

Derivation of Soil Composition from Imaging Spectrometer Data at Tomelloso

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INTRODUCTION

This report is a brief description of the field spectra and soil sampling conducted in July 1999, and May, 2000, in association with DAISEX 1999. The status of lab and image data and initial findings in the relationships between soil wet chemical analysis, physiographic surfaces, and spectra for the Tomelloso study site are also discussed. Recent delivery of the HyMap imagery has made it possible to begin the evaluation of the hyperspectral analysis of soil surfaces and chemical constituents.

Salinity is due mostly to carbonate salts, CaCO_3 , MgCO_3 and NaCO_3 , and will raise the soil pH to 8.5. It creates moisture and nutrient uptake difficulties for intolerant crops. Sodicity, from sodium chloride salts, raises the pH far beyond pH 9, and is highly toxic to all crops. Salinity and sodicity varies spatially and in concentrations of the salt-types. This mixed toxicity is expanding in agricultural lands throughout the semi-arid and arid regions of the world. Farmers face declining productivity due to the lack of adequate drainage in both irrigated and non-irrigated lands. Without proper drainage management, soils accumulate salts near the surface due to parent materials abundant in salt and or imported with irrigation water. Growers have preserved and improved the soil productivity through adjusting cropping practices, such as salt tolerant crops and reclamation amendments. Precision farming techniques promise to increase the efficiency of farming inputs, but requires a synoptic view or map of the fields. Identifying the type of soil salt, carbonate or chloride, and the extent of salinity-sodicity is routine at the field level through field sampling. Recommendations for land reclamation are generally field-wide and based on aerophotos of crop conditions. Detailed grid sampling and interpolate mapping for developing precision farming prescriptions can improve the efficiency of reclamation and salt management, but at great expense. Remote sensing of the salt type and content through hyperspectral imagery is a promising alternative.

In the laboratory, hyperspectral analysis has demonstrated the ability to accurately estimate many of the soil parameters, such as soil texture and salinity [1-3]. The

physical and chemical processes control the accumulation or loss of soil carbonates and other constituents and can be related to landscape processes. Image and terrain analysis can stratify the problem by determining the contributing landscape parameters, and possibly improving the estimation accuracy and spatial extent.

To test measurement techniques, soils with high carbonate contents over spatially consistent areas are required. Salinity generally appears spotty and random in non-calcareous landscapes. The combination of Mediterranean climate and limestone soils of the La Mancha Plain provides a superior location for developing remote sensing techniques with high carbonate content soils. Also, the open dry farmed fields provide a uniform moisture content compared to irrigated areas. While the Tomelloso area has been intensively farmed for centuries, the soil surface has not been graded through "land-leveling" or other mechanical means. Centuries of erosion and sedimentation have augmented the natural features, and disbursed of soil chemical components.

This research opportunity through the 1999 DAISEX flight over the Tomelloso area provided needed airborne imagery to compliment the field data collection for carbonates and other soil components. This release of data and analysis is preliminary, and useful only in describing the field sampling, initial wet chemical analysis, and lab and HyMap spectral analysis.

This study is a collaborative effort between the University of California, Davis, USA, the Universitat de Valencia, Burjassot and the Universidad de Castilla-La Mancha, Albacete, España. The Fulbright Foundation and US Department of Agriculture, Natural Resources Conservation Service also provided funding.

STUDY OBJECTIVES

- Compare existing techniques for estimating the surface organic and mineral contents using lab spectrometry and hyperspectral images and validating with wet chemical analysis.

- Evaluate the use of the relationship of chemical constituents to geomorphic positions for improving image classification.

GEOMORPHIC ANALYSIS

Spatial interpolation of soil characteristics through grided sampling and soil modelling on physical processes and landscape development have been reported by a number of investigators to estimate soil characteristics over fields and regional areas [4-6]. Combined methods using process modelling and mapping of specific soil properties achieve the most accurate spatially explicit detail about specific properties. Geospatial modelling without regard to soil processes requires grid sampling. This method is sampling intensive and unsuitable for regional studies. Increased spatial resolution and map accuracy is obtained, with the same number of samples, by initially defining the relationship of soil characteristics to microclimate, geomorphology, edaphics, and historic crop management practices.

