Reconstruction of agrarian practice and land impact in the drylands: A geoarchaeological approach

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Mankind is an important factor for landscape and soil change. The reconstruction of past human activities in agricultural lands is a challenge in itself because in these archaeological areas, evidence of artefacts is normally scarce or missing. This challenge must be met with a geoarchaeological methodology that goes beyond usual archaeological approaches. In this paper, we develop a step-by-step proposal for the reconstruction of agrarian behavior of dryland environments, considering geosciences, biogeochemistry, biology, and archaeology.

L'espèce humaine joue un rôle important dans les changements affectant les paysages et les terrains superficiels. La reconstitution des activités humaines du passé concernant les terres agricoles représente un défi en lui-même parce que, pour ces secteurs archéologiques, l'évidence d'objets façonnés est normalement rare voire absente. On doit répondre à ce défi par une méthodologie géo-archéologique qui va au-delà des approches archéologiques conventionnelles. Dans cet article, nous décrivons une proposition par étapes, pour la reconstitution des pratiques agraires dans un environnement de sols arides, prenant en compte les géosciences, la biochimie, la biologie et l'archéologie.

El hombre es un factor importante de cambio para los paisajes, así como para los suelos. La reconstrucción de las actividades humanas pasadas sobre las tierras agrícolas es un desafío en sí misma. Esto se debe a que en estas áreas arqueológicas la evidencia artefactual es escasa o nula. El desafío debe ser afrontado con metodologías geoarqueológicas que exceden las aproximaciones arqueológicas usuales. En este trabajo desarrollamos paso a paso una propuesta para la reconstrucción del comportamiento agrario en ambientes áridos considerando aportes de las geociencias, biogeoquímica, biología y arqueología.

The reconstruction of past agricultural practice is a challenging archaeological task. In the drylands, humans have implemented different kinds of activities to make lands adequate for crop production. Some of the most evident features include the construction of different kinds of irrigation systems, earth benches, stone lines, and terraces. Even though crop parcels are often easily identifiable in landscapes, archaeological artefacts are scarce or missing. There are normally some ceramic potsherds on the surface or stratigraphy but agricultural tools were not typically discarded in the fields. In this way, prevailing activities were related to (a) adequacy and maintenance of the fields for crop production; (b) tillage, which left behind specific features in soils according to the technical capacities of the people and the environmental conditions; and (c) extraction, given by the effect of continued harvests on soil nutrients. Each of these activities left its own footprint, which is not accessible through traditional archaeological methods, constituting an exceptional field of research for geoarchaeology.

In this context, the objective of this paper is to propose a step-by-step methodology to study agricultural lands established in world drylands. This proposal is the results of 30 years of experience as a research team working in the drylands of SW Spain and NW Argentina (Peña-Monné *et al.*, 2004; Sampietro Vattuone *et al.*, 2011, 2014, among others).

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Methodological approach

It is recognised that agricultural activities produce positive and negative effects on lands and landscapes on different scales. To a large degree, the weight of one or another depends on management abilities, the technological capacity of the people, and the environmental stability of the place where the activity took place.

Considering the most relevant subjects related to cropland management in a decreasing scale, it is possible to identify changes as follows (***Fig. 1***): (1) on the ecosystemic/landscape/basin scale, there are changes in the distribution of erosion patterns and vegetation; (2) on the scale of crop parcels, it is possible to identify a local decrease in slope gradient as well as fine sand and clay accumulations; the presence of structures could affect normal superficial runoff and produce concentrate fluxes that form rills and gullies, and piping; (3) on the scale of the internal characteristic of croplands (soil horizons or sediment layers), superficial horizons could be deepened or eroded, and changes in the capacity to retain water are also possible as a consequence of tillage and irrigation; (4) on the micromorphological scale, agricultural lands could produce structure degradation and porosity loss, reflected by land compaction (impeding the correct aeration and growth of roots); it is possible to observe changes in colour (normally related to changes in organic matter contents), and texture (clay translocation); (5) finally, on the scale of physicochemical and biological properties, changes in the bioavailability of nutrients as well as in organic carbon presence in lands are common (Homburg and Sandor, 2011).

