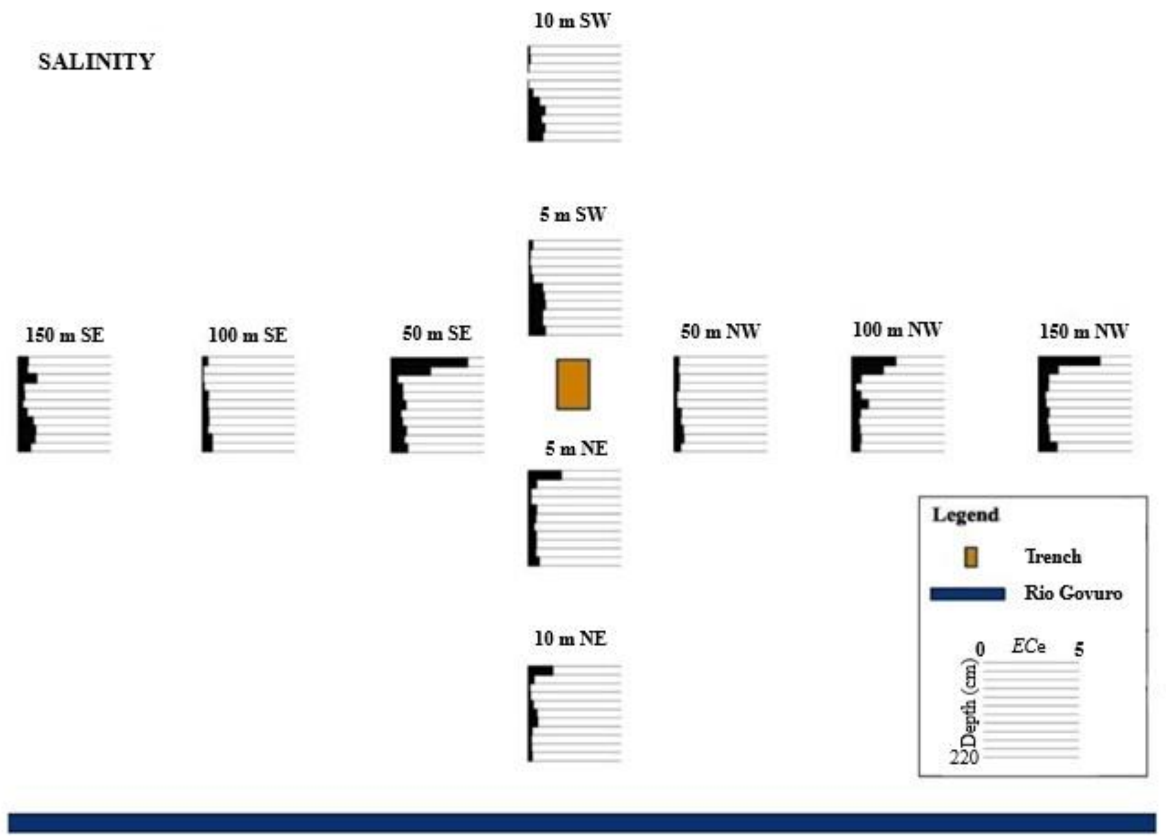

FIG. 6: ESUDER Soil 2: Distribution of soil salinity, EC_e, at low stage of river level, December 2014. Depth scale 0-220 cm. EC_e scale 0-5 mS.cm^{-1}. NW, NE, SW, SE signify NorthWest, NorthEast, SouthWest, SouthEast of the soil pit (trench).

