Ancient Agricultural Soils of a Gridded Field Complex in the Safford Basin

By Jeffrey A. Homburg[1] and Jonathan A. Sandor[2]

[1]Statistical Research, Inc., 6099 Speedway Blvd., P.O. Box 31865, Tucson, Arizona 85751

[2]Agronomy Dept., Iowa State Univ., Ames, Iowa 50011

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INTRODUCTION

Soil properties associated with a Classic Period (~AD 1150-1450) agricultural complex (site AZ CC:2:1[ASM]) were investigated to document and evaluate the soil fertility and productivity of cultivated and uncultivated soils. The precise span of use is unknown, but the presence of associated masonry field house structures, radiocarbon dates from roasting pit features, and a small number of decorated sherds all point to Classic Period use. This field system is located about two miles north of Pima, Arizona, situated on a Pleistocene fan terrace that overlooks the Gila River flood plain (fig. 1). The fields consist chiefly of rock features built into elaborate waffle-like grid patterns, rock piles, and agricultural terraces, with fields spread over a 2.4 by 1.6-km area. Rock mulch systems similar to those at AZ CC:2:1(ASM) have been identified in cobbly landscapes throughout the American Southwest (e.g., Fish and Fish, 1984; Fish and others, 1992; Lightfoot, 1993a, 1993b; Homburg and Sandor, 1997). Ancient Hohokam, Sinagua, and Ancestral Pueblo (formerly Anasazi) farmers placed gravel and cobbles on planting surfaces as a way to reduce soil erosion by wind and water, increase soil temperature to extend the growing season, increase water infiltration, and reduce evaporative water loss from the soil. Rock mulch agricultural practices have also been documented in Israel, Italy, Peru, Argentina, New Zealand, China, the Canary Islands, and other places with a moisture deficit during the growing season (Evenari and others, 1982; Lightfoot, 1996).

Studies of ancient agricultural soils can contribute to research on agricultural sustainability in the context of both modern and prehistoric farming systems (Sandor and Gersper, 1988). Ancient agricultural soils of non-riverine fields in arid and semiarid regions are particularly well-suited for agronomic research because: (1) soil formation processes (e.g., weathering, leaching, and illuviation) proceeds slowly, so soil changes caused by ancient cultivation practices tend to persist and be detectable for about one millennium or longer; (2) most ancient fields have not been cultivated since they were abandoned, so historic farming practices such as plowing and artificial fertilizer applications have not masked or erased soil properties reflecting prehistoric farming; (3) elevated landforms, including alluvial fan and river