Results

Considering that the variables implied on the agrarian activities are diverse and that the analytical results could change over time, we propose the following research steps:

Step 1 – Landscape and ecosystem scale analyses

These analyses require understanding the geomorphological, paleoenvironmental, archaeological, and edaphic characteristics at a regional level. The construction of geoarchaeological models is a very useful tool in this step of research (see Peña Monné and Sampietro Vattuone, 2014, in this issue).

These models make it possible to know the environmental characteristics prevailing before the first human settlements occurred in a region. This knowledge is gained by putting together the natural and cultural formation processes that affected agrarian archaeological sites. Thus, these models constitute the basic evolutionary landscape unit to work on. It is useful to construct thematic maps, including geological, geomorphological, archaeological, pedological, hydrographical, and morphodynamical data.

On this scale it is possible to observe features related to the construction of agricultural terraces, earth benches, stone lines, and irrigation structures. In several cases these structures look like steps in the slopes. These steps decrease inclination and shorten slopes, thus minimising agricultural erosion hazards (***Fig. 2***).

Where these agricultural techniques and land management were inadequate, it is possible to observe macro-scale negative effects, such as gullies and ravines developed over slopes and deep fill in the bottom valleys as a product of runoff. In the presence of agricultural terraces, it is common to find a high number of rapid fill upslope walls that could have affected cultivars in the past. The elimination of vegetative cover due to changes in land use for agricultural purposes produced massive erosive slope processes, increasing bottom valley sediments (***Fig. 3***).

Step 2 – Soil scale analyses

Within the framework of crop parcels or agricultural terraces, it is necessary to consider that the objective of landscape transformation for agricultural purposes is to generate steps for slope stabilisation. These steps are generally contained by walls or earth benches that tend to favor the retention of fine sediments and to promote soil development by water infiltration. To have an idea of the general state of conservation, and of the positive/negative features associated with positive/negative features associated with these steps, it is useful to plan pedestrian surveys over the area. The state of conservation of fills and walls is a good indicator of the general state of soil/land crop bodies. The degree of infill inside agricultural structures constructed along slopes is a good index of the general stability of the surrounding landscape. Normally, the older and/or the more unstable the agricultural area is, the more filled the retaining wall body terraces tend to be (***Fig. 4***). Among the negative effects that could be detected after slope and bottom valley interventions on this scale, it is possible to detect local erosion processes, ranging from rill wash erosion to gullies and piping.

Previously suggested pedestrian surveys have made available the scarce archaeological materials dispersed over surface and in exposed profiles. These materials are useful in providing an idea of the chronological background of the area. Given the extended surface of productive areas, it is almost impossible to apply full coverage strategies, so we suggest selecting sampling areas, taking into account the most representative sections of the agricultural fields which were detected in the previous research step. On the other hand, it is necessary to survey and identify the areas with similar environmental history (i.e., inside the same geomorphological unit) and without anthropic impact, in order to compare them. This provides a real comparative background to know if there was anthropic impact and in which sense (positive or negative). Drawing detailed maps and sketches of sampling sectors is necessary to determine local inclination and the present distribution of natural and cultural features (***Fig. 5***).