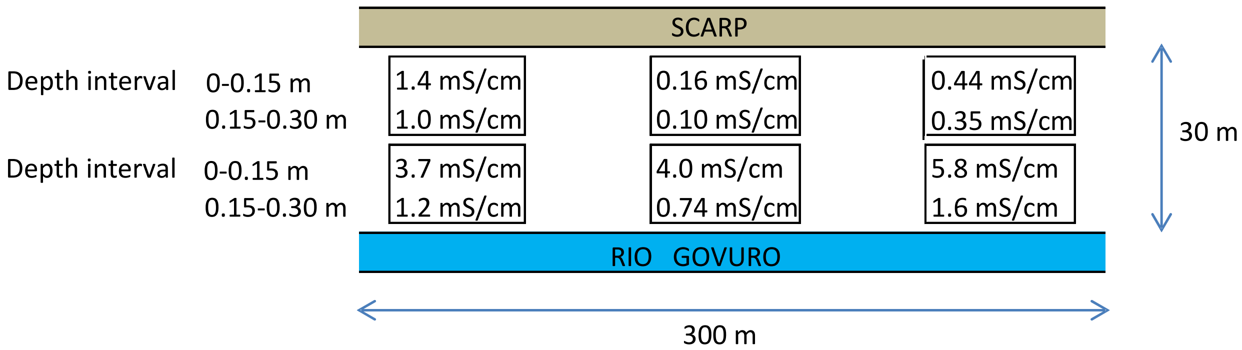

FIG. 7: ESUDER Soil 2: Diagrammatic distribution of soil salinity (EC_e) in 0-0.15 and 0.15-0.30 m depth intervals in December 2013 two months before the annual flood. Each rectangle represents a block of approximately 10 m x 20 m. Each value is for a composite sample made up from approximately 10 uniformly distributed soil samples.

TABLE 1: ESUDER Soil 1: Colour

Depth (m)	Colour	
0-0.2	2.5YR5/3	Dull reddish brown
0.2-0.4	7.5YR5/6	Bright brown
0.4-2.0	7.5YR8/6	Light yellow orange
2.0-4.6	10YR8/8	Yellow orange
4.6-6.0	7.5YR8/6	Light yellow orange

TABLE 2: ESUDER Soil 1: Horizons; transitions between horizons

Horizon (m)	Transition to next horizon	
	Sharpness	Shape
0.0-0.17	Clear	Smooth
0.17-0.30	Gradual	Irregular
0.30-0.85	Abrupt	Wavy
0.85-1.23	Gradual	Irregular

TABLE 3: ESUDER Soil 1: Texture; structure; consistence; bulk density; porosity

Horizon (m)	Texture	Structure	Consistence (moist)	Bulk density ($Mg.m^{-3}$)	Porosity (%)
0.0-0.17	Sandy loam	Single-grained**	Loose	1.29	51
0.17-0.30	Loam	Single-grained**	Friable	1.36	49
0.30-0.85	Loam	Single-grained**	Friable	1.42	46
0.85-1.23	Loam	Single-grained**	Very friable	1.43	46
1.23-2.00	Loam*	Single-grained**	Very friable	1.50	43

*In ESUDER Soil 1, texture was loam in the horizons from 0.17 m to 2.00 m and in every interval of 0.20 m thickness to at least 6.0 m depth.

**As clarified under x4 magnification in updated (year 2022) trench observations, in ESUDER Soil 1 there were no discrete aggregates. The soil consisted principally of discrete crystalline particles with interstitial pores; the relatively high porosity was apparently stabilized by sparse sesquioxides bridging between the discrete crystalline particles.

TABLE 4: Ultimate infiltration velocity, *UIV*, in three positions around soil pit

	UIV ($mm.h^{-1}$)				
Position	ESUDER Soil 1	ESUDER Soil 2	ESUDER Soil 3	ESUDER Soil 4	ESUDER Soil 5
I	1565	244	1330	1330	690
II	1500	252	1550	1680	890
III	1440	146	811	1975	640

TABLE 5: Hydraulic conductivity of saturated soil, K_s, *in situ* (mean of three positions around soil pit)

Depth interval (m)	K_s ($m.day^{-1}$)				
	ESUDER Soil 1	ESUDER Soil 2	ESUDER Soil 3	ESUDER Soil 4	ESUDER Soil 5
0.00-0.30	2.8	1.5	3.0	21	1.2
0.30-0.90	4.9	3.1	3.1	10	4.4

TABLE 6: ESUDER Soil 1: Gravimetric water content at field capacity ($\vartheta_{FC,g}$); gravimetric water content at permanent wilting point ($\vartheta_{PWP,\,g}$); volumetric available-water holding capacity (*AWHC*)

Depth interval (m)	$\vartheta_{FC,g}$ (g water/ 100 g dry soil)	$\vartheta_{PWP,\,g}$ (g water/ 100 g dry soil)	*AWHC* (mm water/ 100 mm soil)
0.00-0.20	4.5	1.3	4.1
0.20-0.40	3.8	1.3	3.4
0.40-0.60	4.2	1.4	4.0
0.60-0.80	4.4	0.8	5.1
0.80-1.00	4.5	2.0	3.6
1.00-1.20	4.7	2.2	3.6
1.20-1.40	4.8	1.6	4.8
1.40-1.60	4.9	1.5	5.1
1.60-1.80	5.0	1.2	5.7
1.80-2.00	5.0	1.2	5.7