On the broad geologic scale, the underlying material to the alluvial fans and basin south of Tomelloso are described by Martin, et al. [7] as “calizas micenas” or Miocene calcareous, over “Mioceno detritico.” In detail, they describe the upper fans or piedmont as “calizas y margas” (limestone and marls) mixed with “conglomerado arcilloso, coarzado con gravas” (conglomerate of clays and gravels) [7]. Sanchez, et al. [8] described two soil types within our project area. Older surfaces were Petric Calcisols, limestone and marl with laminar calcareous crust, formed on alluvial fans, “developed from limestones and detritic materials of the upper Pliocen.” And in the younger alluvium and river wash, he described Haplic Calcisols, as calcisols lacking an argic B horizon and petrocalcic horizon, “developed on detritic materials of alluvial bottom valleys.” This mapping was general and designed for regional studies and planning.

SOIL SAMPLING, JULY 22 – 25, 1999, AND CHEMICAL ANALYSIS

In the first field season, the landscape surfaces were identified by making transects across multiple contiguous landscape positions and exploring the changes in the surfaces. Initially, the project area was separated into three regions based on visible surface color and texture, elevations and topography changes: upper limestone terrace, multi-level alluvial fill, and flood plain areas. Detailed surface descriptions are provided below with the second year's sampling.

Two transects were defined on the upper limestone terrace of dryland grape vines, known as the Vine 1 and 3, each about 250-m long. These transects started near the ridges of the undulating terrace, proceeded down slope across shallow drains and up the low slope to the next the ridge (see color plate figure 1).

The third transect crossed three levels of alluvial fill. This area dissects the upper limestone terrace, and is farmed in grain and native pasture. For overlap, this transect started on

the eroded slope of the upper limestone terrace, crossing two distinct alluvium fill terraces (benches), down onto the fresh alluvium of the river channel, and up a vertical scarp onto the limestone terrace on the opposite side, about 750-m in length. This transect became known as Allu, short for alluvium (see color plate figure 1).

The fourth and fifth transects crossed the broad braided flood plain, an outwash of the ephemeral stream from the dissected terrace. The northern transect started from a remnant of the higher, older surface of alluvial fill, cross recent flood sediments to the older surface again, about 1-km in length. The second segment to the south crossed the fresh stream bottom, and up onto older alluvium deposits at the southern end, near the outlet of the stream onto the low fan, about 250-m in length.

During the July 1999 sampling, in the 5 transect segments, 41 points were collected, each with a GPS location. The surface 2-cm of soil were sampled and sieved for the fine fraction (<2 mm particle size) wet chemical analysis and lab spectroscopy. Munsell soil colors and sieved gravel (>2 mm particle size) volumn content were visually estimated. For each transect segment, a surface roughness measurement was taken by photographing the depth of pins on a solid background, as in the Barrax study. The photographs have been scanned in preparation for charting the surfaces (Personal Communication, M.C. Gonzalez, March 15, 2001).

In addition to soil sampling at each point, three surface spectrum samples were collected using a full range GER 2600 field spectrometer. The GER data has been reviewed. Unfortunately, the signal-to-noise ratio appears severely degraded in the SWIRII region, probably due to using an optical cable foreoptic. The data in the VNIR appears satisfactory and may be usable for organic matter and iron analysis.

As an initial step, only 3 samples from the three major units, Vine1, Allu and the Flat transects, were submitted for wet chemical analysis to UC Davis, Department of Agriculture and Natural Resources soil and plant laboratory (DANR). The variability within the transects was used to determine future analysis needs from the analysis of these nine samples. The differences in acidity (pH), electrical conductivity (EC), free bicarbonate and carbonate, the cations (calcium, magnesium, and sodium), and chloride were not significant within or among the transects. The extractable iron, cation exchange capacity (CEC), calcium carbonate, sulphate-sulphur, and sand-silt-clay (texture), and total carbon did vary along the transects, and were selected for the analyses of the 2000 field season samples.

SOIL SAMPLING, MAY 20, 2000

From the detailed information gathered during the first year's field work, five landscape surfaces could be separated. For the second field season, samples were chosen on these five surfaces where soil appear bare in the 1999 jpeg image. The following surface descriptions, including soil

colors and textures, are for typical surfaces identified during the July 1999 field campaign.