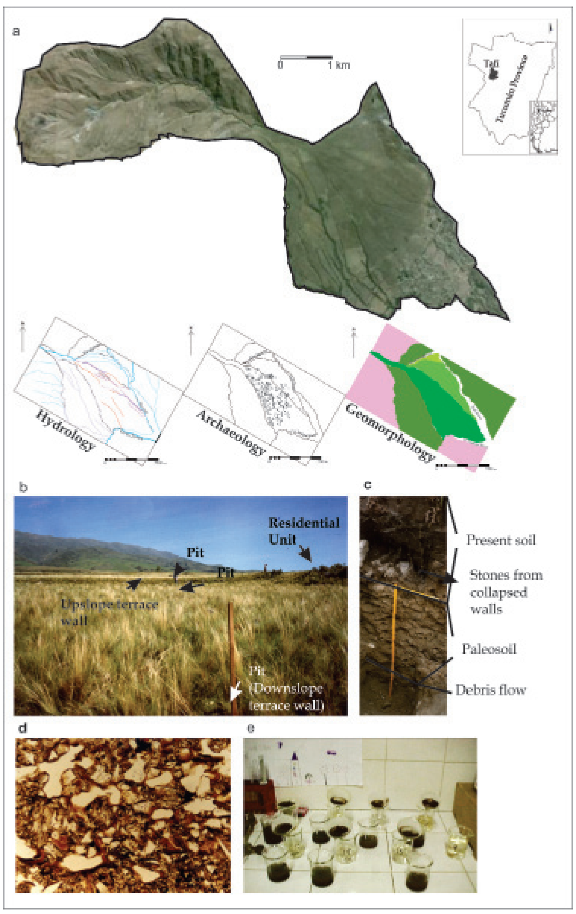

Figure 1: Different scale of analyses: (a) ecosystemic/landscape/basin scale; (b) crop parcels; (c) internal characteristics of cropland profiles; (d) micromorphological evidence; (e) physicochemical analyses.

From a biological point of view, it is necessary to take samples of pollen rain in the area together with samples of superficial sediment to characterise local vegetation from pollen and microfossil evidence.

Step 3 – Analyses of horizons and layers of croplands

To evaluate the physical and morphological characteristics of layers and/or soils from the agricultural areas, it is necessary to dig pits and make pedological descriptions. Increasing thickness of the A horizons and improvement of textures (which tend to be loamy) are among the most relevant features of positive effects of cropland management. In addition, texture changes improve water availability. A horizons and texture, as well as colour change (good index of organic matter contents), are easily observable (***Fig. 6***). In the case of bad management, lands tend towards compaction and porosity loss limits soil air circulation and root growth. Crusting is also common. In these cases, the general cropland structure decays, tending to look massive and compact. In several cases, A horizon erosion is evident. Normally, the Andean foot plow is less land aggressive than the Roman plow. As a result, the identification of Ap horizon, which is usual in areas where sustained agriculture has taken place, is variable. Ap horizons are formed because original aggregates are broken up by plow, promoting vertical downward movement of fine particles and upward movement for big particles and materials (including also archaeological artefacts). In this way, at the maximum penetration depth of the plow, a loamy-clayey layer could be accumulated (Porta Casanellas, 2008).

At this research stage, bulk samples for laboratory soil analysis, pollen, microfossils and archaeobotany must be taken. Pollen analysis makes it possible to know the evolution of the local vegetation over time. It is also possible to find over-representation of those specimens belonging to cultivated taxa. Isolating and identifying microfossils (phytoliths and starch grains) as well as archaeobotanical remains provides knowledge of exploited species. Bulk sam-

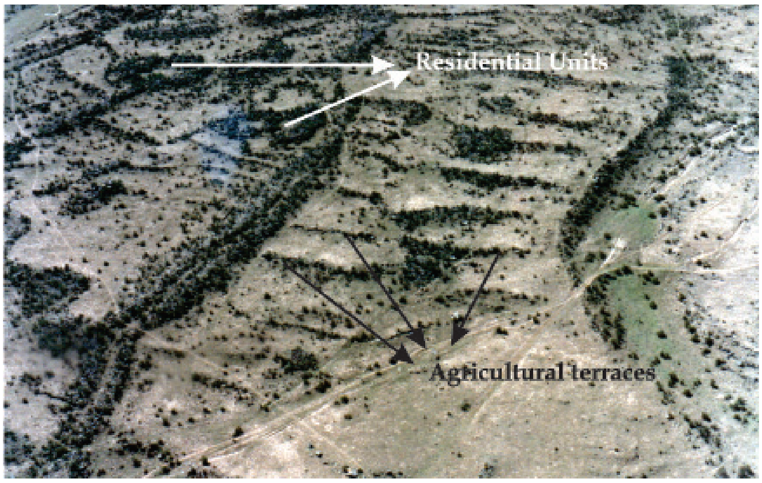

Figure 2: Aerial view of agricultural terraces in Tafí valley (Northwest Argentina).


Figure 3: Bad land management results. Filled bottom valleys at Alfocea (Spain).

Figure 4: Filled and unfilled terraces at (a) Molleyaco (AD 0 – 1000) and (b) Yasyamayo (AD 1000 – 1500) archaeological sites (Northwest Argentina).

ples could be taken following natural stratigraphy or at regular sampling intervals.

