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SOIL-GEOMORPHIC SETTING AND CHANGE IN PREHISTORIC AGRICULTURAL TERRACES IN THE MIMBRES AREA, NEW MEXICO

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Abstract — Soil-geomorphic relationships at some prehistoric agricultural terrace sites in the Sapillo and Mimbres Valleys in southwestern New Mexico were investigated to learn about agricultural management in this semiarid mountainous region, evaluate soil productivity, and determine long-term effects of agriculture on the physical environment. The sites, farmed during the Mimbres Classic period (AD 1000 to 1130), occur within certain geomorphic settings, implying strategies to optimize local climatic and hydrologic conditions for runoff agriculture. The landscape was modified by terracing, which served to reduce runoff velocity, increase soil moisture, and thicken naturally thin soil A horizons. Comparison of these prehistoric agricultural soils with nearby uncultivated soils that are similar in geomorphic setting and degree of development show that significant differences in soil properties still exist, nearly nine centuries after farming ceased. Soil changes resulting from the prehistoric agriculture mostly involved degradation, including accelerated erosion, compaction, and reduced concentrations of nutrients such as nitrogen and phosphorus. Despite soil degradation, maize growth in these soils indicates favorable productivity with nitrogen inputs and improved soil conservation.

INTRODUCTION

Ancient agricultural sites occur throughout the American Southwest, including the region of this field conference in southwestern New Mexico. The diverse range of these farming sites in form, location, and time reveals a remarkable set of strategies developed by American Indians over many generations that have allowed them to grow maize and other crops under dynamic and often precarious conditions in arid environments. These strategies include several types of irrigation agriculture on valley floors, and many kinds of dryland agriculture along valley margins and uplands that depend on rainfall and runoff, some of which are still practiced today by traditional farmers (Sandor, 1995; Doolittle, 2000; Sandor et al. 2007). Many of the dryland agricultural fields are spatially remote from modern U.S. agriculture. The form of runoff agriculture studied in this case dates to the Mimbres Classic period (AD 1000-1130), and involved terracing with series of small rock alignments on valley margin and upland surfaces.

Ancient agricultural systems such as these hold information relevant to challenges in agriculture and natural resource management today, such as techniques for meeting crop water and nutrient requirements without relying on irrigation or fertilizers (Sandor et al., 2007). They also provide long-term perspectives on agricultural land use needed to develop sustainable agricultural systems that are productive and also protective of land resources (Sandor and Eash, 1991; Redman, 1999; Holliday, 2004).

Following environmental and archaeological background information, we present findings on location patterns and archaeological features of the sites, from which agricultural strategies are inferred. We then examine evidence for soil, geomorphic, and vegetation change that was initiated during prehistoric farming, and continues today, along with an assessment of soil productivity. While much of this paper is a synthesis of material published from the original study (Sandor et al., 1986, 1990), updated observations and studies of similar sites elsewhere in the Southwest provide new perspectives on the findings. Generally, quantitative studies of prehistoric agricultural soils are relatively few. However, more studies have been done since the Mimbres soils research, providing an opportunity to compare soil-geomorphic settings and change in different areas, placing the Mimbres findings in a regional context.

ENVIRONMENTAL AND ARCHAEOLOGICAL CONTEXT

The terracing sites studied are located in the Datil-Mogollon Section of southwestern New Mexico within or near the Gila National Forest and Gila Wilderness, on gently sloping surfaces near the Sapillo and Mimbres Valleys (Connell et al., 2005; Hawley, 2005). Research focused mostly on the Sapillo Valley sites. Episodic dissection during the development of the present Gila drainage system produced several upland and valley border erosion surfaces, as well as alluvial terraces. Stable remnants of these surfaces used for terrace cultivation are underlain by alluvium 0.5- to 5-m thick overlying bedrock. The alluvium is derived from silicic to mafic Tertiary volcanics and the Gila Conglomerate (Mack, 2004; Hawley et al., 2000). The surfaces are thought to be of middle to late Pleistocene age, based on degree of soil development and the finding of a Pleistocene horse skull within an alluvial terrace (Wolberg, 1980; Sandor, 1983). Most of the natural soils used for terrace agriculture have relatively organic matter-rich surface horizons and substantial subsurface accumulation of clay (Paleustolls and Argiustolls) (Fig. 1). Surrounding soils include various less-developed soils (Entisols and Haplustolls) on floodplains and young alluvial fans, and shallower soils on steeper sloping uplands underlain by colluvium, thin alluvium, and bedrock.

The climate at these sites is semiarid, with an average of 250 of the 400 mm mean annual precipitation falling during the summer.

