Elevation Influencing Soil Properties and Forest Litter across a catena in the Siliceous Moncayo Massif, SW-Europe

Abstract: Understanding the effects of elevation and related factors (temperature, precipitation, vegetation) on physical and chemical soil properties in quartzitic-derived soils can help to predict changes in response to future land-use or climate forcings. This work aims to contribute to the knowledge of soil properties, soil forming processes and classification of forest soils with elevation in montane stage, with special attention to podsolization and humus forms. The northern flank of the Moncayo Massif (Iberian Range, NE-Spain) provides a unique opportunity to study a forest soils catena within a consistent quartzitic parent material over a relatively steep elevation gradient.

With increasing elevation, pH, base saturation, exchangeable potassium, and fine silt-sized particles decrease, while organic matter, C/N ratio, soil aggregate stability, water repellency and coarse sand-sized particles increase significantly. The soil profiles shared a set of properties in all horizons: loamy-skeletal particle-size, extreme acidity (pH-H_2O <5.6) and low base saturation (<50%). The most prevalent soil forming processes in the catena include organic matter accumulation and even podsolization, which increase with elevation. From the upper to lower landscape positions of wooded montane stage of Moncayo Massif, mull-moder-mor humus and an Umbrisol-Cambisol-Podzol soil unit sequences are found.

Keywords: montane stage, forest soils, catena, humus forms, podzolization.

1. Introduction

A catena is defined as a connected series of soils with respect to relief from the summit to the toeslope (Birkeland 1999). As quoted Ibrahim and Lal (2014), soils within a catena may differ in properties and classification from one landscape position to another because of differences in soil forming factors such as climate (climosequence), vegetation (biosequence), relief (toposequence), parent material (lithosequence), or time (chronosequence). The catena analysis has been and is widely used in the study of soils with different objectives. Thus, the influence of two contrasted parent material on soil properties and humus type was analyzed along altitudinal transects in the Eastern Pyrenees (Martí and Badía 1995); the pedogenesis on different Holocene parent materials was studied by means of a catena in the Swiss Jura Mountains (Martignier and Verrecchia 2013); soil carbon pools and Si pools are measured across a catena in central Ohio (Ibrahim and Lal 2014); mechanical properties variation were studied across a soil catena developed on Eocene marls in the Inner Depression of the Central Spanish Pyrenees (Badía et al. 2015); pyrogenic carbon content, produced by vegetation fires, were quantified across a soil catena in the Pacific Northwest (Jauss et al. 2015), soil organic carbon and nutrients content were measured along a latitude gradient on the northern Tibetan Plateau (Cao et al. 2013), etc.

In a sequence where are kept constant relief, parent material and time, the catena may be synonymous with climosequence biosequence. It is the case of montane stage of northern slope of Moncayo Massif. The variability of soils across this slope will be a function of the variations of climate and vegetation variations. In this sense, the Moncayo Massif provides a unique opportunity to sample forest soils within a consistent and recent quartzitic colluvium acting as parent material over a relatively steep elevation gradient. Early studies describe vegetation (Uribe 2002; Longares, 2004), climate (Cuadrat and Pellicer 1983; Ibarra and Echeverría 2004; Ibarra et al. 2003), geomorphology (Pellicer 1984), geology (IGME 1980) and even soil nutrient cycles (Carceller 1995) and mineralogy (Hoyos et al. 1982). All them recognized the singularity of this mountain of the Iberian Range, besides the semiarid Ebro Basin, which it has earned the protection figure of Natural Site in 1927 and Natural Park in 2007. Despite the importance of nature in the Moncayo Massif there have not been published any contribution on the genesis of soils for an international audience.

In addition to the global pedogenesis, soil humus is a perfect indicator of environmental conditions, which depends on biotic factors, as vegetation type, and on abiotic factors such as climate, altitude, and bedrock (Labaz et al. 2014). While changes in soil evolution can occur over millenaries, changes in forest floor occurs within decades, being a faster shift indicator (Jabiol et al. 2013). The monitoring of humus forms might thus help to know the impact of land-use changes (afforestation, abandonment) or global warming on surface-accumulated organic carbon (Ponge et al. 2011). Nowadays, some suggestions try to include humus form classifications to the standard soil description protocols and in an international soil classification system (Jabiol et al. 2013; Zanella et al. 2011). Both, humus and soil classification is needed to transfer information data (Hartemink 2015).

This study aims (i) to examine soil properties, pedogenesis and soil classification variation with elevation, (ii) to define humus variation from the upper to lower landscape positions, (iii) to assess soil properties variation vertically within pedons across the catena and (iv) to explore relationship between soil characteristics in the wooded montane stage of the siliceous Moncayo Massif (Iberian Range, NE-Spain).

2.Study Area

2.1. Site description

The Moncayo Massif (henceforth Moncayo) rises above the southern edge of the Ebro river (Fig. 1), along the eastern or Aragonese sector of the Iberian Range (NE-Spain). Reaching an elevation of 2313 meters, Moncayo is the summit in the Iberian Range and one of the most prominent peaks of the Iberian Peninsula.

Fig. 1. Location of soil profiles studied along the northeast flank of the Moncayo Massif (Iberian Range, NE-Spain).

This research described six soil profiles sampled specifically from areas in the montane stage, at 1000 m to 1600 m elevation (above mean sea level). The areas specifically feature relatively wet conditions, a dense forest cover along the northeast flank of the Moncayo (Table 1). Moreover parent material is acidic and includes stony colluvium, dominated by quartzitic sandstones, in the form of solifluction mantles related to freeze-thaw activity that characterizes periglacial environments from Pleistocene-Holocene transition (Pellicer 1984, IGME 1980). The mineralogic composition of sandstone parent material (Triassic Tierga Formation), sampled from the bottom of the studied catena (Monte de La Mata), consists of 67% quartz, 15% potassium feldspar, and 8% mica (Carceller 1995).

Table 1
Formation factors of soils analyzed from the Moncayo catena

Total annual precipitation ranges from around 700 mm/yr in Agramonte (1060 m) to about 1400 mm at the summit of the Moncayo (2313 m); it increases at an average rate of 99.5 mm/100 elevation in oakwood stage to 45.2 mm/100 m elevation in beechwood stage (Ibarra et al., 2003). The average annual temperature is about 10º C in Agramonte, decreasing with elevation at a rate of 0.59ºC/100 m (Cuadrat and Pellicer 1983). According to data available for montane stage soils, we interpret the moisture regime as udic, and the temperature regime as spanning from mesic to frigid with elevation. This climatic gradient creates an altitudinally zoned forest composed of deciduous oaks (*Quercus petraea* and *Quercus pyrenaica*) from 900 m to 1200 m, and beech (*Fagus sylvatica*) from 1200 m to 1600 m, with replacement in some areas by Scots pine (*Pinus sylvestris*) due to reforestation starting around the year 1920 (García-Manrique 1960). The understory consists of heathers (*Erica vagans, Erica arborea, Erica cinerea*), hollies (*Ilex aquifolium*), blueberries (*Vaccinium myrtillus*), wavy hair-grass (*Deschampsia flexuosa*), mosses, etc. Previous reports describe other details on vegetation (Uribe 2002; Longares, 2004) and climate-plant-soil relationships (Ibarra and Echeverrría 2004).