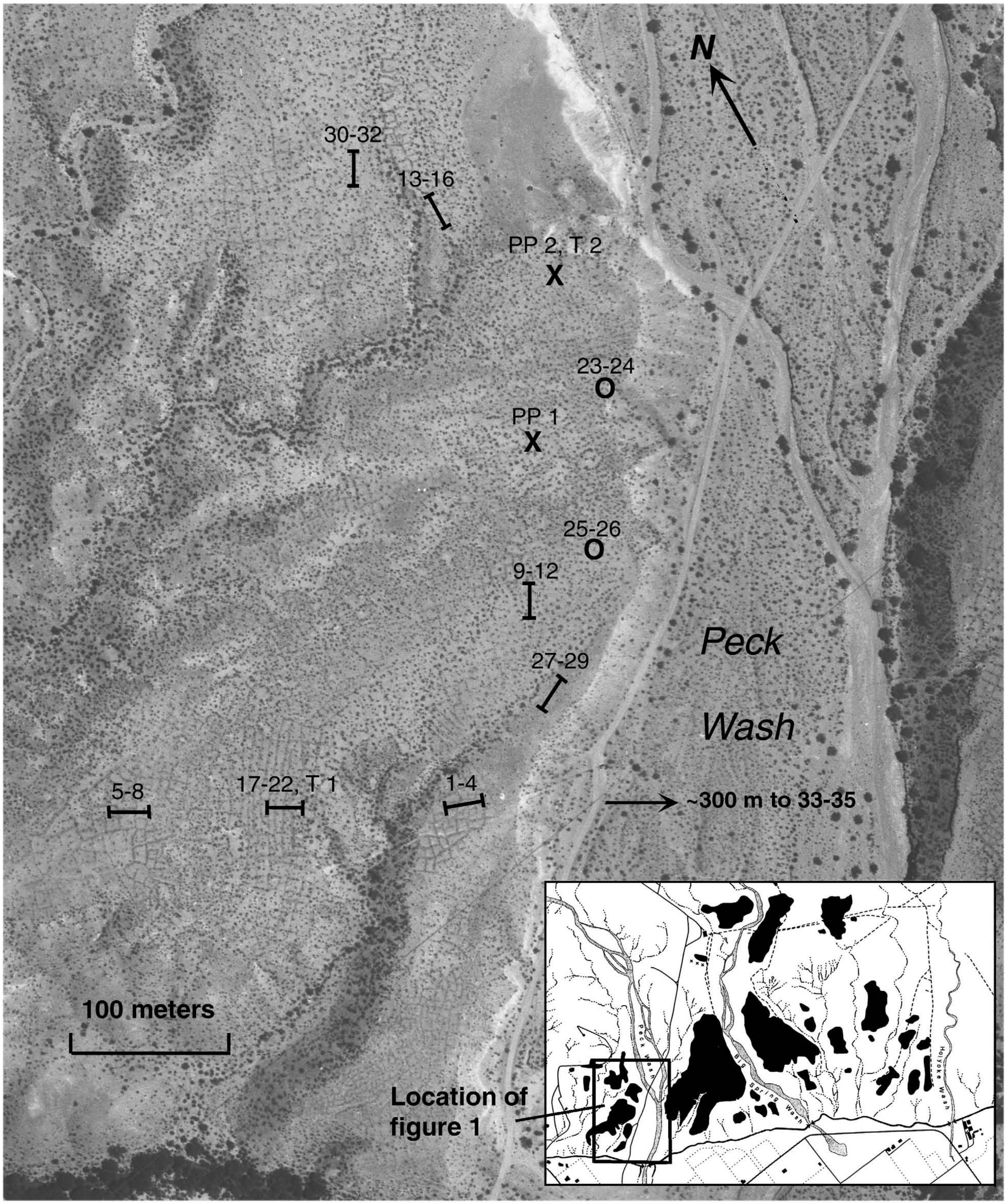

Figure 1. 1960 aerial photograph from the Arizona State Museum Archives, showing soil sampling locations (Prospectors' Pits 1 and 2, Trenches 1 and 2, and Shovel Pits 1-32) within gridded field locality 1. Black areas on inset map indicate locations of all the gridded field complexes (from D.R. Lightfoot, unpublished data).

terraces, are often geomorphically stable, so ancient agricultural soils are readily accessible for study; and (4) the presence or absence of agricultural facilities (rock alignments, rock piles, and terraces) provide important clues for discerning and collecting cultivated and uncultivated soil samples.

The harsh arid setting of the Safford Basin field system stands in stark contrast to the highly productive, irrigated cotton fields of the Gila River flood plain today. Crops cultivated in the thin, droughty soils of the gridded fields probably served to supplement the diet of ancient farmers in the Safford Basin who focused on irrigation. There are advantages to farming on elevated landforms such as that of the gridded field complex, however, including avoiding or minimizing killing frosts caused by cold air drainage. Because of great variability in the length of the growing season and unpredictable floods, combined with highly unpredictable precipitation patterns both spatially and temporally, ancient farmers commonly spread their fields over different soils and landforms as a buffering strategy to ensure adequate food supplies. Such agricultural diversity is a hallmark of prehistoric agricultural systems in the Southwest as a way to minimize the risk of crop failure. The few soil studies conducted thus far in the Southwest indicate that the consequences of prehistoric cultivation in terms of soil productivity are highly variable, due to many interacting environmental and cultural factors such as climate, topography, hydrology, soil type, native vegetation, crop type and variety, agricultural technology, and duration and intensity of cultivation. Previous soil studies have found that ancient farming systems can degrade or enhance the nutrient status of agricultural soils. This study aims to assess the effects of cultivation on soil productivity.