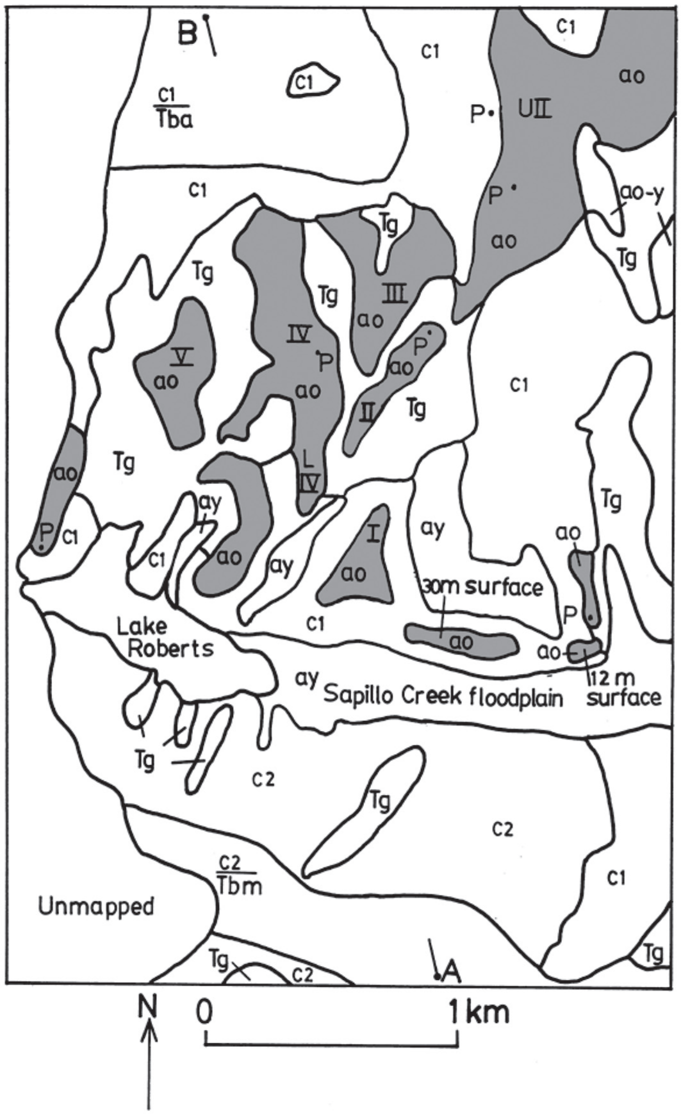

FIGURE 1. Association of Mimbres prehistoric runoff agricultural fields with certain soils. Nearly all known prehistoric fields occur on or near soils with strongly developed argillic horizons (subsurface clay accumulation), shown in gray on map (map unit ao). These soils occupy about 7% of the Sapillo Valley study area. See Sandor et al. (1986 or 1990) for complete soil map and legend. Area also shown in Fig. 3 photo.

The mean annual air temperature is 11 °C with warm summer temperatures of 18 to 21 °C. Vegetation is primarily a mix of grassland and pinyon pine-juniper *(Pinus edulis Engelm.-Juniperus* spp.) woodland.

The prehistoric terraced fields in the Mimbres area are typical of many such sites in the Southwest that that mostly date to about AD 1000 or later. The sites lie within the Mogollon cultural area, characterized by adaptation to a largely semiarid, mountainous region encompassing parts of southeast Arizona, southern New Mexico, and northern Sonora and Chihuahua, Mexico (Cordell, 1997). The agricultural terraces were constructed by placing series of small rock dams across gentle hillslopes and ephemeral stream channels (Fig. 2). Sedimentation upslope of each dam created the terraced fields. A detailed description of similar field types and associated structures at an extensive Mogollon site in Arizona was given by Woodbury (1961) and literature on many other sites is reviewed by Doolittle (2000). Similar agricultural methods have been used historically and to the present by Pueblo groups such as the Hopi and Zuni, and other traditional farming peoples of the Southwest (Hack, 1942; Doolittle, 2000).

Within the Mogollon area, these particular sites are associated with the Mimbres culture. Surface rooms and pottery at the sites correlate with nearby tree-ring dated pueblos of the Classic Mimbres period, which lasted from about AD 1000 to 1130 (Anyon et al. 1981; Hegmon, 2002; Lekson, 2006). Pottery sherds diagnostic of this period only were found within terraced soils at the sites, though the specific duration of site use within this period is uncertain. This period constitutes the population zenith (estimated at 2700 for the Mimbres Valley and 5600 for the region by Hegmon et al., in press) for the Mimbres cultural sequence and there is evidence for intensive and expanded land use and alteration of the natural vegetation and fauna at this time (Minnis, 1985; Stokes and Roth, 1999; Poole, 2002; Stokes, 2003). Minnis (1985) proposed that irrigation agriculture on major floodplains was the primary means of crop production, but that increased demand for food during the Mimbres Classic period pressed the limit of floodplain production. So, dryland farming on piedmonts probably represents expansion and diversification of agriculture, likely in conjunction with irrigation agriculture on the floodplains during a time of increased population. Climatological reconstructions from tree-ring and other data indicate relatively moist conditions favorable for dryland agriculture occurred during much of the Mimbres Classic period (Minnis, 1985). Botanical specimens and pollen recovered from Mimbres Classic pueblos indicate that maize *(Zea mays* L.) was the principle crop, with beans *(Phaseolus vulguris* L. and *Phaseolus acutifolius* var. *lutifolius* Freem.) and squash *(Curcubita* spp.) also important. Although dependence on agriculture reached a maximum during this time, natural food resources probably still accounted for about half of the diet (Minnis, 1985).