3. Materials and methods

Six soil profiles were sampled along the montane stage from 1000 m (Monte de La Mata) to 1600 m (near San Gaudioso hermitage). The sampled profiles occurred beneath areas covered in oak (*Quercus petraea*, *Quercus pyrenaica*), beech (*Fagus sylvatica*), and Scots pine (*Pinus sylvestris*) forest (two profiles for each vegetation type, Table 1). Selected profiles were representative of the study area and provided reliable data for interpreting soil-forming processes in the wooded montane stage. Pedons were described according to FAO guidelines (FAO 2006). We report the specific morphological characteristics of each soil horizon, including color (under moist and dry conditions), structure, consistency, roots and accumulations for each pedon. Humus identification was based in morpho-functional classification at group level, as proposed by Jabiol et al. (2013). Soil samples were air-dried and sieved (mesh size 2 mm) to determine the percentage of gravel (> 2 mm) and fine earth (< 2 mm). Laboratory analyses were performed on the fine earth fraction. Soil pH was determined from potentiometric measurements of a 1:2.5 (w/v) suspension of soil and water (current pH or pH-H_20) and with 1N KCl (potential pH or pH-KCl) (McLean 1982). Cation exchange capacity (CEC) and exchangeable base cations were determined by NH_4^+ retention after leaching with a neutral solution of 1N NH_4OAc (Rhoades 1982), following analytical procedures specified for WRB classification (IUSS 2014). Additionally, exchangeable Al and Fe were extracted with an unbuffered, 1M KCl solution. Al and Fe were extracted with NH_4 oxalate-oxalic acid (Blakemore 1985) to estimate total "active" Al and Fe species. This selective extraction of Al and Fe by ammonium oxalate (Al_{ox} and Fe_{ox}) has been used to quantify the extent of podzolization and identify Podzols (McKeague et al. 1983) based on estimates of Al_{ox}+1/2Fe_{ox} (IUSS, 2014; Soil Survey Staff, 2014). Al and Fe were analyzed by ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometry). Total organic carbon was determined by the wet oxidation method (Nelson and Sommers 1982), which is considered equivalent to Total C in the absence of soil carbonates. Total N was determined by the Kjeldahl method (Bremner and Mulvaney 1982).

Fine earth fraction particle size distributions were determined by the discontinuous sedimentation method after removal of organic content with H_2O_2 (30%) and clay dispersal with 5% Na-hexametaphosphate (Gee and Bauder 1986). The coarse sand fraction ranges from 2000-500 µm, fine sand from 500-50 µm, coarse silt from 50-20 µm, fine silt from 50-2 µm and clay is < 2 µm in bulk diameter. Soil Aggregate Stability (SAS) was assayed for 1-2 mm diameter aggregates using the wet-sieving method (Kemper and Koch 1966). The water content at field capacity (-33 kPa) was measured volumetrically using pressure plate extractors (Richards 1947).

Soils were classified according to WRB (IUSS 2014) and Soil Taxonomy (Soil Survey Staff, 2014) systems. Both taxonomies have been endorsed by the International Union of Soil Science (IUSS) as the internationally accepted soil classification systems (Hartemink 2014).

We calculated Pearson correlation coefficient to evaluate the degree of linear association among variables. Correlation coefficients (R) presented in the text are statistically significant at the $P < 0.01$ level unless otherwise noted. Simple and multiple linear regressions among soil properties were carried out using Statview statistical package; in this case, the determination coefficient (R^2) is provided. Principal Component Analysis (PCA) was carried out using XLSTAT Software (version 2015), with Varimax rotation and Kaiser Normalization following standardization of the data, as previous works (Badía et al. 2008).

4. Results and discussion: variations with elevation and soil depth

4.1. Morphological properties

Lower elevations host simpler sequa such as (O)-Ah-Bw-C or (O)-Ah-C-R. But with elevation, an O-Ah-E-Bhs-C sequence indeed appears within pine and beech forest sites. The profiles analyzed contained thick horizons of litter (O) within Ah horizons, especially beneath pinewood with heather at the highest elevation, but also beneath beech forest. The O horizons consisted of three distinct layers, including 1) OL (Oi) undecomposed litter (new or old), 2) an OF (Oe) fragmentation layer where plant remains are partially decomposed by biological activity (especially fungi) but with plant morphology still recognizable, and 3) an OH (Oa) humus layer without recognizable plant structures and fine granular morphology. Surface samples indicated thicker organic layers developed beneath Scots pine forests than that developed beneath beech forests, which the pine forests often replaced. At low elevations, within oak forests, soils contain only the OL horizon of this sequence. Given O and Ah horizon characteristics (Table 2), the humus group along the toposequence can be designated as Mesomull at the base of the slope, Hemimoder at intermediate elevations and Humimor at higher elevations, following the classification system described in Jabiol et al. (2013). This humus sequence (Mesomull-Hemimoder-Humimor) is the result of a progressive reduction of the soil biological activity with elevation. Climate constraints (cold), acidity and poor nutrient content of the soil can be factors that limit biological activity with elevation (Zanella et al. 2011). In a siliceous toposequence in the Eastern Pyrenees also found downslope mull humus type with OL layers, which evolved to OL-OF (OH) sequa with higher elevation (Martí and Badía 1995).

Table 2
Humus characteristics of soil toposequence along the northern flank of the Moncayo.

In northern Germany, the Netherlands and northern Poland, ancient Scots pine stands showed thicker O horizons than those associated with beech forests (Leuschner et al. 2013). This indicates that pine stands may have ~75% more carbon in their organic layers than ancient beech forests, although total C content in beech forest soils (organic layer and mineral soil) was •25% greater due to higher C concentrations within the mineral soil, mainly in 0-50 cm depth (Leuschner et al., 2013). Similarly, Labaz et al. (2014) observed, in the Stolowe Mountains of SW Poland, that the replacement of ancient European beech forests by Norway spruce stands transformed moder humus to mor and contributed to its increasing thickness with elevation.

Beneath the O horizon is an Ah horizon darkened by the incorporation of organic matter. The color of these Ah horizons ranges from 7.5 YR 3/1 (very dark gray) in pine forests at high elevation to 10YR 6/2 (light brownish gray) in oak forests at low elevations, becoming paler at depth, particularly in eluvial horizons (E). A whitish horizon (E horizon, albic), which contains only scarce organic matter and bases, lies below the O and A horizons. The whitish E horizon color derives from the quartzitic sand and silt, bleached and unstructured due to the removal or segregation of organic matter and free iron oxides (Buurman and Jongman 2005). At high elevations, the Bhs horizons exhibit a redder hue and higher chroma, which suggests iron, aluminum and/or organic matter accumulation. Bhs horizons have mainly a 7.5 YR 4/4 color (moist). Similar colors characterize boreal Bhs horizons occurring in cold climates at high latitudes and elevations, such as those found in the Italian Alps (Monaci et al., 1990) and in the U.S. (Base and Brasher, 1990). The structure, which exhibits fine, granular morphology in the Ah horizons, disappears in E horizons and becomes subangular to blocky in Bw and Bhs horizons, if stoniness is not very high. Compaction of the soil matrix renders it relatively hard but it is never cemented (Appendix A).

Some horizons O (OF and OH), A and Bhs include dense root system of herbaceous and shrub vegetation (Appendix A), which may take advantage of its greater availability of nutrients and water (Buurman and Jongmans 2005).

4.2. Chemical and physical characteristics.

4.2.1. Common properties.

The profiles studied along the catena share a number of common properties, including strong acidity (pH-H_2O <5.6; pH-KCl <4.4) and base saturation of less than 50% in all horizons (Appendix B). The pH-KCl) and the pH-H_2O) are positively correlated (r = 0.88). Among the exchangeable basifying cations, Ca was the most abundant (0.8-6 $cmol_+$/kg), followed by Mg (0.04-1.6 $cmol_+$/kg) and K (0.04-0.6 $cmol_+$/kg). Exchangeable Al ranges from 0.3 to 1.1 $cmol_+$/kg, which greatly exceeded the exchangeable Fe (0.01-0.05 $cmol_+$/kg). The sum of exchangeable bases (by 1 M NH_4OAc, pH 7), plus exchangeable Al (by 1 M unbuffered KCl solution) was also less than 50% in all horizons of the profiles analyzed (Appendix C).

Exchangeable basifying cations measured in this study occurred at the same order of magnitude as that found in podzolic soils of Sierra de Urbasa (Val and Iñiguez 1981a). However, the exchangeable Ca and Mg content measured in this study was much higher, and the Al and Fe content much lower (by a factor of ten), than that measured by Bogner et al. (2012) in Haplic Podzols of the Lehstenbach catchment in southeast Germany (extracted with 1M NH_4Cl); the pH-H_2O measured from those Podzols was also lower than that measured in the soils described here.

The profiles studied also show a number of shared physical properties, including high stoniness and textural class ranging from sandy loam to loam (Fig. 2). Soils specifically have a loamy-skeletal particle-size class according to the Soil Taxonomy system (SSS, 2014). The Ah horizons exhibit a high soil aggregate stability (SAS), usually with a second maximum in B horizons (Appendix D)

Fig. 2. Textural classes for soil horizons analyzed (n = 25).