METHODS

Soil sampling focused on a variety of agricultural features in the westernmost locus of the field, west of Peck Wash and north of the Gila River flood plain (fig. 1). This area, designated Locality 1, was chosen for soil sampling because of its easy access and because a wide range of agricultural feature types are present, including grid alignments, rock piles, and agricultural terraces. In all, 49 soil samples were collected for analysis, 40 from 15-cm-deep shovel pits (SP) or shallow trenches placed in agricultural features and nearby uncultivated controls, and nine from two different soil profiles exposed in recent prospectors pits that were designated PP 1 and PP 2 (three samples from PP 1 and six from PP 2). The locations of all of these sampling locations except for the controls for the agricultural terraces are shown in figure 1.

Soil sampling concentrated on the grid features; eight gridded rock alignment and grid interior pairs were sampled and compared to six control samples from similar soils and landscape positions where there was no indication of cultivation. Three rock piles were sampled, along with control samples adjacent to each rock pile. A trench (T 1) and 6 SP's were excavated to sample the agricultural terraces located on the prominent east-facing escarpment in the southern part of Locality 1. Nine samples were collected from agricultural terrace contexts, including three samples from terrace rock alignments and three from the terrace positions located immediately above and below each sampled alignment. Three control samples for the terrace samples were collected from the escarpment east of Locality 1 and Peck Wash, an area with a comparable slope to that of the agricultural terraces. Deeper soil profile samples were obtained from the two prospector's pits, including a grid interior in the profile of PP 1 in the central part of Locality 1 and from a trench (T 2) excavated between PP 2 and a rock pile in the northern part of Locality 1. Six soil profiles were described, which entailed identifying soil horizons, recording morphological properties such as depth, color, texture, structure, and consistence, and classifying pedons according to the U.S. Department of Agriculture (USDA) Soil Taxonomy. Soil analysis included tests that tend to reflect long-term stability, such as particle-size distribution, bulk density, pH, organic and inorganic carbon, nitrogen, total and available phosphorus, and calcium carbonate equivalent. t-Tests were used to evaluate statistical differences between cultivated and uncultivated soils of different agricultural contexts.

RESULTS AND DISCUSSION

Petrocalcic and argillic horizons are dominant throughout the Safford gridded fields (figs. 2-4). Both of these diagnostic subsurface horizons function to impede or block water infiltration,

Figure 2. Photograph of thick petrocalcic horizon exposed in Prospectors' Pit 1.

Figure 3. Photograph showing shallow petrocalcic horizon below agricultural terraces and rock alignments.

Figure 4. Photograph of argillic horizon exposed in Prospectors' Pit 2.

and thereby conserve moisture in the rooting zone. Soil textures consist mainly of loams and sandy loams, which have a high capacity for holding plant available moisture and promoting rapid aeration and infiltration. Three soil map units are identified in the gridded field complex in the Natural Resources Conservation Service (NRCS) soil survey of the Safford area: (1) Bitter Spring-Pinaleno complex, 0-5% slopes, in the far western part of the field complex where the present soil study was conducted; (2) Pinaleno-Cave complex, 0-5% slopes, throughout most of the complex; and (3) Pinaleno cobbly loam, 2-5% slopes, in the northeastern part of the complex. At the family level of the USDA Soil Taxonomy (Soil Survey Staff, 1998), the Bitter Spring series is classified as Loamy-skeletal, mixed, superactive, thermic Typic Calciargids; the Cave series as Loamy, mixed, superactive, thermic, shallow Typic Petrocalcids; and the Pinaleno series as Loamy-skeletal, mixed, thermic Typic Haplargids. These soil series have little to no hazard of water and wind erosion, low to fair moisture holding capacity, medium to rapid runoff, and very slow to moderate permeability. Rooting depth, which is estimated at about 60 to 90 cm for the Bitter Spring and Pinaleno series and 13 to 60 cm for the Cave series, is limited by a weakly to strongly cemented zone of calcium carbonate. From a modern mechanized agricultural perspective, these soils are not regarded as suitable for cultivation due to their droughty nature, high gravel content, restricted rooting depth, low organic matter content, and low to medium natural fertility. It is noteworthy, however, that many archaeological projects have documented widespread evidence of ancient farming activity on these and similar soils throughout much of Arizona.