TABLE 7: ESUDER Soil 1: *p*H

Depth interval (m)	***p*H$_{1:2.5}$ in 0.01M $CaCl_2$**	***p*H$_{1:2.5}$ in distilled water**
0.00-0.20	4.7	6.1
0.20-0.40	4.7	6.0
0.40-0.60	4.5	5.7
0.60-0.80	4.2	-
1.00-1.20	4.2	5.7
1.40-1.60	4.3	-
1.80-2.00	4.4	-
2.00-2.20	4.6	5.4
2.20-2.40	4.4	-
2.60-2.80	4.3	-
3.00-3.20	4.3	-
3.40-3.60	4.3	-
3.80-4.00	4.3	5.4
4.20-4.40	4.2	-
4.60-4.80	4.2	5.5
5.00-5.20	4.3	-
5.40-5.60	4.2	-
5.80-6.00	4.2	5.5

TABLE 8: ESUDER Soil 2: Colour; transitions between horizons

Depth interval (m)	Colour of matrix	Colour of mottles	Transition to next horizon	
			Sharpness	Shape
0.00-0.13	10YR3/1 Brownish black		Sharp	Wavy
0.13-0.60	10YR7/1 Light grey	10YR6/6 Bright yellowish brown	Gradual	Planar
0.60-1.07	2.5Y7/1 Light grey	2.5Y5/1 Yellowish grey	Abrupt	Wavy
1.07-1.60	5Y3/1 Olive black	2.5Y5/6 Yellowish brown		

TABLE 9: ESUDER Soil 2: Texture; structure; consistence; density; porosity

Horizon (m)	Texture	Structure		Consistence (humid)	Density ($Mg.m^{-3}$)	Porosity (%)
		Type	Degree			
0.0-0.13	Sandy clay loam	Crumb	Weak	Loose	0.99	63
0.13-0.60	Sandy loam	Single-grained		Friable	1.38	48
0.60-1.07	Sand	Single-grained		Loose	1.57	41
1.07-1.60	Sandy clay loam	Angular blocky	Weak	Friable	1.79	33

TABLE 10: ESUDER Soil 2: Gravimetric water content at field capacity ($\vartheta_{FC,g}$); gravimetric water content at permanent wilting point ($\vartheta_{PWP,g}$); volumetric available-water holding capacity (*AWHC*)

Depth interval (m)	$\vartheta_{FC,g}$ (g water/ 100 g dry soil)	$\vartheta_{PWP,g}$ (g water/ 100 g dry soil)	*AWHC* (mm water/ 100 mm soil)
0.00-0.20	23.9	8.3	15
0.20-0.40	15.1	3.3	16
0.40-0.60	14.8	1.6	20
0.60-0.80	16.7	0.7	25
0.80-1.00	19.9	1.5	29
1.00-1.20	18.0	3.0	25

TABLE 11:
ESUDER Soil 2: *p*H

Depth interval (m)	$pH_{1:2.5}$ in 0.01M $CaCl_2$
0.00-0.20	8.0
0.20-0.40	8.0
0.40-0.60	7.9
0.60-0.80	8.0
0.80-1.00	8.0
1.00-1.20	8.0
1.20-1.40	7.7
1.40-1.60	7.8

TABLE 12: ESUDER Soil 3: Colour; mottles; transitions between horizons

Depth interval (m)	Colour of soil matrix	Mottles (showing reduced colours)			Transition to next horizon	
		Abundance	Size	Boundary	Sharpness	Shape
0-0.25	7.5R2/1 Reddish black	Few	Very fine	Diffuse	Gradual	Smooth
0.25-0.37	10R2/1 Reddish black	Common	Fine	Diffuse	Sharp	Smooth
0.37-0.66	7.5R4/2 Greyish red	Few	Very fine	Sharp	Abrupt	Smooth to wavy
0.66-1.04	10R5/2 Greyish red	Very few	Very fine	Diffuse	Gradual	Wavy
1.04-1.44	7.5YR7/1 Light brownish grey	Very few	Very fine	Distinct	Sharp	Wavy
1.44-2.00	5YR8/1 Light grey	Very few	Very fine			