4.2.2.Variations with depth

Upslope soils show an increase in pH-H_2O values with depth, which ranges from 4.0-4.7 from A horizons to 4.9-5.3 for lowermost horizons in profiles from both pine and beech forests. Profiles located in downslope areas of oak forests exhibited the opposite tendency. Increasing pH with depth is common in Podzols (Bogner et al. 2012; Camps and Aizpurúa 2007; Carceller 1995).

Organic carbon content (C) showed a clear decreasing trend with depth, from 2.3–10.0% in A horizons to 0.2-1.5% in lowermost horizons. The same parameter showed a relative increase in Bhs horizons (3.1–4.2%) where present. Total N is significantly correlated to carbon content in soils (R = 0.87). The C/N ratio in oak profiles was highest within the Ah horizon (10.0-11.8) and decreased with depth. For Ah-E-Bhs-BC sequa within pine and beech forest soils, C/N was high in Ah horizons (11.0–22.1), decreased in E horizons (5.7–11.5) to go back up in Bhs horizons (7.6-18.5). The Ah horizon had the highest proportions of bases (3.3-7.5 $cmol_+$/kg), and exhibits a relative increase in the Bhs horizon (2.2-3.4 $cmol_+$/kg) where present, but appears in lower proportions in E and C (or BC) horizons. The contents of oxalate-extracted Al (Al_{ox}) and Fe (Fe_{ox}) exhibit maxima at certain soil depths corresponding to either Bw, Bs or Bhs horizons (Fig. 3). According to these maxima or horizons with maximum concentrations, Al_{ox} ranges from 0.10% in Bw for oak forest soils to 0.70% in Bhs of beech forest soils and 1.0% in Bhs of pine forest soils. At the same time, Fe_{ox} ranges from 0.20% in Bw of oak forest soils to 0.49% in Bhs beech forest soils and 0.80% in Bhs of pine forest soils. The highest Al_{ox} and Fe_{ox} values occurred in Bhs horizons, while their lowest values occurred in E horizons. For example, the percentage of Al_{ox}+1/2Fe_{ox} ranges from 0.53 to 1.39% in Bhs horizons and from 0.05 to 0.11% in E horizons.

Upslope, litter (O horizons composed by OL-OF-OH layers) overlies a dark Ah horizon. The presence of a dark and structured Ah umbric horizon does indicate some biological activity which, if constraints further could generate the lack of the Ah horizon, and an O-E-Bhs-C sequence, typical of other Podzols (Labaz et al. 2014). Topsoil horizons provide a permanent supply of low molecular weight organic acids (fulvic acids), which react with metal-organic complexes (Al and Fe), migrate downwards through E horizons (cheluviation) as soluble complexes, and then accumulate (chiluviation) in Bhs horizons (Buurman and Jongman 2005; Sauer et al. 2007). The accumulation of Al and Fe is interpreted as the result of saturation of organic ligands adsorption sites (Ferro-Vázquez et al. 2014) and even from microbial degradation of some organic ligands (Lundstrom et al. 2000; Grand and Lavkulich 2011).

The CEC for each profile exhibited maxima within the Ah and Bhs horizons, which can be related to high content of aromatic and alkyl chain compounds with high bonding capacity (Beyer 1996; Girona et al. 2015). CEC specifically relates to the content of organic matter (OM) and to a lesser extent, clay content:

CEC (cmol/kg)=1.278 (OM)+4.50; r^2=0.553; n= 25; p<0.001

CEC (cmol/kg)=0.697 (clay)+1.728; r^2=0.173; n= 25 ; p<0.05

CEC = 1.177 (OM)+0.337 (clay); n=25; r^2=0.536; p<0.001

The linear regressions given above indicate that the clay particle size fraction, which is relatively scarce in the soils analyzed, seems to have low cation exchange capacity. In studying the mineralogy of two soil profiles in the montane stage of the Moncayo, Hoyos et al. (1982) found that soil clay minerals were primarily illite, being particularly abundant in surface horizons. In addition to illite, they also observed vermiculite, hydromica, and kaolinite as well as interlayers of vermiculite-illite, vermiculite-chlorite, and vermiculite-kaolinite Soil acidity and strong leaching would weather illite to vermiculite and even to kaolinite under conditions of moderate weathering. Val and Iñiguez (1981b) identified similar clay mineral composition in Podzolic soils from the nearby Sierra de Urbasa, with illite and kaolinite in greater abundance than vermiculite, montmorillonite, chlorite, and various interstratified minerals.

The variation of certain physical properties with depth also followed a different pattern in the profiles beneath beech and pine forest at high elevations, than those corresponding to oak profiles. Soil aggregate stability (SAS) is thus highest in Ah horizons (90-96%) and decreases consistently with depth in oak forest profiles. In beech and pine forest profiles however, the highest SAS values occurred in A and B horizons (80-94%), while the lowest values occurred in E horizons (28-83%). SAS is significantly correlated with organic matter content (r=0.61), and even with Ca^{2+} (r=0.41) and Mg^{2+} (r=0.64) but not with clay-sized particles (r=0.04). It is well known that cations and organo-metallic compounds form bridges between particles and the SOC enhances aggregation through the bonding of primary soil particles (Bronick and Lal 2005).

The relative clay increase in B horizons (Fig. 3) may relate to some illuviated crystalline clays or to dispersion of illuviated Al and Fe in the particle-size separation (joining to the measured clay fraction). Although proportion of fine particles increase with depth, clay films (coatings of oriented clay on the surfaces of pores and peds) are not present on peds or in pores within Bs or Bhs horizons.

Field capacity is significantly related to organic matter (OM) as well as clay content:

FC(%)=0.62 (clay%)+10.70; R^2=0.474; n= 25; P<0.001

FC(%)= 0.518 (OM%)+16.60: R^2=0.336; n=25; P<0.001

FC(%)=0.30 (OM%)+0.485 (clay%)+10.998; R^2= 0.558; n=25; P<0.001

Both, a relatively high field moisture capacity and availability of nutrients in Ah and Bhs horizons can explain the abundance of fine roots in both horizons (Buurman and Jongman 2005). In any case, the water holding capacity of each profile ranges from moderate to very low due to the high degree of stoniness (quartzite sandstone) typical of all soils analyzed.

High water repellency (WR) is observed in surface horizons (Ah) and sometimes in subsurface (Bhs) horizons beneath pine forests (WDPT>3600 s). WR in this study correlates positively the OM content (r= 0.71; p<0.01) and to a lesser degree, with coarse sand particles (r= 0.42; p<0.05), similarly to previous works (Badía et al. 2013a and references therein). A higher WR in topsols beneath coniferous forests (spruce, pine) relative to beech forests (Butzen et al. 2015), evergreen oaks (Badía et al. 2013a), or scrublands Zavala et al. 2009) has been usually found. This may be due to the contribution of resins, waxes and aromatic oils from coniferous litter (González-Pérez et al. 2004). As a result of higher WR, an increase of overland flow is detected, which may have a hydro-geomorphological influence (Butzen et al. 2015).

Fig. 3a, b, c. Soil depth variation of different components: Organic C, Al_{ox}+1/2Fe_{ox}, and clay-sized particles (in %, w/w).

Table 3
Pearson correlation coefficients showing the degree of linear association (negative and positive) between soil properties and elevation. * p<0.05; **p<0.01; ***p<0.001

4.2.3.Variations with elevation

There are a number of soil properties and processes that vary with elevation. Value (or lightness, in the Munsell color system), base saturation, soil reaction, potassium and fine silt significantly decrease (p<0.01) with increasing elevation. By contrast, coarse sand, stoniness, organic matter and related properties (SAS, CEC, WR, C/N) increase, to a lesser or greater extent, with elevation (Table 3). PCA revealed these trends (Fig. 4) by identifying two principal components that accounted for 29.3% and 21.5% of the overall variation, respectively. Elevation parameters are clustered relative to the axes representing each component. The lower right quadrant shows positive scores for the first principal component and negative scores for the second one; this space represents soil properties that are enhanced with elevation. The upper left quadrant represents soil properties diminished with elevation (Fig. 4).
Both OM and C/N ratio increases with elevation, which is related to the rainfall increase and net primary production and litter input to the soils (Klopfenstein et al. 2015) and the temperature decrease, reducing biological activity and the humification degree of organic matter (Girona et al. 2015; Zanella et al. 2011). Soils at high-elevation sites have particularly large OC stocks in forest soils of the German Alps due to low air temperature and, specially, high precipitation (Prietzel and Christophel 2014)

Organic matter positively correlates with total nitrogen, CEC, Mg, structural stability, and water repellency. The abundance of SOM generates a dark color, for this reason value and chroma (color purity) are negatively correlated with SOM. Base saturation (V) correlated positively with soil reaction (pH-H_2O and pH-KCl) and negatively with Al and Fe (Fig. 4). A positive correlation between elevation and organic matter and C/N ratio has been well documented in the literature as well as the negative correlation of elevation with pH and base saturation (Martí and Badía 1995; Klopfenstein et al. 2015).