Quantitative data for the soil profiles, agricultural contexts, and controls are summarized in tables 1-4 and figure 5. No statistical differences were identified in the bulk density tests. The lack of consistent trends suggests that ancient cultivation practices did not cause long-term compaction. The bulk densities were mainly between about 1.30 and 1.45 g/cm^3, and none of the samples exceed 1.55 g/cm^3, the level at which root growth may be restricted (Wild 1993:117). Soil pH was significantly lower in all likely agricultural contexts than the controls. Because the controls have moderately alkaline pH levels (ca. pH 8.1-8.4), the reduction to about

Table 1. Soil chemistry and bulk density data for soil profiles in prospector's pits.

Soil Horizon	Depth (cm)	pH	Organic C (g/kg)	CCE[1] (%)	N (g/kg)	Total P (mg/kg)	Avail. P (mg/kg)	Bulk Density[2] (g/cm3)
PP1								
A	0-2	8.1	9.8	7.2	0.96	756	14.2	--
Abk	2-12	8.7	6.2	9.8	0.76	649	11.9	1.30
Bk	12-30	8.4	9.0	14.4	1.01	635	11.5	--
PP2								
A	0-4	9.1	0.7	9.5	0.22	628	4.8	--
Btk1	4-17	8.5	3.3	14.6	0.41	705	8.8	1.35
Btk2	17-40	8.5	0.7	24.0	0.36	911	6.5	1.51
Btk3	40-59	8.5	1.6	33.4	0.37	1428	6.8	1.39
2Btk4	59-77	8.4	0.7	42.9	0.27	1390	8.7	1.35
2Btk5	77-100	8.6	0.7	37.1	0.20	1043	7.0	1.69

[1]Calcium carbonate equivalent

[2]Bulk density values are missing for samples with weakly aggregated peds.

Table 2. Particle-size data (%) for soil profiles in prospector's pits.

Soil Horizon	Depth (cm)	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Coarse Silt	Fine Silt	Clay
PP1										
A	0-2	5	6	8	10	28	56	24	9	11
Abk	2-12	5	5	8	11	28	57	23	11	10
Bk	12-30	7	5	7	2	33	54	21	15	9
PP2										
A	0-4	5	4	7	5	31	53	23	17	7
Btk1	4-17	3	4	4	2	15	28	17	26	29
Btk4	17-40	5	4	4	2	15	30	11	26	33
Btk5	40-59	3	5	6	2	19	35	14	31	20
2Btk1	59-77	0	3	4	2	13	22	13	27	38
2Btk2	77-100	0	2	2	0	18	22	21	15	42

Table 3. Soil chemistry and bulk density data for grid features, agricultural terraces, rock piles, and controls.