At first glance, the rough semiarid terrain lacking access to irrigation water on which these terraced fields occur appears to be marginal or unsuited for agriculture, and in fact there is little or no modern farming on such landscapes. Nevertheless, there are several agroecological reasons why such areas would have been advantageous for farming relating to the need to manage risk in uncertain environmental conditions through agricultural diversification. For example, valley margin and upland fields could remain productive during major valley floor flooding that might damage or destroy irrigated crops. Also, valley floors are more freeze-prone than valley edges and hillslopes. Valley bottom soils can also have salt and sodium problems, or other unfavorable properties. At Zuni for example, where most fields were traditionally located at valley edges on alluvial fans and footslopes, many floodplain soils have excessively high clay contents considered by farmers to be poor for maize production. Specific soil and geomorphic patterns of terraced site location that indicate the advantages of farming these valley margin and upland sites, and management practices to enhance site productivity, are discussed in the next section.

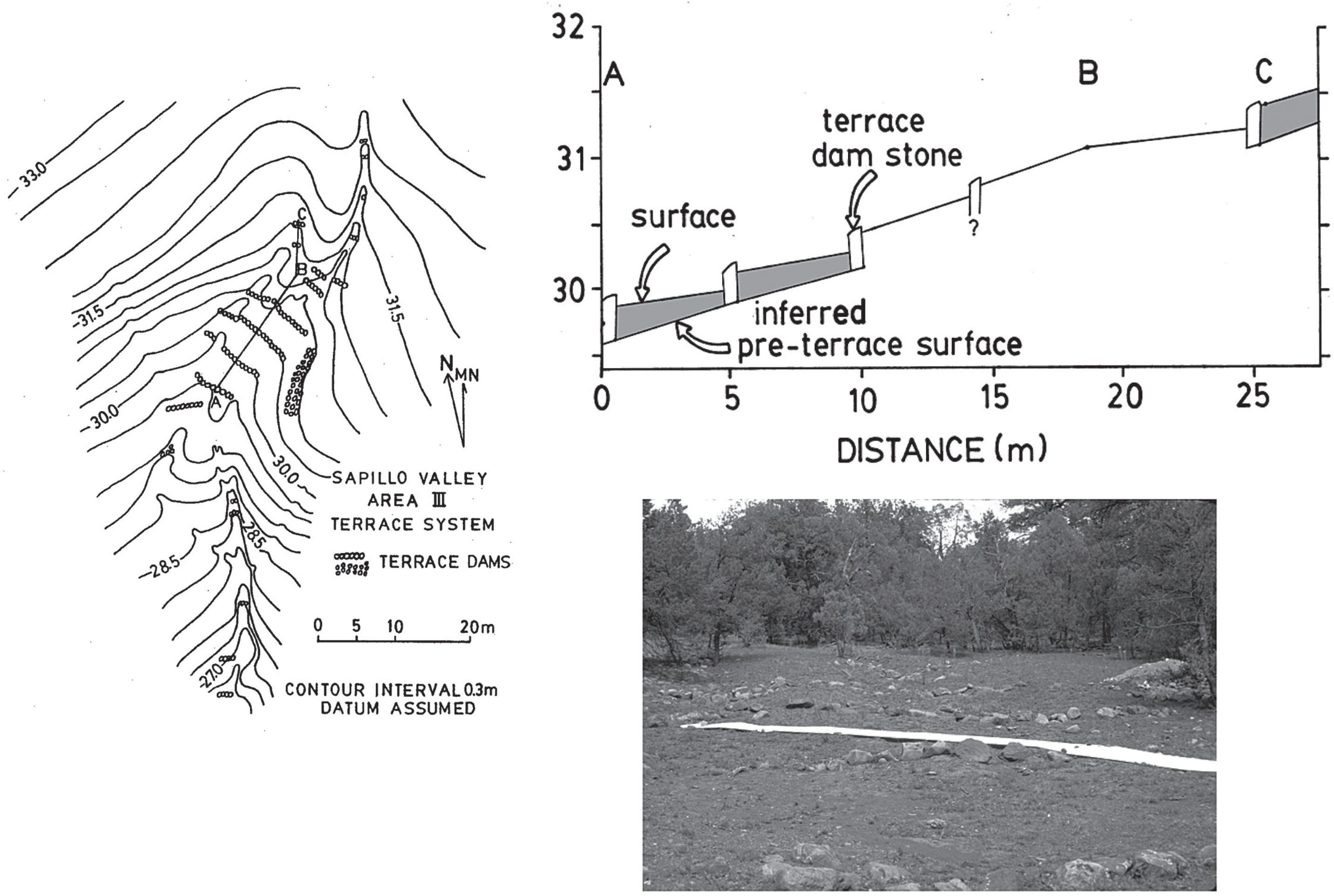

FIGURE 2. Example of Mimbres prehistoric runoff agricultural terraces. Thickened soil A horizons resulting from wedge-shaped sediment deposition upslope of agricultural terrace dam stones shown in gray. White strip in photo is 10 m scale.