Fig. 4. Principal components analysis of soil properties from the Moncayo toposequence. Two distinct clusters highlight the respective positive (lower cluster) and negative (upper cluster) effects of elevation on soil properties.

At the highest elevation considered in this study (1600 m), beneath pine forest vegetation, amorphous Al and Fe content is 16 times higher in the Bhs horizon than in the E horizon (1.39% and 0.09% Al_{ox}+1/2Fe_{ox}, respectively), which is also found in Podzols from subalpine stage of the Pyrennes (Boixadera et al. 2008). Soils did not show signs of podzolization beneath oak forests in Moncayo Massif but they will expressing progressively with elevation.

4.3. Processes and soil classification

Soil forming processes in the Moncayo include weathering, accumulation of organic matter, and podzolization, which results in different sequa and diagnostic horizons. Downslope, beneath deciduous *Quercus* forest, soils exhibit relatively simple OL-Ah-C sequum, with dark, acidic surface horizons rich in organic matter and low base saturation (Ah, umbric horizon) on a stony C layer, which classified as *Skeletic Umbrisol, Loamic* (i.e., beneath sessile oak vegetation). The profile sometimes includes a cambic subsurface horizon, with a base saturation of less than 50%, leading to its WRB classification as a *Dystric Cambisol, Humic, Loamic* (i.e., Pyrenean oak vegetation). With increasing elevation, at about 1300 m elevation, beneath beech forest, podzolization processes become evident but B-horizon do not meet all the requirements for a spodic horizon, ie color, classifying the soil profile as intergrade of *Cambisols*, specifically a *Dystric Skeletic Cambisol, Loamic, Protospodic*. Soils in the upper half of the catena therefore have an O-Ah-E-Bhs-C sequum, where Ah meets the requirements for an umbric horizon, E meet albic material requirements, and Bhs meet the requirements of spodic horizon that meet Podzol (IUSS 2014) and Spodosol classification critera (WRB and Soil Taxonomy System, only different by organic C content (0.6% in Soil Taxonomy system, instead of 0.5%). In accordance with this combination of diagnostic horizons and materials, upslope soils are classified as *Skeletic Umbric Albic Podzol, Loamic*. Summarizing, Umbrisol and Cambisol soil WRB units (Dystrudepts by STS) evolved to Podzols (Haplorthods by STS) with elevation (Fig. 5).

Fig. 5. Soil classification for the catena studied along the northern flank of the Moncayo.

The presence of Podzols at the Moncayo Massif is significant for geographic reasons. Podzolization is considered part of a natural progression of soil development from glacial retreat starting 9,000-13,000 years ago, colonization of till or scoured rock surfaces, and subsequent ecological succession to boreal forest (Lundstrom 2000; Waroszewski et al. 2015). Podzolization occur on a widespread basis throughout the northern hemisphere where cover 485 million ha, mainly in Scandinavia, the northwest of Russia and in eastern Canada (Bridges et al. 1998). Nearly 20% of European soil continent consist of Podzols (Toth et al. 2008) but become anecdotic in Spain where cover only about 0.1% of its surface (Gómez-Miguel and Badía 2016). Podzols in Spain are most abundant in Galicia (NW Spain), where they arise from quart-rich parent materials developing beneath coniferous forest vegetation in a cold and very humid climate (Macías and Calvo de Anta 2001; Carballas et al. 2016). The presence of Podzols at the Moncayo Massif is a consequence of the coincidence of similar soil forming factors in this part of the Iberian Range (NE-Spain), which had been warned by some pioneering works (Hoyos et al. 1982; Carceller 1995). Podzols/Spodosols have been described only in small and scattered areas in NE-Spain, as the Catalan Pyrenees (Bech et al., 1981; Boixadera et al., 2008) at about 2000 meters elevation on granitic till, acidophilous vegetation (*Pinus uncinata*), high rainfall (udic moisture regime) and low temperatures (cryic temperature regime). Podzols have also been described in the Basque Country (Camps and Aizpurúa 2007) at about 1000 m elevation on stable sandy colluvium, acidophilous shrubs (heather), high rainfall (udic moisture regime) and moderate temperatures (mesic-frigid temperature regimes). Under similar environmental conditions, Podzol-like profiles have been described in the Sierra de Urbasa, Navarra (Val Legaz and Iñiguez 1981a); these soils were associated with heath and beech vegetation, exhibiting udic-mesic regimes, and developing on Oligocene sandstones. Val Legaz and Iñiguez (1981b) concluded these soils have macro- and micro-morphologic podzolic characteristics but their B-horizons do not always meet spodic diagnostic criteria.

Podzols described in the Moncayo Massif may represent the most southern examples of Podzols in Europe with the particularity of being located at the southern edge of the semiarid Ebro Basin, beside saline, gypseous and calcareous soils (Badía et al. 2011; Badía et al. 2013b; Badía and Del Moral 2016) highlighting the soil pedodiversity of the Moncayo and the didactic potential of the region (Badía et al. 2013c).

5. Conclusions

Soils of the Moncayo Massif exhibit a significant increase of coarse sand, stoniness, organic matter, C/N ratio, SAS and WR with elevation. By contrast, fine silt, lightness, pH, base saturation and potassium, significantly decrease with elevation across soil catena. The soil profiles described in the wooded montane stage show a number of common physical properties, including a loamy-skeletal particle-size class, extreme acidity (pH H_2O<5.6) and very low base content (<50%).

In the wooded montane stage of the siliceous Moncayo Massif is undergoing the accumulation of organic matter and podzolization processes that intensify with elevation. For that reason, the humus mull in oak forest, downslope, evolves to moder in beech forests and mor in the pine forests of highest elevation. Humus upslope provides organic acids to from metal-organic complexes (Al and Fe), which migrate and accumulate in an illuvial Bhs-spodic horizon. As a result of podzolization, various properties (organic C, C/N, Fe, Al, field capacity, cations, clay-sized particle) exhibit irregular variations with depth, giving minimum contents within E and C horizons and maximum values in the Ah and Bhs horizons. As a result of this, Umbrisol and Cambisol soil WRB units (Dystrudepts by STS) evolved to Podzols (Haplorthods by STS) with elevation highlighting the environmental singularity of the Moncayo Massif.

Appendices

Appendix A. Macromorphological characteristics of the soils analyzed from the Moncayo catena.
Appendix B. Chemical properties of the soils analyzed from the Moncayo catena
Appendix C. Exchangeable cations of the soils analyzed from the Moncayo catena
Appendix D. Physical properties of the soils analyzed from the Moncayo catena