TABLE 13: ESUDER Soil 3: Texture; structure; consistence; density; porosity

Depth interval (m)	Texture	Structure			Consistence	Density ($kg.m^{-3}$)	Porosity (%)
		Type	Class	Degree			
0-0.25	Sandy loam	Single-grained			Very friable	1.29	51
0.25-0.37	Sandy loam	Single-grained			Friable	1.53	42
0.37-0.66	Sandy loam	Single-grained			Friable	1.70	36
0.66-1.04	Loam	Angular platy	Fine	Weak	Firm	1.79	32
1.04-1.44	Loam	Angular blocky	Very fine	Weak	Firm	1.87	29
1.44-2.00	Sandy clay loam	Angular platy	Fine	Moderate	Firm	1.72	35

TABLE 14: ESUDER Soil 3: Gravimetric water content at field capacity ($\vartheta_{FC,g}$); gravimetric water content at permanent wilting point ($\vartheta_{PWP,\ g}$); volumetric available-water holding capacity (*AWHC*)

Depth interval (m)	$\vartheta_{FC,g}$ (g water/ 100 g dry soil)	$\vartheta_{PWP,\ g}$ (g water/ 100 g dry soil)	*AWHC* (mm water/ 100 mm soil)
0.00-0.20	9.2	4.9	5.5
0.20-0.40	7.0	2.9	6.4
0.40-0.60	7.6	4.0	6.2
0.60-0.80	10.6	4.9	10.5
0.80-1.00	14.6	7.8	12.4
1.00-1.20	16.3	8.6	14.3
1.20-1.40	14.7	7.6	13.2
1.40-1.60	14.7	8.1	11.5
1.60-1.80	12.9	9.1	6.7
1.80-2.00	16.0	8.7	12.7

TABLE 15: ESUDER Soil 3: *p*H

Depth interval (m)	**$pH_{1:2.5}$ in 0.01M $CaCl_2$**	**$pH_{1:2.5}$ in distilled water**
0-0.25	7.1	7.6
0.25-0.37	7.0	8.0
0.37-0.66	7.2	8.1
0.66-1.04	7.5	8.4
1.04-1.44	8.0	9.0
1.44-2.00	8.4	9.7

TABLE 16: ESUDER Soil 4: Colour; transitions between horizons

Depth interval (m)	**Colour**	**Transition to next horizon**	
		Sharpness	**Shape**
0-0.17	10YR5/4 Dull yellowish brown	Sharp	Smooth
0.17-0.34	7.5YR5/3 Dull brown	Gradual	Smooth
0.34-0.56	5YR6/8 Orange	Diffuse	Smooth
0.56-0.83	7.5YR7/6 Orange	Diffuse	Smooth
0.83-1.80	7.5YR7/8 Yellow orange	Diffuse	Smooth
1.80-2.00	2.5YR6/8 Orange		

TABLE 17: ESUDER Soil 4: Texture; structure; consistence; density; porosity

Depth interval (m)	Texture	Structure Type	Structure Class	Structure Degree	Consistence (moist)	Density ($kg.m^{-3}$)	Porosity (%)
0-0.17	Sandy loam	Angular blocky/ single-grained	Medium	Weak	Very friable/ loose	1.35	49
0.17-0.34	Sandy loam	Angular blocky	Medium	Weak	Friable	1.49	44
0.34-0.56	Sandy loam	Angular blocky	Medium	Weak	Firm/ Friable	1.82	31
0.56-0.83	Loam	Angular blocky	Medium	Weak	Firm	1.80	32
0.83-1.80	Loam	Angular blocky	Medium	Weak	Firm	1.85	30
1.80-2.00	Loam	Angular blocky	Medium	Weak	Firm	1.92	28

TABLE 18: ESUDER Soil 4: Gravimetric water content at field capacity ($\vartheta_{FC,g}$); gravimetric water content at permanent wilting point ($\vartheta_{PWP, g}$); volumetric available-water holding capacity (*AWHC*)

Depth interval (m)	$\vartheta_{FC,g}$ (g water/ 100 g dry soil)	$\vartheta_{PWP, g}$ (g water/ 100 g dry soil)	*AWHC* (mm water/ 100 mm soil)
0.00-0.20	6.1	1.9	5.7
0.20-0.40	5.0	1.7	4.8
0.40-0.60	4.4	1.7	5.0
0.60-0.80	4.5	1.5	5.4
0.80-1.00	5.2	1.5	6.7
1.00-1.20	4.9	1.6	6.0
1.20-1.40	5.8	1.4	8.1
1.40-1.60	5.8	2.0	7.0
1.60-1.80	8.2	3.3	9.1
1.80-2.00	8.0	3.1	9.4