SOIL-GEOMORPHIC SETTING AND FUNCTION OF AGRICULTURAL TERRACES

Location of the Mimbres agricultural terrace sites within certain geomorphic settings and soils suggests a set of placement criteria to achieve favorable conditions for runoff agriculture (Figs. 1-3). Compared to a regional elevation range of 1400 to 3200 m, sites occur between 1800 and 2000 m, as do many similar sites in the Southwest (Sandor, 1995). The likely reason for placing fields at these elevations was to maximize the probability of obtaining sufficient water for crop needs, while permitting a margin of safety in the variable frost-free period. Analysis of rainfall and temperature data in south-central New Mexico indicated that 1900 m was the optimal elevation for dryland maize agriculture (Human Systems Research, 1973). Topographic placement characteristics of the Mimbres sites include gentle slopes, mostly 3 to 10 %, and small drainage areas of 1 to 8 ha. These gentle slopes and small watersheds allow runoff but reduce the possibility of high runoff velocities that may damage crops. Hydrologists have demonstrated that small watersheds also have a relatively greater frequency of runoff events and runoff yield per unit area in arid regions (Osborn and Renard, 1970). A well-documented application of this hydrologic knowledge in ancient agriculture is in the runoff farms of the Negev Desert (Evenari et al., 1982). Although other researchers have noted the importance of slope aspect with regard to temperature at agricultural sites in the Southwest (e.g., Homburg and Sandor, 1997), no locational pattern with respect to slope aspect was observed in the Mimbres area.

An important purpose of terracing in runoff agriculture is to reduce runoff velocity by decreasing slope angle (average terraced slope angle at the Mimbres sites is 0.65 that of original) and slope length (Fig. 2). In this way, terracing protects against erosion and crop damage and encourages trapping of runoff for crop use. Soil moisture measurements taken before and after a runoff event suggest increased available water in terraced soils relative to unterraced soils in similar landscape positions (Sandor, 1983, p. 81-8). Studies elsewhere in the Southwest also show increased soil moisture in terraced and other kinds of fields using rock con-

figurations such as rock grids, piles, and mulch (Sandor, 1995; Homburg and Sandor, 1997).

The soils used for terrace agriculture have distinctive natural properties. Most of the agricultural terraces in the study area occur on, or just downslope from, soils with shallow, strongly developed horizons of clay accumulation (Bt, or argillic horizons). These soils are the oldest of the study area, developed in volcanic-derived alluvium on stepped surfaces of Pleistocene age along valley borders (Figs. 1, 3). Deliberate placement of terraced fields with respect to these soils is implied because the soils occupy only a small percentage of the area, and no fields were found in surveys of other areas with similar elevation and topographic settings, that lacked the argillic horizons (Sandor, 1983). These soils are effective runoff producers and also promote higher moisture in the crop root zone because water is detained above the slowly permeable argillic horizon. In this context, terracing would also serve to thicken the naturally thin loamy A horizon overlying the argillic horizon to meet soil volume requirements for crop roots and increase water infiltration and retention. Runoff derived from unterraced soils with argillic horizons would benefit terraced fields located directly downslope. Herbel and Gile (1973) monitored soil moisture in the intermontane basins of south-central New Mexico and found relatively favorable conditions for plant growth in soils with similar characteristics. This strategy of exploiting argillic horizons has analogues in the placement of fields by the Hopi in areas with shallow, nearly impermeable shale (Hack, 1942) or coarse over fine stratified sediments (Dominguez and Kolm, 2005), and the placement of prehistoric fields in soils with subsurface horizons cemented by carbonate (petrocalcic horizons) or silica (duripans) (Sandor, 1995; Homburg et al., 2004).

ENVIRONMENTAL CHANGE RESULTING FROM TERRACE AGRICULTURE

Mimbres prehistoric agricultural land use had a significant long-term impact on the landscape. Limitations and uncertainties in evaluating soil change from land use centuries ago make it