Step 4 – Micromorphological scale of analysis

The success or failure of land management is also observable through the degree of compaction and alteration of land aggregate structures. Micromorphological studies of soil thin section analyses of unaltered blocks are very useful in this sense (Sampietro Vattuone *et al.*, 2005). They make it possible to observe different degrees of pedoturbation introduced by several agents, such as worms, roots, rodents, and man, among others (***Fig. 7***).

One relevant aspect to be taken into account when estimating the productive capabilities of an agricultural area is to know what plants were cultivated, through pollen, archaeobotany and/or microbotany (phytoliths and starch grains). On the other hand, each species has its own nutritional needs and leaves behind particular fingerprints on soils. Due to the fact that continued harvests imply a sustained extractive activity, nutrient restitution is necessary. A common Andean practice used for generating interpretation problems to infer productive capacities is intercropping, as reflected by the microfossil record. Intercropping is the practice of cultivating several species in the same parcel and at the same time, achieving soil nutrient complementarity and nutrient restitution. It is also used for plague control. An example of this practice is the association of kidney beans with maize. Bean has nodules with nitrogen-fixing bacteria in their roots, which provide much-needed soil nitrogen to maize, while beans demand a large amount of phosphorus. The maize straw left after harvest restitutes the phosphorus taken by beans (Tapia and Fries, 2007). Examples like this are abundant in traditional Andean agriculture.

Step 5 – Physicochemical analyses of croplands

For the evaluation of anthropic impact on agricultural lands we propose the implementation of several nutrient availability tests. From experience, we know it is highly recommended to test organic matter content and different phosphate species, and that the behaviour of available micronutrients such as iron, copper, and manganese is more complex to elucidate (***Fig. 8***) (Sampietro Vattuone *et al.*, 2014). Well-managed lands that benefitted from addition of the organic matter in different ways (runoff, irrigation, manure, and/or straw) could have been even more enriched over time. Water use practices could have increased contents of organic carbon as well as nitrogen and phosphorus by taking advantage of periodical floods (like the Zuni Indians in the SW United States) (Homburg *et al.*, 2005), besides the use of fertilizers and straw. However, permanent harvests without reposition produce nutrient deficits, with the lack of organic matter, nitrogen, and phosphorus being especially important.

Another factor is that intensive use of irrigation systems in drylands may entail salinity problems (i.e., increasing sodium and calcium salts). These features are easily investigated by conductivity and cation exchange capacity tests.

Biological changes related to agricultural practices are even less known. Among beneficial biological changes we can mention


Figure 5: Detail of fine sediments accumulated upslope terrace wall (Hualfín, Northwest Argentina).


Figure 6: Profile colour changes at El Paso agricultural site (Northwest Argentina).

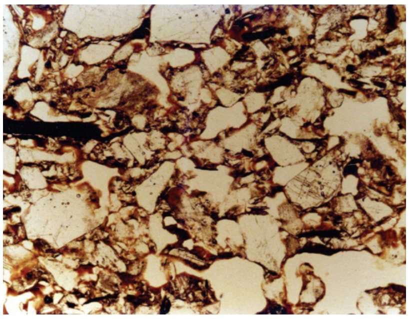

Figure 7: Soil thin sections from El Tolar agricultural site showing unaltered clay coatings (Northwest Argentina).

nitrogen fixation in the case of specific crops and increase of mycorrhizae, while negative agents are the concentration of pathogenic fungi (Homburg and Sandor 2011).

Conclusions

As demonstrated in this paper, the reconstruction of agrarian practices in drylands is a multiscale and interdisciplinary task. Geoarchaeology offers the ideal tools to gain a broad and thorough perception of the set of variables. It makes it possible to focus gradually on landscape as a whole and then on physicochemical variations of croplands considering crop nutrient consumption. Through geoarchaeology it is possible to fluently integrate geological, geomorphological, edaphic, biogeochemical, biological and archaeological parameters.

As a corollary, we must clarify that the abandonment of croplands often produces land degradation at first. This is due to the lack of maintenance, accelerated runoff erosion, erosion behind walls by concentration of superficial runoff, piping, and aeolian erosion due to the lack of native plant and rock cover. However, landscapes tend to reach a new equilibrium over time, thus favouring the development of native vegetation due to the improvement of the local lands. This process makes it possible to reconstruct past agricultural practices and their environmental impact.