The first surface, "Upper Terrace", at the highest elevation position, is probably closest to Sanchez, et al. [8] description of Petric Calcisols. This calcareous piedmont tilts towards the low flood plain and town of Tomelloso, very gradually at 3-5%. This ancient terrace of alluvial outwash from the hills to the south-east, formed authigenic caliche lenses within the soil profile. Through erosion and farming practices, such as ripping, these calcareous lenses were brought to the surface as rock and gravels. This surface is bright in color (Munsell 5YR7/4 dry) with large gravels (65% >2-mm) of broken caliche or marl, as a very gravelly sandy clay loam soil texture. These positions are undulating with distinctive drains, slopes towards the drains range up to 5%.

These shallow drains are the second surfaces, "Terrace Drains." The surfaces are distinctive in the accumulation of clays and dark red brown color (5YR3/4 dry). The Terrace Drains are 1 – 4 meters lower than the ridges of the terraces, with fewer gravels (45%), as a gravelly clay loam soil texture.

The lower surfaces are alluvial fills within the dissection of the Upper Terrace that Sanchez, et al. [8] grouped into the second soil type within this project area, Haplic Calcisols. The highest of these alluvial surfaces were the first sediments, and extended across the entire dissection to form the "Upper Bench." The surface is slightly darker in color (5YR4/4 dry) with gravels (45 %) of broken caliche and red igneous stones, as a gravelly loam soil texture. This position is flat, less than 1% slope. A natural leave of courser texture and less gravels, exists at the boundary of the Upper and Middle Bench, a 20 – 30 centimeters rise on the Upper Bench surface.

Through changes in floor gradient or stream flow, this surface was also cut and sediments deposited to form the next lower position, "Middle Bench", lower by about 1 – 2 meters. This surface is nearly the same in color (5YR4-5/4 dry) with few igneous gravels (15%), a loam soil texture. These positions are also flat, less than 1% slope.

The lowest position is on stream bottom and braided outwash identified as "Flood Plain." These alluvial deposits are described as red clays [8] and are about 2 - 3 meters lower in elevation within the dissection of the Benches, and less than a meter in the broad flood plain. This surface is dark brown-red in color, about the same as the Terrace Drains, (5YR4/4 dry) with few igneous gravels (less than 5%) loam soil texture. This position is also flat, less than 1% slope.

During the 2000 field season, 300g of soil was collected at 126 points within 14 blocks. In a 3 x 3 sampling matrix, at 40 meters apart, 9 replicates were taken per block. Field visual estimate of the gravels volume and GPS locations were taken as in the 1999 season. Field spectra was not collected. The 3 x 3 sampling matrix will be used to interpolate a 120 x 120-meter area within the image for training the classification.

SOIL CHEMISTRY FROM MAY 2000 FIELD CAMPAIGN

Fewer analyses were conducted on the samples for 2000. The selected chemical analysis showed sufficient differences within 1999 transects or samples, or are reported spectrally distinguishable in the literature. Extractable iron, calcium carbonate, total carbon, sulphate and sand-silt-clay (texture) have a direct influence on the soil spectra. The cation exchange capacity (CEC) can be used as an alternate measure of clay concentration in low organic matter soils. Texture will be analysed in the future. This analysis consumes 300 grams of sample material. When all other analysis are completed, samples will be systematically combined for within-block averages.

Figures 2a - 2d are box plots of the chemical analysis for the 126 samples from the 2000 campaign. Within each box, the mean for the block, or physiographic position, is at the narrowed middle of the box, surrounded by the light tone denoting the extent of the 95% Confidence Limits. The "whiskers" show the minimum and maximum ranges in the analysis, and the box dimensions indict the first and third quartile. Within these plots we see the overlap or significant differences in the chemistry.

In Figure 2a, the carbonate analysis for the Flood Plain (FP) separates strongly from all other positions except for one block in the Middle Bench (MB), MB253. The classical explanation of greater carbonate in the FP is due to continual accumulation of dissolved carbonates from higher terraces to the FP surface. At the same time, the dissolved carbonates leach and precipitate in the unsampled subsurface of these higher terraces.