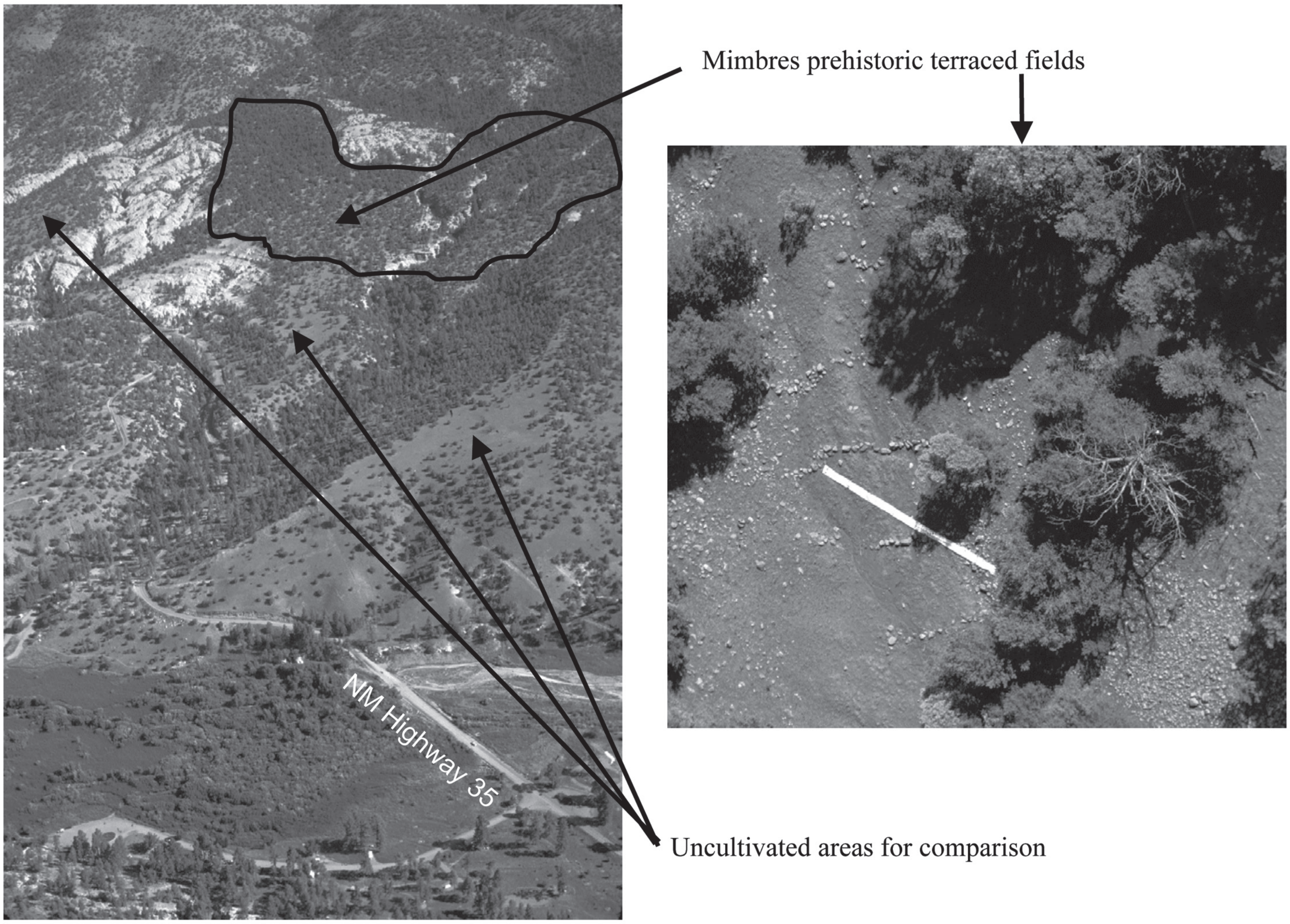

FIGURE 3. Main part of Sapillo Valley study area, showing location of some prehistoric runoff agricultural terraces and uncultivated areas used to infer soil change. Same area as shown on Figure 1 map. White strip in photo is 10 m scale.

important to consider research methods carefully. Soil and landscape changes were inferred by comparing prehistoric agricultural soils with uncultivated soils in nearby areas having similar geomorphic settings (Fig. 3). The uncultivated areas serve as references or controls for the cultivated areas, essentially a space-for-time substitution (McLauchlan, 2006). Evidence for the validity of these comparisons is presented in Sandor et al. (1986). Human disturbance of the prehistoric fields since abandonment is thought to be minimal because the agricultural terraces and associated archaeological features are intact and artifacts from later periods are absent. Recent land use within this part of the Gila National Forest and Gila Wilderness has been limited to some cattle grazing controlled by the US Forest Service. Given the dynamic nature of soils, landscapes, and ecosystems, as well as land use overprints, soil change interpretations are based on the idea that uncultivated reference soils are not equivalent to the original soils, but rather represent what the cultivated soils would be like today had they not been farmed.

Vegetation change and accelerated erosion

Evidence for vegetation change and accelerated erosion initiated by prehistoric cultivation is presented first because these factors are considered major contributors to the long-term soil changes. In contrast to more grass-covered uncultivated areas, some cultivated areas are nearly devoid of grass cover and apparently have been since they were cleared for agriculture. A possible reason for the failure of grass, mainly blue grama (*Bouteloua gracilis*), to better re-establish itself after abandonment comes from research done on a similar problem on the Great Plains in eastern Colorado. There, Wilson and Briske (1979) observed only a few blue grama plants growing back on cultivated land abandoned for the past 40 years and reported that attempts to re-establish blue grama from seed seldom succeeded. They attributed the problem to the rare occurrence of the special climatic conditions required for seedling development in the present climate. Their findings suggest that the grassland in the study area is essentially relict from the Pleistocene or early Holocene, having become established under moister conditions. Maintenance of existing blue grama cover continues because, once established, blue grama is hardy and drought-resistant.

Other possible factors contributing to sparse grass cover may involve sedimentation following dam construction. Hubbell and Gardner (1944) concluded from studies of rangeland in New Mexico that sedimentation, in amounts similar to that resulting from agricultural terracing, was especially detrimental to blue grama. Subsequent erosion of agricultural fields, discussed next, could have perpetuated adverse conditions for re-establishment of grass.

Some prehistoric cultivated areas, especially those with sparse grass cover, exhibit sheet and gully erosion. Incisions range in size from rills up to gullies 1.2 m deep and 4 m wide. In many locations, gullies cut through argillic horizons that required a stable landscape and thousands of years to form. The network of gullies, especially pronounced in part of the Sapillo Valley study area, contrasts with the uneroded uncultivated surfaces. Evidence indicating that accelerated erosion began during prehistoric cultivation is that: 1) gullies cut through agricultural terraces and associated fills that contain archaeological artifacts, showing that cultivation preceded gullying; and 2) dams built within some gullies, commonly near breached terrace dams, indicate attempts to repair gullies. Doolittle (1985) also observed prehistoric dams within gullies in New Mexico and Stewart and Donnelly (1943) reported that the Zuni used similar measures to stop gullies in agricultural fields. Evidence that erosion has continued intermittently to the present includes observations of renewed gully incision during storms and exposure of tree roots in gully banks. Besides the erosive effect of rainsplash on cultivated surfaces exposed by reduced grass and surface stone cover, gullies may have been initiated by runoff scouring soils at terrace dam bases. Surface stone rearrangement to create agricultural terrace dams and cleared fields between dams is another possible mechanism leading to and perpetuating accelerated erosion.