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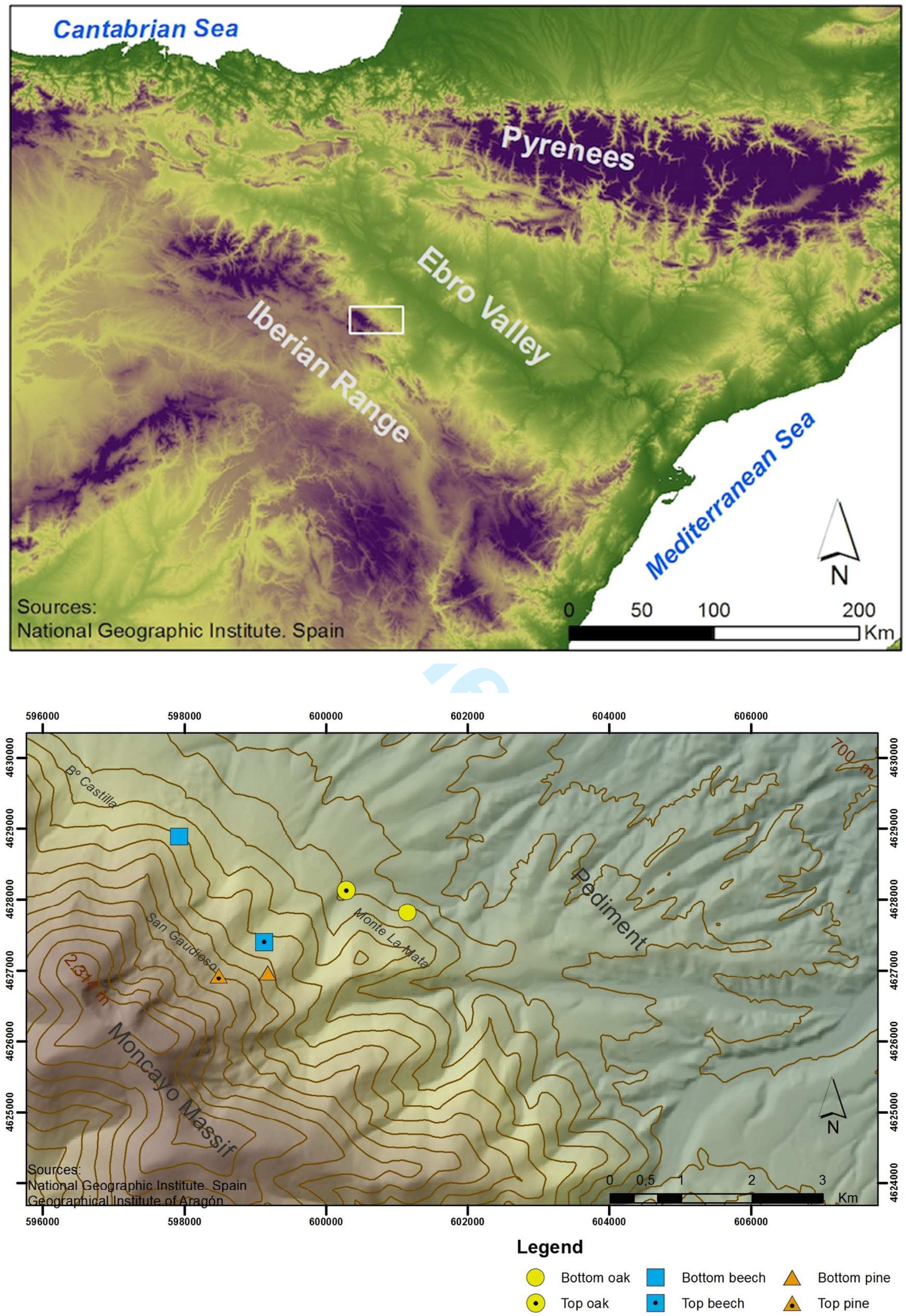
Fig. 1. Location of soil profiles studied along the northeast flank of the Moncayo Massif (Iberian Range, NE-Spain)