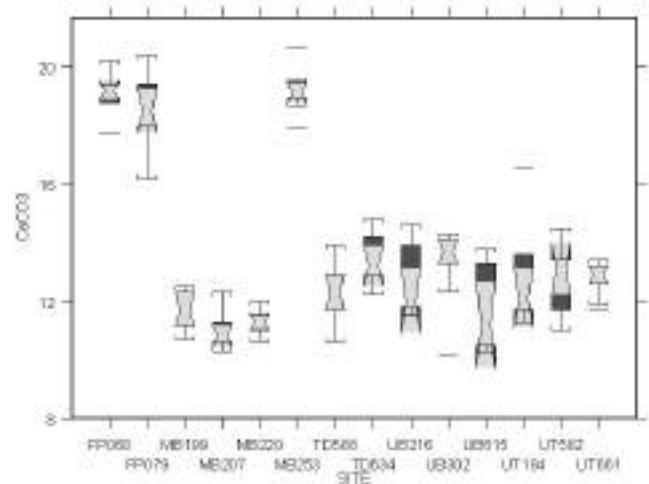


Fig. 2a Box plot of the percentage carbonate within the blocks.

The distinctive carbonate value of MB253 may be due to sample misnaming or misclassification of the position in the field. In the lower elevation towards Tomelloso, the separation in the surfaces is subtle, less than a meter in

elevation. Insufficient detail is available from topographic maps for separating the positions on elevations alone. The author's reflection on dissimilar chemical constituents, amounts of surface gravels and other indicators, have raised some doubts of the correctness of the placement of this block, and possibly others, into physiographic categories during the field sampling. An enhanced HyMap image will help separate surface differences in further study of the physiographic categories for the block samples.

These position categories are mixed in Total Carbon, Figure 2b. The Upper Terrace nearly separates from all other categories, except for highly variable Terrace Drain. This may be due to the vineyard cropping of clean tillage of both positions. Greater concentration of lignin and other resistant organic matter from the vines may increase carbon accumulation slightly. The mix in the Middle Bench (MB) may due to sample location and differences in farming practices of cropping and fallow.

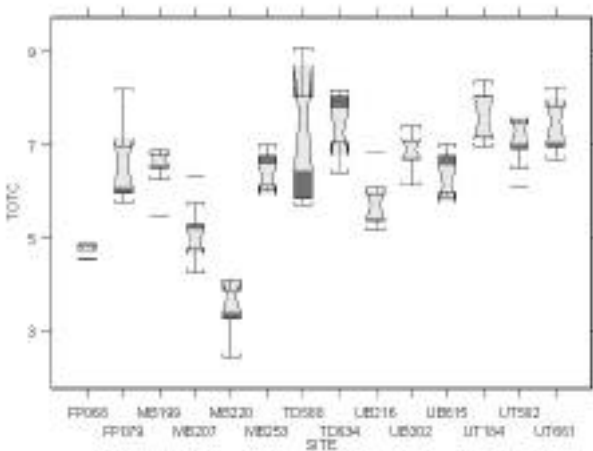


Fig. 2b Box plot of the percentage total carbon variability within blocks.

In figure 2c, the iron separates significantly the Upper Terrace and Terrace Drain from the younger benches. Also, there appears to be a trend for increasing iron content with decreasing elevation and age within the Benches. Generally it's taught that as soils age, the iron ratio to silicates, and other minerals, increases. As carbonate stone weathers, the iron minerals may be eroded with the clay and silt sediments to the lower positions.

Results from sulphate, CEC, and future analysis for texture require more development and possibly other analysis, such as clay type, before much can be said in trends or differences.

In all the box plots, the single bar above or below the whiskers indicates the existence of measurement anomaly. In the future, individual sample results from the laboratory will be re-evaluated. In a block of 9 replicates a significant outlier may effect the mean, confidence limits and other

statistical analysis of the data. We anticipate re-submitting a few samples to the DANR.

LABORATORY SPECTRAL ANALYSIS

Spectra from the same nine samples submitted to the lab from the July 1999 transects were collected using a LabSphere diffusion sphere attachment to a Cary 5 laboratory spectrophotometer, at the Center for Spatial Technology and Remote Sensing, UC Davis (CSTARS). The sample preparation included sieving a second time for plant residue; first was in the field. The samples from the 2000 field season have been prepared but not analysed due to time constraints.