Agricultural soil change

To investigate long-term changes in the prehistoric agricultural soils, three kinds of soils were compared. Uncultivated soils in geomorphic settings similar and adjacent to agricultural sites provided references for measuring changes in cultivated soils. The A and BAt (transitional horizon between A and Bt) horizons were thought to represent the main cultivated zone. Uncultivated and cultivated A horizons were also compared with sediment (local, reworked soil) accumulated upslope of small trees which had recently fallen across uncultivated surfaces. These deposits, referred to as 'recent sediment deposits', are similar in thickness and texture to cultivated A horizons. The recent sediment deposits, considered analogous to terraced but uncultivated A horizons, were used to distinguish those soil changes resulting from cultivation from those changes which could result from terracing alone. The most visible change in the prehistorically cultivated soils is increased A horizon thickness resulting from deposition within agricultural terraces. The deposit within an agricultural terrace is a wedge-shaped body of soil upslope of each dam (Fig. 2) that resulted from local soil redistribution by alluvial and colluvial processes (Sandor, 1983). Deposits vary in thickness depending on dam height, distance upslope from the dam, and original and depositional slopes (Leopold and Bull, 1979). Whereas uncultivated A horizon thickness is typically 5-7 cm, A horizon thickness in cultivated areas varies from 5 cm (i.e., no thickening) to as much as 60 cm, with most in the 10-30 cm range. The isolated position of the remnant Pleistocene surfaces (i.e., separated from surrounding areas by drainageways incised deeply into bedrock, see Fig. 3), and the thinness of A horizons upslope of cultivated areas, indicate that thickening of cultivated A horizons resulted from local redistribution of topsoil. No textural or mineralogical differences were found between uncultivated A horizons, cultivated A horizons, or recent sediment deposits (Sandor et al., 1986). Most A horizons are loams or sandy loams with about 18 % clay.

Color and structure differences between uncultivated and cultivated A horizons suggest degradation of the fertility and physi-

cal condition of the cultivated soils. In contrast to darker-colored uncultivated A horizons with granular structure, cultivated A horizons commonly are lighter in color and have a more blocky, nearly massive structure (Fig. 4). These changes in soil morphology are indicators of compaction and lower concentrations of organic matter in cultivated A horizons (Figs. 5, 6). Organic matter (measured by organic carbon) and nitrogen concentrations in the prehistorically cultivated A horizons have declined over 40 % on a mass concentration basis. Although organic matter losses decrease with depth, they continue into upper Bt horizons at 50 to 75 cm depth, deeper than for any other soil property measured. Organic matter and N levels in the recent sediment deposits are similar to those in the uncultivated A horizons, indicating that terraced soils prior to cultivation had at least as much organic matter as the natural soils. Similar losses of organic matter and the important nutrient N have been reported in many studies of soils under modern cultivation (McLauchlan, 2006). Major mechanisms for organic matter and nutrient losses under cultivation include 1) disturbance of soil structure, causing increased aeration and exposure of organic matter to microbial decomposition, 2) microbial activity stimulated by the greater frequency of wetting and drying cycles, 3) the direct loss of biomass in the conversion of most naturally vegetated areas to cropland, and 4) nutrient removal with crop harvesting. The persistence of degradation in the prehistoric agricultural soils so long after farming ceased may partly relate to the vegetation changes and accelerated erosion. Phosphorus, another key nutrient, also shows a pattern of lower concentration in cultivated A and BAt horizons (Sandor et al., 1986). Phosphorus fractionation studies reveal losses from the fraction most available to plants.

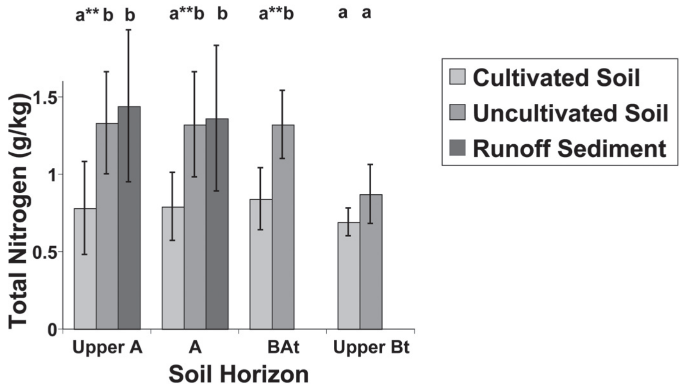

FIGURE 5. Comparisons of total nitrogen in uncultivated and Mimbres prehistoric agricultural soils. Bars are means (lines within bars show ± 1 standard deviation) from prehistoric cultivated soil, uncultivated soil, and recent sediment deposit sample groups. ** = significant overall differences among sample groups at the 0.01 probability level. Different letters indicate individual mean differences at the 0.05 probability level. Refer to Sandor et al. (1986) for details on statistical analyses.