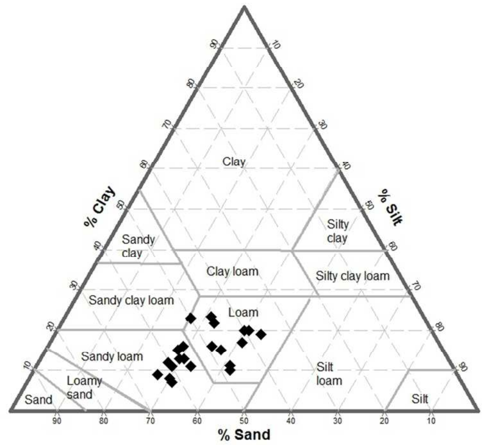
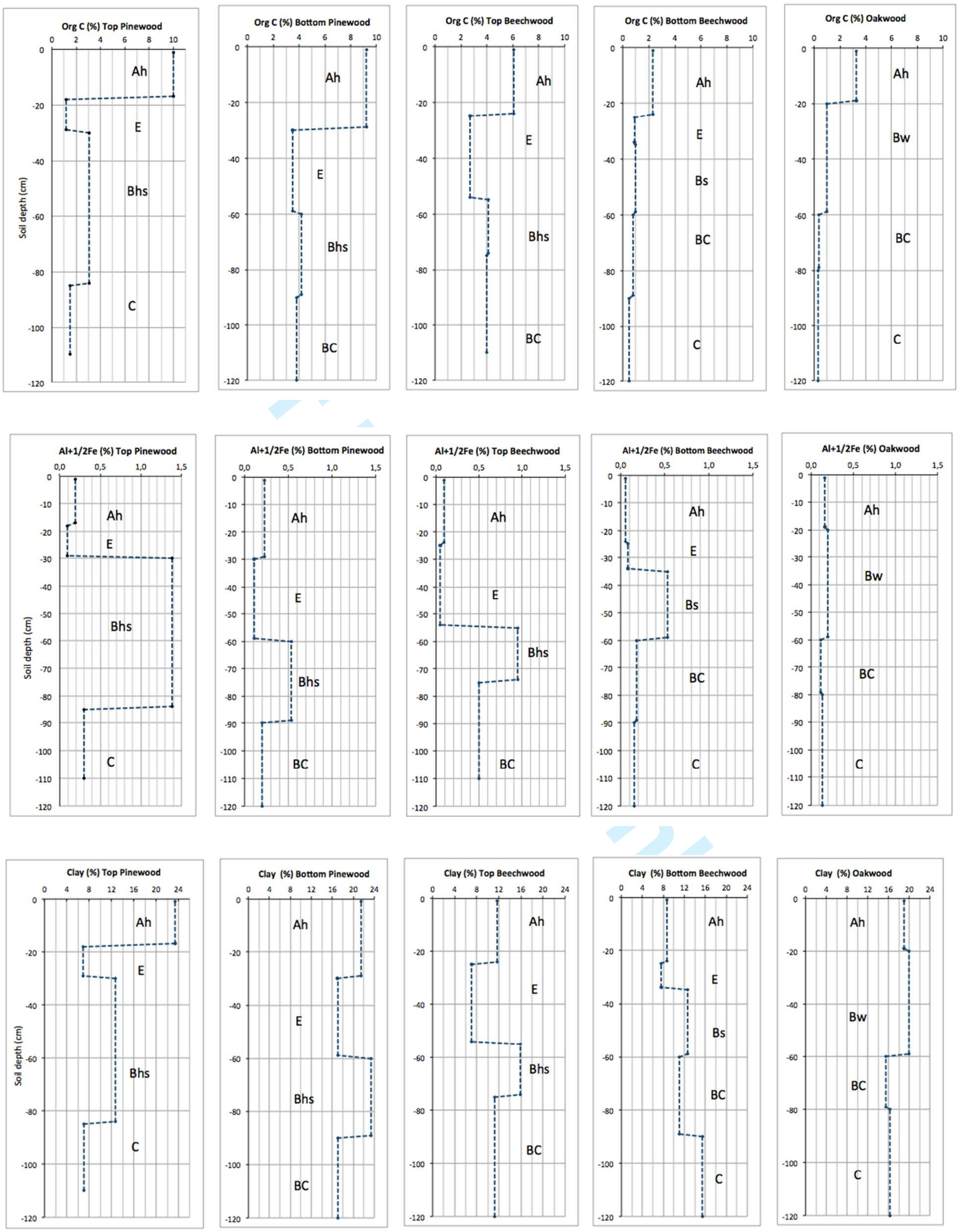
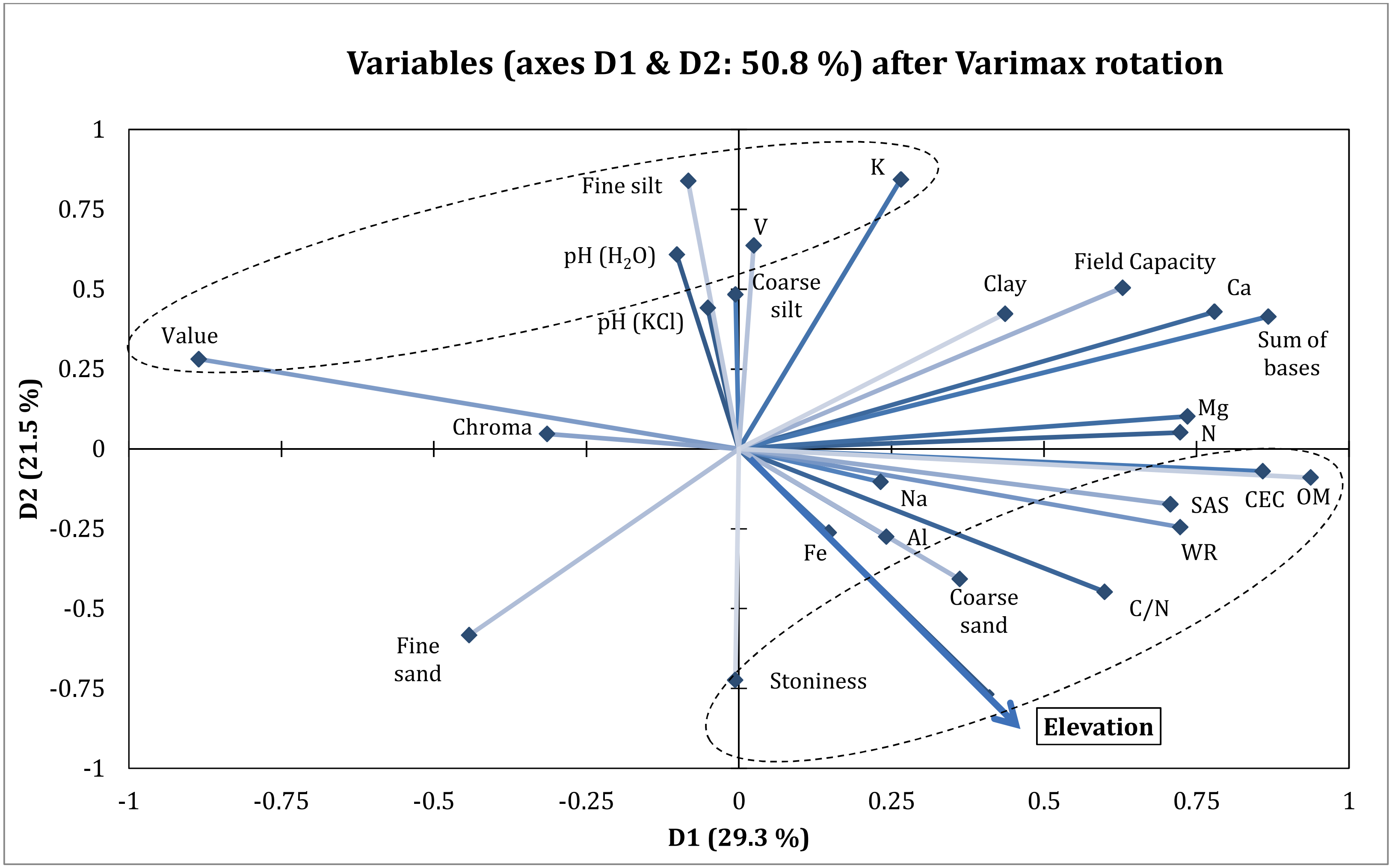
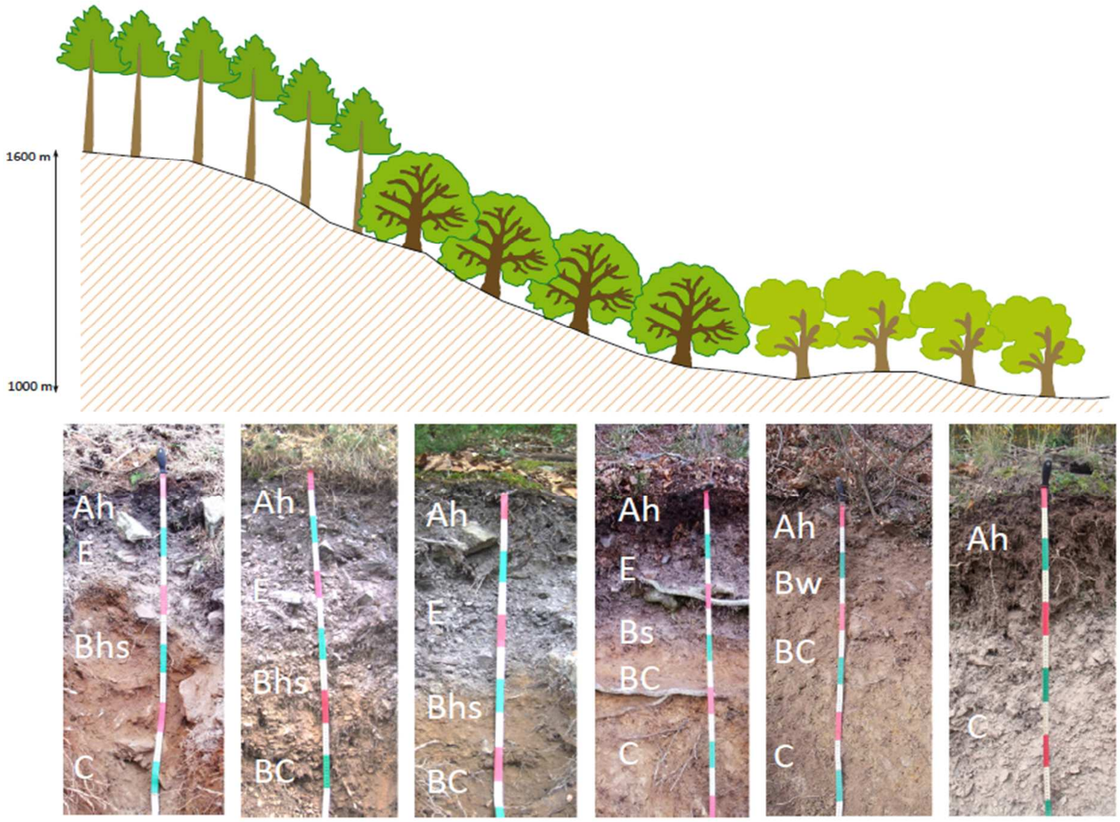


Fig. 2. Textural classes for soil horizons analyzed (n = 25).
467x221mm (72 x 72 DPI)

Fig. 3a, b, c. Soil depth variation of different components: Organic C, Al_{ox}+1/2Fe_{ox}, and clay-sized particles (in %).




Variables (axes D1 & D2: 50.8 %) after Varimax rotation
D2 (21.5 %)
D1 (29.3 %)
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
1
Fine silt
K
V
pH (H2O)
Coarse silt
pH (KCl)
Value
Clay
Field Capacity
Ca
Sum of bases
Mg
N
Chroma
Na
SAS
CEC
OM
WR
Al
Fe
Coarse sand
C/N
Fine sand
Stoniness
Elevation



Forest	Scots Pine		Beech		Oak	
Elevation (m asl)	1590	1476	1353	1282	1046	1018
System						
WRB (IUSS, 2014)	Skeletic Umbric Albic Podzol (Loamic)	Skeletic Umbric Albic Podzol (Loamic)	Skeletic Umbric Albic Podzol (Loamic)	Dystric Skeletic Cambisol (Loamic, Protospodic)	Dystric Cambisol (Humic, Loamic)	Skeletic Umbrisol (Loamic)
STS (2014)	Typic Haplorthod	Typic Haplorthod	Typic Haplorthod	Spodic Dystrudept	Typic Dystrudept	Humic Dystrudept

Fig. 5. Soil classification for the catena studied along the northern flank of the Moncayo.