Sample Type and Location	pH	Org. C (g/kg)	CCE[1] (%)	N (g/kg)	C:N Ratio	Total P (mg/kg)	Avail. P (mg/kg)	Bulk Density2 (g/cm3)
Grid Alignment								
SP 1	7.7	5.9	8.0	0.62	9.6	626	20.2	1.42
SP 3	7.7	6.0	4.7	0.52	11.5	666	26.1	1.39
SP 5	7.4	3.9	5.8	0.41	9.6	559	11.5	1.36
SP 7	7.7	5.6	3.8	0.54	10.2	496	10.4	1.43
SP 9	7.5	5.3	5.7	0.51	10.6	662	11.4	--
SP 11	7.9	3.9	6.2	0.35	11.3	529	8.6	1.28
SP 13	7.9	5.3	6.9	0.41	13.0	691	10.6	1.43
SP 15	8.1	5.5	9.2	0.59	9.4	597	6.2	--
Grid Interior								
SP 2	8.0	4.6	1.9	0.42	10.9	723	9.4	1.45
SP 4	8.1	5.0	4.0	0.42	11.9	965	9.8	1.47
SP 6	7.5	3.3	2.1	0.32	10.4	484	13.8	--
SP 8	7.8	4.8	3.5	0.41	11.8	691	9.1	1.36
SP 10	7.5	2.3	5.9	0.27	8.3	640	5.9	--
SP 12	7.7	1.6	9.1	0.24	6.9	699	10.5	1.42
SP 14	8.2	3.9	11.6	0.40	9.7	865	5.2	--
SP 16	8.2	3.3	12.0	0.35	9.3	833	5.2	1.38
Grid Control, SE Locality 1								
SP 27	8.3	1.4	9.2	0.34	4.1	587	4.9	1.50
SP 28	8.4	2.5	11.0	0.41	6.0	715	5.2	1.48
SP 29	8.5	7.5	15.1	0.57	13.0	750	5.3	1.49
Grid Control, West of PP 2								
SP 30	8.5	3.3	9.3	0.40	8.3	746	9.7	1.17
SP 31	8.4	4.0	10.7	0.42	9.6	787	7.2	1.12
SP 32	8.4	4.7	12.5	0.41	11.4	613	5.2	1.30
Below Terrace Alignment								
SP 17	8.1	3.0	11.7	0.58	5.2	657	10.2	--
Trench 1a	8.1	3.4	6.2	0.41	8.2	596	5.9	--
SP 20	7.6	3.0	6.2	0.71	4.2	699	13.3	1.47
Terrace Rock Alignment								
SP 18	7.8	5.1	5.5	0.45	11.3	510	11.3	--
Trench 1b	7.6	5.5	6.0	0.60	9.2	591	15.4	1.45
SP 21	7.8	4.6	5.1	1.08	4.3	710	26.5	1.29
Above Terrace Alignment								
SP 19	8.0	5.5	4.4	0.42	12.9	584	5.3	1.40
Trench 1c	7.7	8.6	4.1	0.45	19.1	647	9.2	1.49
SP 22	8.2	7.3	3.7	0.53	13.8	477	7.0	1.14
Terrace Control								
SP 33	8.2	11.7	5.8	0.59	19.9	432	11.6	1.32
SP 34	8.2	9.5	6.2	0.64	14.7	457	10.5	1.38
SP 35	8.0	5.0	5.2	0.69	7.2	493	12.4	1.43
Rock Pile								
Trench 2	9.0	2.5	6.0	0.40	6.3	372	5.4	1.45
SP 23	7.7	4.1	9.1	0.42	9.6	560	8.9	1.28
SP 25	8.1	3.0	7.7	0.46	6.5	432	17.5	--
Rock Pile Control								
Trench 2	9.3	9.3	12.4	0.42	22.4	672	5.9	1.41
SP 24	8.3	8.9	10.2	0.42	21.3	632	3.7	--
SP 26	8.2	4.5	5.6	0.42	10.7	651	7.1	--

[1]Calcium carbonate equivalent. [2]Bulk density values are missing for samples with weakly aggregated peds.

Table 4. Particle-size data (%) for grid features, agricultural terraces, rock piles, and controls.