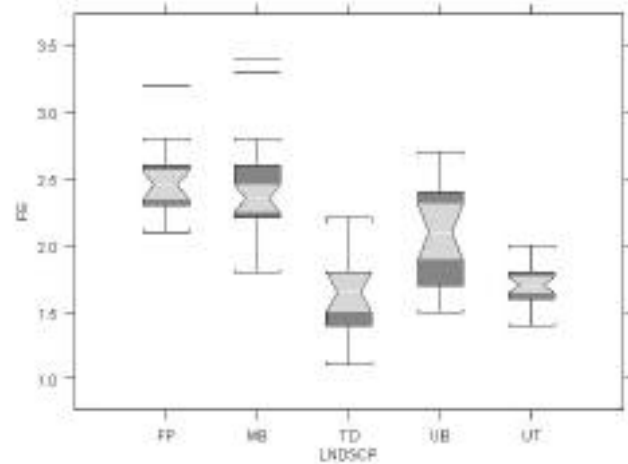


Fig. 2c Box plot of parts per million iron among the surfaces positions.

In color plates, figures 3a – 3c, comparisons are made between transects shown in the images to the lab spectral derivatives and wet chemical analysis. In figure 3a, the spectra from transect of Upper Terrace and Terrace Drain are compared in the VNIR and SWIRII ranges. In the false-color infrared image, the drain appear very dark in the VNIR reflectance, compared to the Upper Terrace. The three wet chemical results for Vine 1 transect also showed a separation of Upper Terrace from the Terrace Drain for the total carbon, CaCO₃ and iron. The difference in carbonate appears minor, most the total carbon difference would be from organic carbon. The Upper Terrace spectra, Vine 1.0 and 1.6, show good separation from the Terrace Drain samples, Vine 1.3 and 1.4 spectra. The lab spectral analysis is consistent with the wet chemical analysis. A kernel of 1 bandwidth was used to generate the derivative change from band to band. This technique concentrates on the spectral shape, instead of band reflectance intensity alone. In the VNIR, the iron and organic carbon are distinguishable [9], and in both the spectra and derivative change of the spectra, we see a definite separation of the landscape surfaces, differences of 0.003 or greater. Carbonates show their strongest diagnostic vibrational adsorption bands at 2300 to 2350-nm of SWIRII in our lab instrument and the HyMap. Weaker band regions are 1850 to 1870, 1970 to 2000, and 2120 to 2160-nm [10]. Generally,

the first of these three are lost to atmospheric moisture, and the last is overwhelmed by clay-OH absorption. In the SWIRII, the categories separate in the pronounced carbonate band shape near 2350-nm in the spectra and in the change of slope in the derivatives, differences of 0.005. The differences in wet chemical analysis for calcium carbonate do not appear that different.

In figure 3b, the Allu transect has similar separations in total carbon, probably due to organic carbon and iron content. These same groupings are apparent in the spectra and to some degree in the derivative changes of the spectra. Allu 1.7 was sampled on the natural levee at the edge of the Upper Bench and Middle Bench. The sediments in this low raise are coarser materials. This may be explain the lower iron content due to less clay. In both Vine 1.6 and Allu 1.7 the derivative change is positive with similar total-carbon and iron contents. The wet chemical analysis differences in carbonate for the Vine and Allu transects do not support separation of the carbonate peaks among the sample derivative differences.

For the Flat transect, in figure 3c, the Flood Plain is consistent in both the VNIR and SWIRII, and with the wet chemical analysis for the samples chosen.

The comparison of spectra and wet chemical analysis is encouraging. A consistent relationship between chemistry and spectral differences is illustrated in these transects samples. Further work in eliminating outliers and utilizing both 1999 and 2000 datasets is needed before conclusions can be made.