Table 1
Formation factors of soils analyzed from the Moncayo catena

Ref. Profile	UTM location (30 T)		Geomorphology	Parent material	Climate*	Vegetation	Soil sequum
	X Y	Altitude (msnm)	Slope, Aspect				
Top pinewood (San Gaudioso)	0598480 4626904	1590	30%, head slope NE	Angular quartzite sandstone colluvium	1112 mm 6.3ºC	*Pinus sylvestris* *Ilex aquifolium* *Vaccinum myrtillus* *Erica vagans* *Erica arborea*	O-Ah-E-Bhs-C
Bottom pinewood (Curva Herradura)	0599333 4626468	1476	35%, head slope NE	Angular quartzite sandstone colluvium	1040 mm 6.9ºC	*Pinus sylvestris* *Ilex aquifolium* *Erica arborea* *Deschampsia flexuosa*	O-Ah-E-Bhs-BC
Top beechwood (Fuente Frailes)	0599130 4627400	1353	25%, shoulder slope NE	Subangular quartzite sandstone colluvium	983 mm 7.7ºC	*Fagus sylvatica* *Ilex aquifolium* *Erica arborea* *Erica australis*	O-Ah-E-Bhs-BC
Bottom beechwood (Camino Bco. Castilla)	0598093 4628828	1282	40%, shoulder slope NE	Angular quartzite sandstone colluvium	912 mm 8.1ºC	*Fagus sylvatica* *Vaccinum myrtillus* *Erica arborea* *Ilex aquifolium* *Abies alba*	O-Ah-E-Bs-BC-C
Pyrenean oakwood (Bco. Monte de la Mata)	0600243 4628086	1046	30%, back slope NE	Angular quartzite sandstone colluvium	678 mm 9.5ºC	*Quercus pyenaica* *Cistus laurifolius* *Erica sp. pl.* *Cytisus scoparius*	(O)-Ah-E-Bw- BCg-Cg
Sessil oakwood (Monte de la Mata)	0601146 4627798	1018	30%, back slope NE	Angular quartzite sandstone colluvium	650 mm 9.7ºC	*Quercus petraea* *Cytisus scoparius*	(O)-Ah-C-R

* Temperature estimated according to Cuadrat & Pellicer (1983) and Rainfall estimated according to Ibarra et al. (2003)

Table 2
Humus characteristics (n=5) of soil toposequence along the northern flank of the Moncayo.

	Forest cover and elevation (m)		
	Pinewood	**Beechwood**	**Oakwood**
	1600-1500	**1400-1300**	**1100-1000**
Horizon thickness (cm)			
OL	1-2 cm	1-4 cm	1-2 cm
OF	4-6 cm	3-7 cm	absent
OH	1-6 cm	discontinuous	absent
Ah horizon:			
Transition Ah-O	< 3 mm	≥ 5 mm	< 3 mm
pH water	< 5	< 5	> 5
Aggregation	micro	macro	macro
Humus Group	Humimor	Hemimoder	Mesomull

Table 3
Pearson correlation coefficients showing the degree of linear association (negative and positive) between soil properties and elevation. * p<0.05; **p<0.01; ***p<0.001

Negative	pH (H_2O)	pH (KCl)	K^+	V	Value	Fine silt	Coarse silt	Clay
Altitude	-0.402*	-0.234	-0.603***	-0.443*	-0.615***	-0.588***	-0.361	-0.159

Positive	OM	C/N	Al_{ox}	CEC	SAS	WR	Stones	Coarse sand
Altitude	0.440*	0.498*	0.374	0.358	0.567**	0.463*	0.476*	0.413*

Appendix A

Macromorphological characteristics of the soils analyzed from the Moncayo catena.

Profile	Elevation (m)	Horizon	Depth (cm)	Color (Dry)	Color (Wet)	Structure	Compaction	Roots Diameter & abundance	Accumulations
Top Pinewood	1590	Ah	18	7.5YR 3/1	10YR 2/1	s, G	SO	vf to m, Many	
		E	30	7.5YR 6/2	7.5YR 4/2	no	SHA	f-m, Common	
		Bhs	85	7.5YR 4/4	7.5YR 3/3	w, Sbk	SHA	vf to m, Common	C, Fe/Al, c
		C	110	10YR 6/3	10YR 4/3	no	SHA	f, Few	
Bottom Pinewood	1476	Ah	30	10YR 5/2	10YR 3/2	s, G	SO	vf-f, Common	
		E	60	7,5YR 7/3	7,5YR 5/3	no	SHA	f-m, Few	
		Bhs	90	7.5YR 6/4	7.5YR 4/4	w, Sbk	SHA	f to c, Common	C, Fe/Al, c
		BC	120	10YR 6/3	10YR 4/3	no	SHA	f-m, Common	
Top Beechwood	1353	Ah	20	10YR 5/1	10YR 3/1	s, G	SO	vf to m, Many	
		E	40	10YR 6/1	10YR 4/1	no	SHA	vf-f, Few	
		Bhs	60	7.5YR 6/4	7.5YR 4/4	s, Sbk	HA	vf to m, Common	C, Fe/Al, c
		BC	90	10YR 6/4	10YR 4/3	no	SHA	m-c, Very few	
Bottom Beechwood	1282	Ah	45	7.5YR 6/2	7.5YR 5/2	m, G	SHA	vf to c, Common	
		E	55	10YR 7/2	10YR 5/2	no	SHA	vf-f, Very few	
		Bs	80	10YR 7/4	10YR 5/4	m, Sbk	SHA	vf to c, Few	Fe/Al, c
		BC	110	10YR 8/3	10YR 6/4	no	SHA	f to c, Common	
		C1	150	10YR 8/4	10YR 6/4	no	SHA	vf to m, Few	
		C2	180	10YR 7/4	10YR 6/6	no	SHA	vf-f, Very few	
Pyrenean Oakwood	1046	Ah1	5	10YR 6/2	10YR 4/2	s, G	SHA	vf-f, Common	
		Ah2	20	10YR 7/3	10YR 5/3	m, Sbk	SHA	f-m, Common	
		Bw	60	10YR 7/3	10YR 5/4	w, Sbk	HA	f to c, Few	
		BCg	80	10YR 8/3	10YR 5/4	w, Sbk	HA	f to c, Few	
		Cg	120	10YR 8/4	10YR 6/4	w, Sbk	HA	f to c, Very few	
Sessil Oakwood	1018	Ah	30	10YR 5/3	10YR 3/2	s, G	SHA	f to c, Common	
		C	100	10YR 8/2	10YR 6/3	no	SHA	f to c, Few	

Abbreviations: Grade of structure; no, no structure; w, weak; m, moderate; s, strong. Form: G, granular; Sbk, Sub-angular blocky. Dry consistence: LO, loose or non-coherent; SO, soft; SHA, slightly hard; HA, hard; Roots diameter, vf, very fine (<1 mm), fine (1-2 mm), medium (2-5 mm), coarse (> 5 mm). Accumulations: C, Organic C, Fe/Al, Iron and aluminium (OxA), c, clay-size particles

Appendix B

Chemical properties of the soils analyzed from the Moncayo catena

Profile	Elevation (m)	Horizon	Depth (cm)	pH H_2O (1:2.5)	pH KCl (1:2.5)	Org C (%)	C/N (%)	Bases Sum ($cmol_+$/kg)	CEC NH_4OAc ($cmol_+$/kg)	BS (%)	Al_{ox} (%)	Fe_{ox} (%)	Al_{ox} +1/2Fe_{ox} (%)
Top Pinewood	1590	Ah	18	4.1	3.1	10.0	22.1	6.16	43.0	14.3	0.121	0.143	0.192
		E	30	4.0	2.9	1.2	11.5	2.18	8.9	24.4	0.057	0.065	0.089
		Bhs	85	5.2	4.0	3.1	18.5	3.44	27.1	12.7	0.988	0.802	1.389
		C	110	5.1	4.1	1.5	12.7	1.91	13.7	14.0	0.224	0.144	0.296
Bottom Pinewood	1476	Ah	30	4.5	3.3	9.2	12.1	5.94	20.7	28.7	0.123	0.213	0.230
		E	60	4.4	3.2	3.5	7.0	2.79	7.7	36.1	0.064	0.091	0.110
		Bhs	90	5.0	3.9	4.2	7.6	2.83	9.8	28.8	0.322	0.462	0.533
		BC	120	5.3	4.3	3.8	7.8	2.04	7.6	26.7	0.224	0.144	0.296
Top Beechwood	1353	Ah	20	4.0	2.9	6.1	11.0	3.73	10.8	34.5	0.063	0.054	0.090
		E	40	4.2	3.2	2.7	5.7	1.51	3.7	40.8	0.036	0.026	0.049
		Bhs	60	4.9	4.2	4.1	8.2	2.24	8.9	25.2	0.703	0.488	0.947
		BC	90	4.9	4.3	4.0	8.3	2.03	6.1	33.3	0.446	0.113	0.503
Bottom Beechwood	1282	Ah	45	4.3	3.0	2.3	20.2	3.26	9.5	34.5	0.030	0.042	0.051
		E	55	4.4	3.2	0.9	11.9	1.59	5.3	29.7	0.041	0.083	0.082
		Bs	80	4.3	3.7	1.0	12.5	2.12	9.5	22.2	0.303	0.465	0.536
		BC	110	4.9	3.7	0.8	12.4	1.79	6.6	27.3	0.072	0.213	0.178
		C1	150	4.7	3.7	0.6	10.2	1.15	5.2	22.0	0.068	0.165	0.151
		C2	180	4.9	3.8	0.2	10.2	1.42	7.7	18.4	0.065	0.145	0.138
Pyrenean Oakwood	1046	Ah1	5	5.2	4.3	5.4	11.6	7.53	18.6	40.4	0.078	0.166	0.161
		Ah2	20	5.2	3.8	2.6	9.4	3.62	11.0	32.8	0.084	0.169	0.169
		Bw	60	5.0	3.8	1.0	6.2	2.52	8.9	28.4	0.096	0.202	0.197
		BCg	80	4.9	3.8	0.3	3.1	1.52	6.6	23.2	0.072	0.085	0.114
		Cg	120	4.8	3.8	0.3	3.0	1.61	6.3	25.5	0.070	0.124	0.133
Sessil Oakwood	1018	Ah	30	5.5	4.2	3.0	10.0	6.12	16.9	36.1	0.185	0.280	0.325
		C	100	5.1	3.7	0.4	3.4	1.75	5.5	31.8	0.038	0.059	0.068