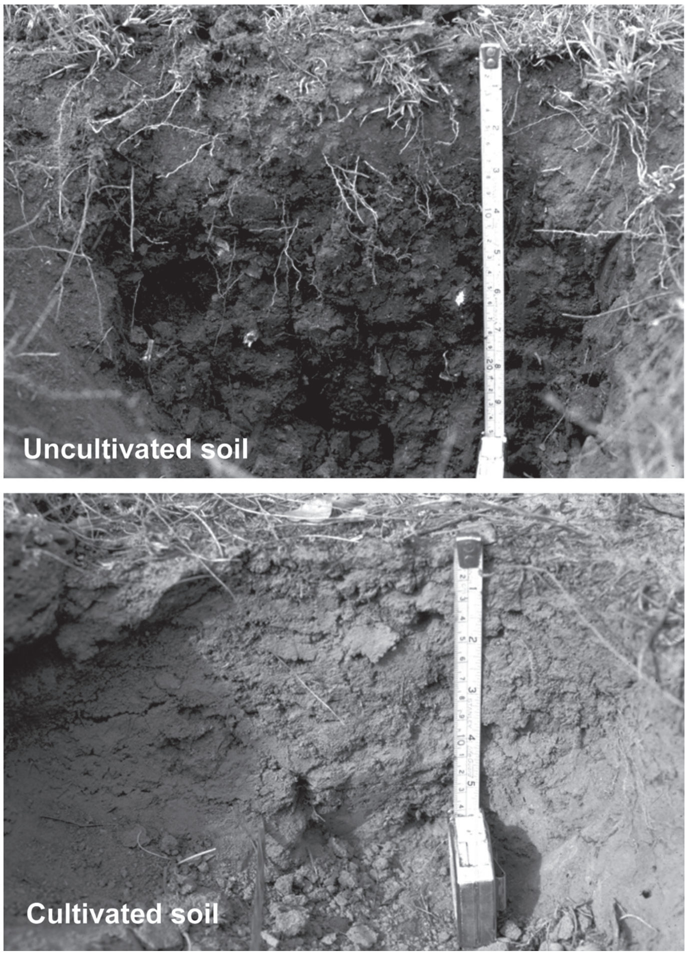

FIGURE 4. Comparison of uncultivated soil (upper photo) and Mimbres prehistoric agricultural soil (lower photo). Note more massive structure and lighter color of agricultural soil, indicating compaction and lower levels of organic matter.

Organic matter and N losses are also evident on a volume concentration basis (i.e., mass per unit area to equal depths) but to a slightly lesser extent than on a mass concentration basis (mass/soil mass), because bulk density is higher in cultivated A horizons. However, in terms of total quantities (i.e., mass per unit area through the soil), cultivated soils are commonly similar (organic C, total N) or enriched (P) relative to uncultivated soils because cultivated A horizons upslope of agricultural terrace dams are thicker. However, increased soil thickness probably resulted from local redistribution of topsoil, implying net losses of organic matter, N, and P from cultivated areas.

Bulk density data indicate that cultivated A horizons are compacted relative to uncultivated A horizons and data from recent sediment deposits suggest that the compaction resulted from cultivation rather than terracing (Fig. 6). Compaction of the cultivated soils is probably best explained by the relationship of bulk density to organic matter content. The beneficial effects of organic matter in maintaining a porous, granular topsoil with relatively low bulk density are well-known (Sandor and Eash, 1991; McLauchlan, 2006). When soil organic matter decreases significantly, soils tend to compact and structurally degrade. Figure 6 shows that while uncultivated soils have higher organic matter levels and lower bulk densities, and maintain the significant relationship between these two variables, prehistoric cultivated soils

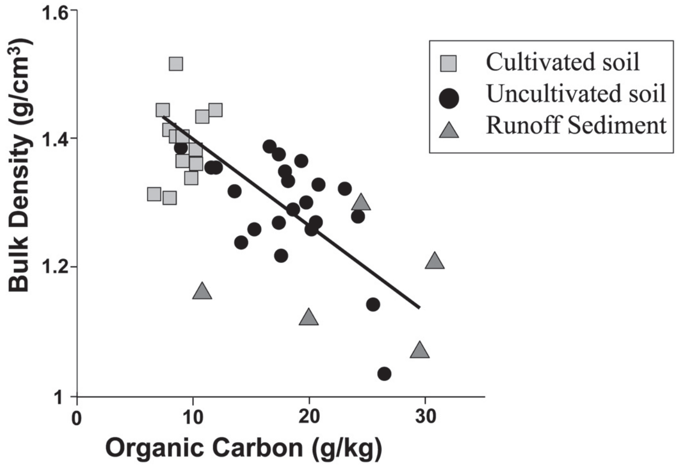

FIGURE 6. Relationships between bulk density and organic carbon in uncultivated and Mimbres prehistoric agricultural soils. Linear regression for uncultivated soils (r = 0.63, black line) is significant at the 0.01 probability level.

are more uniformly distributed around lower levels of organic matter and higher bulk densities. The degree of compaction measured in the cultivated soil is enough to decrease maize root growth and yields.