Sample Type and Location	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Coarse Silt	Fine Silt	Clay
Grid Alignment									
SP 1	4	4	6	16	14	44	19	14	23
SP 3	4	5	8	18	18	53	20	10	17
SP 5	3	4	4	11	18	41	25	15	19
SP 7	5	3	3	2	25	38	27	16	19
SP 9	7	6	7	11	18	49	26	11	13
SP 11	4	5	5	14	19	47	26	13	14
SP 13	5	5	6	11	19	47	22	15	16
SP 15	7	6	5	10	12	41	20	17	22
Grid Interior									
SP 2	2	3	5	14	17	41	23	13	23
SP 4	3	3	5	12	20	43	23	15	19
SP 6	5	4	5	12	18	43	25	13	19
SP 8	3	4	6	14	18	45	22	18	16
SP 10	7	6	9	17	18	58	22	11	10
SP 12	6	5	6	15	21	53	25	10	11
SP 14	9	6	7	14	18	54	21	13	11
SP 16	3	3	6	10	20	42	24	19	14
Grid Control, SE Locality 1									
SP 27	3	5	7	11	25	48	21	15	16
SP 28	3	4	7	13	19	46	17	19	18
SP 29	4	3	6	18	14	44	17	21	18
Grid Control, W of PP 2									
SP 30	5	5	6	15	21	51	32	6	11
SP 31	5	5	6	16	21	54	24	14	8
SP 32	5	5	5	14	22	51	25	14	10
Below Terrace Alignment									
SP 17	9	7	7	4	25	51	26	13	10
Trench 1a	12	7	6	8	20	53	28	10	8
SP 20	5	6	7	9	24	51	29	12	8
Terrace Rock Alignment									
SP 18	8	8	8	11	17	53	24	12	11
Trench 1b	5	5	5	7	20	42	33	14	11
SP 21	5	6	6	0	28	45	32	14	9
Above Terrace Alignment									
SP 19	5	6	6	4	27	48	29	14	9
Trench 1c	4	4	4	0	28	40	36	15	9
SP 22	5	5	6	0	29	45	32	13	10
Terrace Control									
SP 33	5	5	5	2	25	43	27	12	17
SP 34	5	6	6	2	26	46	26	11	18
SP 35	5	5	6	12	16	44	29	12	15
Rock Pile									
Trench 2	4	4	6	16	12	42	18	21	19
SP 23	3	6	11	27	11	58	16	14	12
SP 25	5	6	8	8	33	59	21	10	9
Rock Pile Control									
Trench 2	2	4	4	0	18	28	14	31	27
SP 24	4	4	6	0	36	49	16	19	16
SP 26	3	5	6	17	21	53	25	12	9