Abbreviations: Bases Sum: Exchangeable Ca, Mg, K and Na (by 1M NH_4OAc pH7); CEC: Cation Exchange capacity (by 1M NH_4OAc pH7); BS. Bases saturation: (Bases sum/CEC)*100; Al, Fe-KCl: Exchangeable Aluminium, Iron (upon exchange by un unbuffered 1M KCl solution); Al_{ox}, $Fe_{ox:}$ Active or amorphous Al, Fe compounds extracted by an acid ammonium oxalate solution.

Appendix C

Exchangeable cations of the soils analyzed from the Moncayo catena

Profile	Elevation	Horizon	Depth	Exchangeable basifying cations NH_4OAc				Bases Sum	CEC	BS	Fe KCl	Al KCl	CECe
	(m)		(cm)	Ca^{2+}	Mg^{2+}	K^+	Na^+	($cmol_+$/kg)	($cmol_+$/kg)	($cmol_+$/kg)	($cmol_+$/kg)	($cmol_+$/kg)	($cmol_+$/kg)
Top Pinewood	1590	Ah	18	4.28	1.62	0.168	<0.1	6.16	43.0	14.3			
		E	30	1.78	0.19	0.113	<0.1	2.18	8.9	24.4			
		Bhs	85	2.03	1.18	0.131	<0.1	3.44	27.1	12.7			
		C	110	1.42	0.30	0.095	<0.1	1.91	13.7	14.0			
Bottom Pinewood	1476	Ah	30	5.19	0.39	0.210	0.15	5.94	20.7	28.7	0.454	0.011	6.41
		E	60	1.37	1.22	0.130	<0.1	2.79	7.7	36.1	0.605	0.019	3.41
		Bhs	90	1.34	1.21	0.190	<0.1	2.83	9.8	28.8	0.974	0.017	3.82
		BC	120	0.83	0.90	0.200	0.11	2.04	7.6	26.7	0.355	0.005	2.40
Top Beechwood	1353	Ah	20	2.03	0.66	0.140	0.90	3.73	10.8	34.5	0.931	0.032	4.69
		E	40	0.81	0.40	0.040	0.26	1.51	3.7	40.8	0.612	0.014	2.14
		Bhs	60	0.99	0.63	0.120	0.50	2.24	8.9	25.2	1.105	0.045	3.40
		BC	90	0.83	0.56	0.120	0.52	2.03	6.1	33.3	0.564	0.008	2.60
Bottom Beechwood	1282	Ah	45	2.90	0.10	0.168	<0.1	3.26	9.5	34.5			
		E	55	1.21	0.18	0.100	<0.1	1.59	5.3	29.7			
		Bs	80	1.42	0.40	0.201	<0.1	2.12	9.5	22.2			
		BC	110	1.11	0.42	0.167	<0.1	1.79	6.6	27.3			
		C1	150	0.83	0.14	0.083	<0.1	1.15	5.2	22.0			
		C2	180	0.98	0.19	0.150	<0.1	1.42	7.7	18.4			
Pyrenean Oakwood	1046	Ah1	5	6.00	0.97	0.460	<0.1	7.53	18.6	40.4			
		Ah2	20	2.46	0.64	0.423	<0.1	3.62	11.0	32.8			
		Bw	60	1.68	0.39	0.350	<0.1	2.52	8.9	28.4			
		BCg	80	1.12	0.10	0.204	<0.1	1.52	6.6	23.2			
		Cg	120	1.22	0.16	0.131	<0.1	1.61	6.3	25.5			
Sessil Oakwood	1018	Ah	30	4.28	1.12	0.569	0.15	6.12	16.9	36.1			
		C	100	1.41	0.04	0.204	<0.1	1.75	5.5	31.8			

Abbreviations: Exchangeable Ca. Mg. K and Na (by 1M NH_4OAc pH7); CEC: Cation Exchange capacity (by 1M NH_4OAc pH7); BS. Bases saturation: (Bases sum/CEC)*100; Al. Fe-KCl: Exchangeable Aluminium. Iron (upon exchange by un unbuffered 1M KCl).CECe, Cation Exchange capacity effective.

Appendix D

Physical properties of the soils analyzed from the Moncayo catena

Profile	Elevation (m)	Horizon	Depth (cm)	Stones (%)	Sand (%)	Silt (%)	Clay (%)	Texture class (USDA)	SAS (%)	FC (%)	WR (s)
Top Pinewood	1590	Ah	18	75.0	49.8	26.8	23.4	Sandy clay Loam	92.4	25.2	>3600
		E	30	60.4	62.1	31.0	7.0	Sandy Loam	76.6	16.1	2
		Bhs	85	59.9	56.7	30.6	12.7	Sandy Loam	93.9	15.5	>3600
		C	110	85.1	61.6	31.4	7.0	Sandy Loam	95.2	18.3	1
Bottom Pinewood	1476	Ah	30	64.2	45.6	32.9	21.5	Loam	94.2	28.2	>3600
		E	60	58.3	42.4	40.6	17.0	Loam	82.7	20.9	3
		Bhs	90	73.2	45.2	31.4	23.4	Loam	94.6	25.3	1
		BC	120	56.8	47.2	44.7	8.1	Loam	96.6	12.0	1
Top Beechwood	1353	Ah	20	80.9	60.7	27.6	11.7	Sandy Loam	86.5	17.5	1
		E	40	83.1	62.0	30.9	7.1	Sandy Loam	55.2	14.1	1
		Bhs	60	72.5	55.0	29.1	15.9	Sandy Loam	90.8	24.2	1
		BC	90	95.1	55.9	32.8	11.3	Sandy Loam	89.1	21.8	1
Bottom Beechwood	1282	Ah	45	79.3	64.0	27.4	8.7	Sandy Loam	85.2	15.5	2
		E	55	64.7	62.5	29.9	7.7	Sandy Loam	27.9	14.1	10
		Bs	80	56.3	57.5	29.9	12.6	Sandy Loam	80.8	18.5	4
		BC	110	59.8	59.9	29.1	11.1	Sandy Loam	67.9	15.6	2
		C1	150	74.3	56.2	28.5	15.4	Sandy Loam	42.0	18.3	2
		C2	180	79.0	56.2	28.5	15.4	Sandy Loam	40.3	17.2	1
Pyrenean Oakwood	1046	Ah1	5	24.0	37.3	43.7	19.0	Loam	89.9	29.9	8
		Ah2	20	37.2	39.2	40.5	20.2	Loam	78.4	23.9	1
		Bw	60	38.9	40.4	39.5	20.0	Loam	28.4	20.1	1
		BCg	80	38.2	47.1	37.4	15.5	Loam	9.9	17.9	1
		Cg	120	50.0	48.6	35.2	16.2	Loam	9.0	17.3	1
Sessil Oakwood	1018	Ah	30	59.1	48.2	42.2	9.6	Loam	96.1	22.8	4
		C	100	81.6	47.5	41.1	11.5	Loam	31.0	17.8	1

Abbreviations: SAS, Soil aggregate stability; FC, Field capacity, WR, Water repellency