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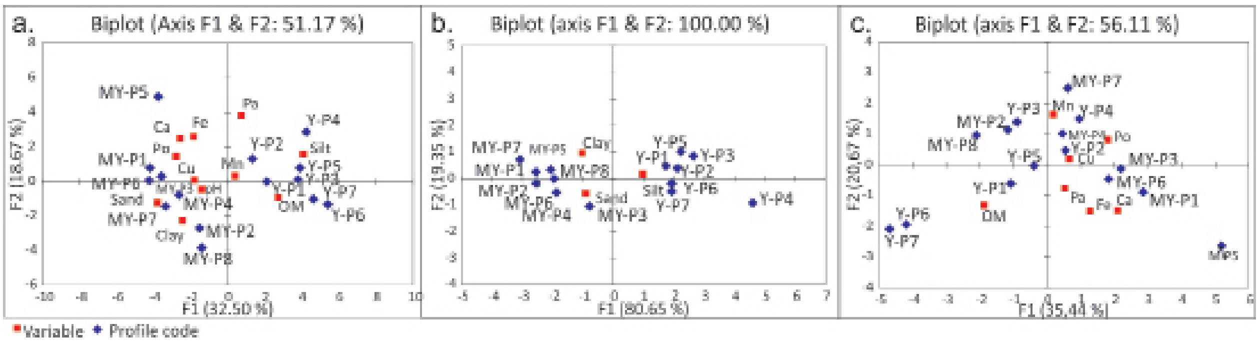

Figure 8: Biplot graphics showing soil chemical responses to agricultural use from Yasyamayo profiles (Northwest Argentina): Y1, Y6 and Y7 control profiles; Y2 – Y5 agricultural profiles. (A) response to all variables; (B) response to texture; (C) response to nutrients.

Reference

Homburg, J.A., Sandor, J.A. 2011. Anthropogenic effects on soil quality of ancient agricultural systems of the American Southwest. *Catena*, 85. 144–154. DOI: 10.1016/j.catena.2010.08.005

Homburg, J.A., Sandor, J.A., Norton, J.B., 2005. Anthropogenic influences on Zuni soils. *Geoarchaeology*, 20(7). 661–693. DOI: 10.1002/gea.20076

Peña-Monné, J.L., Sampietro-Vattuone M.M. 2014. Geoarchaeological and paleoenvironmental reconstructions through evolutionary models: dryland applications. *European Geologist*, 38. (this volume).

Peña-Monné, J.L., Julián, A., Chueca, J., Echeverría, M.T., Ángeles, G. 2004. Etapas de evolución holocena en el valle del río Huerva: Geomorfología y Geoarqueología. In Peña-Monné, J.L., Longares, L.A., Sánchez, M. (Eds.) *Geografía Física de Aragón. Aspectos generales y temáticos*. Universidad Zaragoza e Institución Fernando el Católico. 289-302.

Porta Casanellas, J. 2008. *Introducción a la edafología: uso y protección del suelo*. Ediciones Mundi-Prensa. España.

Sampietro Vattuone, M.M., Sayago, J.M., Kemp. R. 2005. Soil micromorphology and anthropic impact in Tafí valley Northwest Argentina. *Geoarchaeological and Bioarchaeological Studies*, 3. 37-42.

Sampietro Vattuone, M.M., Roldán, J., Maldonado, M.G., Lefebvre, M.G., Vattuone, M.A. 2014. Agricultural suitability and fertility in occidental piedmont of Calchaquíes Summits (Tucumán, Argentina). *Journal of Archaeological Science*, 52. 363-375. DOI: 10.1016/j.jas.2014.08.032

Sampietro Vattuone, M.M., Roldán, J., Neder, L., Maldonado, M.G., Vattuone. M.A. 2011. Formative Pre-Hispanic Agricultural Soils in Northwest Argentina. *Quaternary Research*, 75(1). 36-44. DOI: 10.1016/j.yqres.2010.08.008

Tapia, M. E., Fries, A. M. 2007. Guía de campo de los cultivos andinos. FAO. Lima. Perú.