How do the findings of soil degradation from this Mimbres study compare with those from other studies of soils in past and present American Indian agriculture in the Southwest? Since the Mimbres study, research on soil change at several other ancient agricultural sites in the Southwest has been conducted or is ongoing. Examples are at Bandelier National Monument (Powers in Gauthier et al., 2007), Casas Grandes in Chihuahua, Mexico, the Coconino Plateau (Sullivan, 2000), the lower Verde River Valley (Homburg and Sandor, 1997), the Gila River Indian Community south of Phoenix, the Gila River Valley at Safford (Homburg et al., 2004), Sunset Crater area in northern Arizona (Berlin et al., 1990; Edwards, 2002), and Zuni (Homburg et al., 2005; Sandor et al., 2007). Findings from some studies suggest regional patterns; others indicate more singular aspects of the Mimbres agricultural system and soil change. Soil changes from ancient Southwest agriculture interpreted from these studies range from enhanced soil quality to soil degradation, with several intermediate cases (Sandor and Homburg, 2008).

Although some of the other studies also suggest soil degradation in terms of lower nutrient levels, the Mimbres study seems to show the clearest case, possibly because relatively definitive uncultivated reference soils were more available there. Many valley margin and upland agricultural sites are relatively intact and do not show such consistent degradation, perhaps reflecting the overall subtlety of dryland field systems in the Southwest. Soil studies of ancient to contemporary traditional fields on alluvial fans at Zuni, which stands out as one of the most continuously inhabited and farmed areas in the Southwest, indicate that traditional agriculture overall has not seriously degraded soil resources and in many ways has enhanced soil quality (Homburg et al., 2005; Sandor et al,. 2007). There is evidence for soil degradation in some Zuni agricultural soils, but these seem mostly associated with recent mechanized tillage. In this light, the Mimbres prehistoric agricultural landscape seems to indicate higher sensitivity to disturbance relative to some other areas. Although the soil degradation observed may have been enough to negatively affect agricultural production, it was probably not severe enough to be a major factor in regional abandonment. In modeling Classic Mimbres agriculture, Poole (2002) concluded that agricultural production through the period was sufficient to support the population.

Soil fertility and productivity

To test whether observed differences between cultivated and uncultivated soils corresponded to actual changes in agricultural productivity, and to further evaluate the fertility of the prehistoric agricultural soils, a crop growth experiment was conducted under controlled conditions in a greenhouse. Chapalote, a traditional variety of maize common in the Southwest throughout the prehistoric period, was grown for 28 days in samples of uncultivated and cultivated A and BAt horizons weighted by horizon thickness. Table 1 includes pertinent results comparing maize growth (measured by dry weight biomass) in soil without fertilizer additions, and in soil with nitrogen and phosphorus added or withheld. A complete presentation of the experiment is given in Sandor and Gersper (1988).

Greater maize growth in the uncultivated soil for treatments where N fertilizer was withheld is attributed to the greater native N content of the uncultivated soil. With N added, maize growth was similar in both cultivated and uncultivated soils and much greater than when the soils were not fertilized. This implies that during prehistoric farming, yields would have improved significantly with N inputs. Simultaneous testing with barley (a standard test plant), and comparison to similar greenhouse trials run previously with modern agricultural soils, suggest that the prehistoric agricultural soils are potentially productive by modern standards, especially if fertilized with N.

TABLE 1. Results of greenhouse experiment comparing Chapalote maize growth (28 days) in uncultivated and Mimbres prehistoric agricultural soils. Nutrient treatments are NPKS (nitrogen, phosphorus, potassium, sulfur) and PKS (nitrogen withheld). Data are means from 3 replicate plant sets per treatment and 4 plants per set. * = Significant difference between soils at the 0.05 probability level.

Nutrient Treatment	Soil	Dry matter g/plant set	Nitrogen mg/plant set
None	Cultivated	2.0	15
	Uncultivated	3.6*	32
Complete (NPKS)	Cultivated	19.4	234
	Uncultivated	17.9	216
No Nitrogen Added (PKS)	Cultivated	2.0	16
	Uncultivated	3.7*	31

Decreased concentrations of important plant nutrients like N and P suggest that these prehistoric farmers did not use fertilizers. In general, there is little evidence for the use of fertilizers during Southwest prehistory (review in Sandor, 1995). However, alternative methods of maintaining sufficient nutrient levels observed in the Southwest, such as additions of sediment, organic debris, and nutrient-enriched water in captured runoff, wide plant spacings, and fallowing, are ways in which traditional American Indian farmers have maintained soil fertility (e.g., Sandor, 1995; Doolittle, 2000; Sandor et al. 2007).

CONCLUSIONS

There is much to learn from ancient agricultural sites in the Southwest concerning strategies for arid land agriculture and the conservation of land and water resources. Occurrence of these Mimbres sites within certain geomorphic settings implies specific climatic, geomorphic, and soil criteria for terrace agriculture that archaeologists can use in reconstructing prehistoric agricultural strategies. Ancient agricultural practices such as runoff harvesting are also relevant to current agricultural concerns such as water and nutrient supply.

These sites also extend time perspectives on environmental impacts and agricultural sustainability. In this case, prehistoric cultivation generally resulted in soil and landscape degradation, including accelerated erosion, compaction, and decreased concentrations of soil organic matter, nitrogen, and phosphorus. The persistence of landscape degradation nearly nine centuries after farming ceased is a reminder of the fragility of many ecosystems and underscores the need for soil conservation and careful management of agricultural land.

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