HYMAP IMAGE ANALYSIS

Because the Tomelloso area was not originally within the scope of the DAISEX 1999 mission, generation of image products was delayed until all the products for the primary locations had been delivered. The authors are grateful for the extra effort expended by the DAISEX committee and DLR to atmospherically and geometrically correct this imagery. The initial atmospheric correction

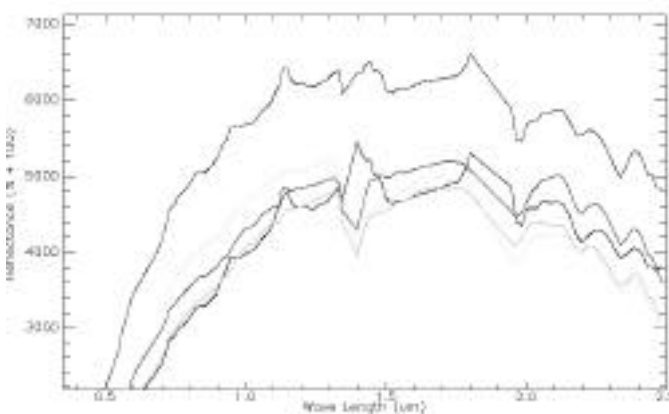


Fig. 4 Selection of spectra averaged from pixels, in order from the top at 0.8-um: Upper Terrace, Upper Bench, Middle Bench, Flood Plain, and Terrace Drain.

shows some over correction, especially in pixels of bare soil, as shown in figure 4. Future corrections were discussed with DLR staff. Initial visual comparisons of the image to GPS locations indicate the geometric and georeferencing corrections are of good quality.

One method being studied for analysing the spectrum is a technique advocated by Clark and Roush [11] called Continuum Removal. The spectral curve consists of two parts: the trend line and deviation from the trend line. This technique uses the maximum reflectance from a range of bands bracketing the bands of interests to establish the trend. The depth of the absorption is then apportioned to unity.

Using preliminary HyMap data, before geometric correction, spectra samples were extracted from regions of interest (ROI) visually located in the image for the block sampling. Within the ENVI software (RSI, Denver, Colorado USA), a sample of pixels can be extended to surrounding pixels, to increase the sample size, by using the mean and standard deviation of a specified band of the selected pixels. For the 2340-nm band of the carbonate region, ROIs were allowed to “grow” within 1-standard deviation. The average spectra for these ROIs, for the 2000 to 2500-nm range, are shown using the continuum removal process in figure 5.

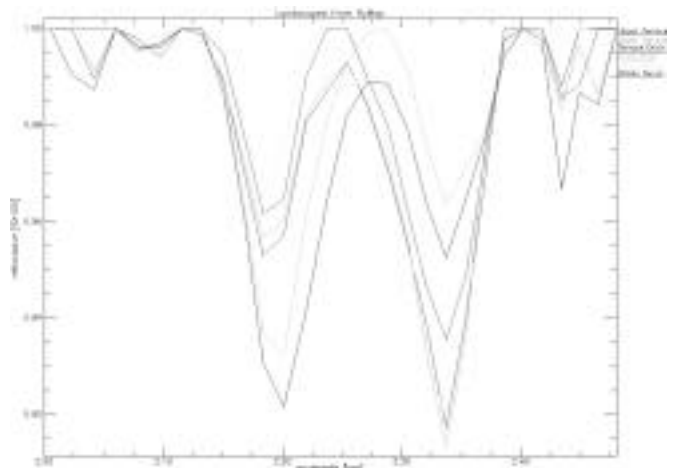


Fig. 5 The continuum removal process applied to representative image samples of the landscape positions, in order at 2.2-um: Upper Bench, Middle Bench, Upper Terrace, Upper Terrace, Flood Plain, and Terrace Drain. The clay hydroxyl absorption peak is 2.2-um and the carbonate absorption peak is 2.35-um.

While all of this is very preliminary, and cannot be associated to the wet chemical analysis results from field samples, due to unknown exact locations, it is interesting to note how the clay band absorption is inverse to the absorption in the carbonate bands. There also seems to be a distinct and consistent grouping of landscapes for clay and carbonate region absorption depths.

CONCLUSIONS

This is preliminary data and analysis. Some the trends appear promising. No conclusions should be drawn

with this initial review of the data. Future work includes review and resubmitting samples for wet chemical analysis, and collecting the lab spectra for all the second year block samples. The chemical and spectral analyses will then be compared to the corrected HyMap image. When the data collection and evaluations are complete, the results and conclusions will be meaningful.

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