TABLE 19: ESUDER Soil 4: *p*H

Depth interval (m)	$pH_{1:2.5}$ in 0.01M $CaCl_2$	$pH_{1:2.5}$ in distilled water
0-0.17	7.0	7.9
0.17-0.34	6.5	7.2
0.34-0.56	5.9	7.0
0.56-0.83	6.0	7.4
0.83-1.80	6.0	7.2
1.80-2.00	6.0	7.4

TABLE 20: ESUDER Soil 5: Colour; transitions between horizons

Depth interval (m)	Colour	Transition to next horizon	
		Sharpness	Shape
0-0.09	2.5YR2/2 Very dark reddish brown	Sharp	Smooth
0.09-0.21	2.5YR3/2 Dark reddish brown	Sharp	Smooth
0.21-0.50	2.5YR5/6 Bright brown	Gradual	Smooth
0.50-0.88	2.5YR5/8 Bright brown	Diffuse	Smooth
0.88-2.00	10R4/8 Red		

TABLE 21: ESUDER Soil 5: Texture; structure; consistence; density; porosity

Depth interval (m)	**Texture**	**Structure**			**Consistence (dry)**	**Density ($kg.m^{-3}$)**	**Porosity (%)**
		Type	**Class**	**Degree**			
0-0.09	Silty loam	Crumb/ single-grained	Very fine		Loose	1.33	49
0.09-0.21	Sandy loam	Angular blocky	Very fine	Weak	Slightly hard	1.37	48
0.21-0.50	Sandy loam	Angular blocky	Very fine	Weak	Slightly hard	1.44	46
0.50-0.88	Sandy loam	Angular blocky	Very fine	Weak	Slightly hard	1.61	39
0.88-2.00	Sandy loam	Angular blocky	Very fine	Weak	Slightly hard	1.54	42

TABLE 22: ESUDER Soil 5: Gravimetric water content at field capacity ($\vartheta_{FC,g}$); gravimetric water content at permanent wilting point ($\vartheta_{PWP,g}$); volumetric available-water holding capacity (*AWHC*)

Depth interval (m)	$\vartheta_{FC,g}$ (g water/ 100 g dry soil)	$\vartheta_{PWP,g}$ (g water/ 100 g dry soil)	*AWHC* (mm water/ 100 mm soil)
0.00-0.20	7.4	2.7	6.3
0.20-0.40	6.8	2.8	5.5
0.40-0.60	7.0	3.0	6.1
0.60-0.80	7.6	3.4	6.8
0.80-1.00	7.8	3.6	6.7
1.00-1.20	8.4	3.6	7.6
1.20-1.40	8.5	3.5	7.7
1.40-1.60	8.7	3.7	7.7
1.60-1.80	8.1	3.2	7.6
1.80-2.00	9.3	3.5	8.9

TABLE 23: ESUDER Soil 5: *p*H at three positions around pit

Depth interval (m)	Position I		Position II		Position III	
	$pH_{1:2.5}$ in 0.01M $CaCl_2$	$pH_{1:2.5}$ in distilled water	$pH_{1:2.5}$ in 0.01M $CaCl_2$	$pH_{1:2.5}$ in distilled water	$pH_{1:2.5}$ in 0.01M $CaCl_2$	$pH_{1:2.5}$ in distilled water
0.00-0.20	6.5	7.0	7.0	7.7	7.0	7.3
0.20-0.40	6.9	8.2	7.1	8.3	6.9	8.0
0.40-0.60	7.0	7.9	7.2	8.0	7.0	7.4
0.60-0.80	7.0	8.0	7.2	8.1	7.0	7.2
0.80-1.00	7.1	8.0	7.3	8.1	7.0	7.6
1.00-1.20	7.1	7.9	7.2	8.0	5.4	5.4
1.20-1.40	7.1	7.9	7.3	8.0	5.0	5.7
1.40-1.60	7.1	7.9	7.2	8.0	4.6	5.7
1.60-1.80	7.2	7.8	7.2	7.8	5.2	6.0
1.80-2.00	7.0	7.6	7.1	7.9	4.7	5.3

END OF ARTICLE