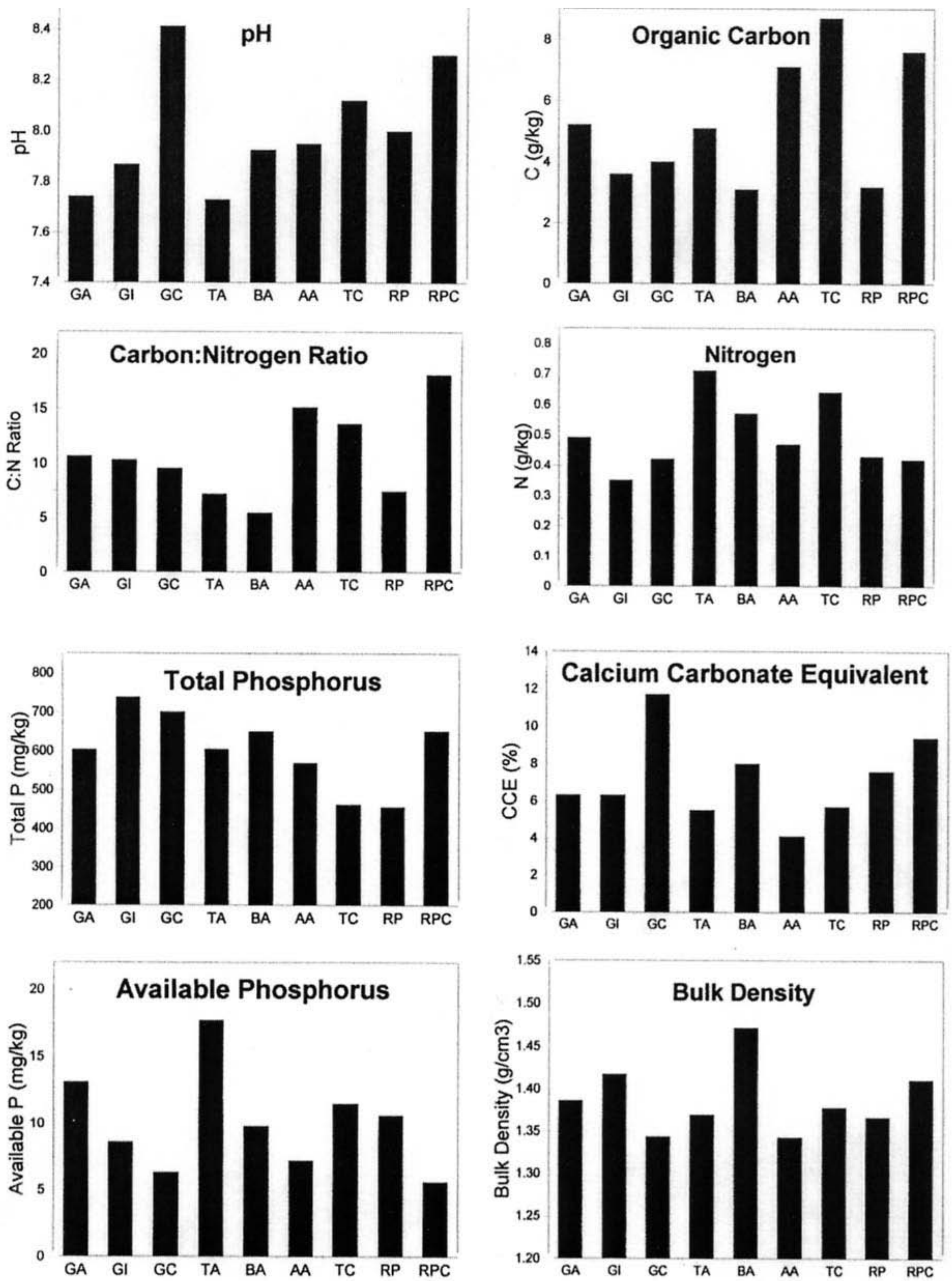

Figure 5. Histograms of soil chemistry and bulk density data.

7.7 to 8.0 in the cultivated soils is a beneficial effect for crop production, due to increased plant availability of many essential nutrients. Decreased pH values were probably caused by organic acids associated with elevated levels of organic matter. Organic carbon and total nitrogen were found to be higher in the soils of grid alignments than the grid interiors and their controls. These differences are statistically significant at the 0.05 level of significance. By contrast, agricultural terrace samples had lower levels of organic carbon and similar to slightly reduced nitrogen levels than their controls Compared to the controls, rock pile soils have similar levels of total nitrogen and reduced levels of organic carbon. There is little difference in the mean carbon:nitrogen ratios between the grid alignments and interiors and their controls, but the controls have higher ratios than the rock pile soils and the soils within and below the terrace alignments. The C:N ratios of soils presumed to have been cultivated are mainly in the range of 6:1 to 11:1, which indicates that most organic debris is highly decomposed, a form in which much of the nitrogen is available to plants.

Many agricultural contexts, including grid alignments, terrace positions above alignments, and rock piles, have significantly lower total phosphorus levels than their controls. Because total phosphorus levels are slow to change in the soil, reductions may reflect long-term cultivation effects. More important to agricultural production, however, is the amount of plant available phosphorus. The soils of all agricultural rock features have elevated levels of available phosphorus compared to their controls, and these differences are statistically significant for the grid and terrace alignments. Phosphorus requirements for crops are not well understood for many Arizona soils, but available phosphorus levels below 2 mg/kg (or 2 ppm) are usually considered low, and values above 5 mg/kg are considered sufficient. All of the cultivated soils from the Safford gridded fields have available phosphorus levels above 5 mg/kg.

Soil analyses indicated that rock mulch features (grid alignments, terrace alignments, and rock piles) and terrace positions immediately below the alignments are the most productive agricultural contexts. It is noteworthy that the upper and lower terrace positions near the alignments are where existing vegetation, mainly creosotebush, is concentrated today, thus indicating the continued effectiveness of rock mulch features in conserving moisture in the rooting zone. It is possible that the lower soil productivity of grid interiors was caused at least in part by cultivation. However, it seems more likely that rock clearings within the grids functioned primarily to facilitate runoff to the grid alignments immediately downslope rather than serving as planting surfaces. Removal of gravel from the grid interiors has likely enhanced runoff due to formation of a desert crust, similar to ancient farming practices documented in the Negev Desert of Israel (Evenari and others, 1982).

SUMMARY AND CONCLUSIONS

Soils in the Safford gridded field complex consist chiefly of gravelly loams and clay loams dominated by shallow petrocalcic or argillic horizons. Both of these horizons strongly impede or block water infiltration and hold moisture in the rooting zone within or above these zones. Compared to uncultivated soils, agricultural soils generally have reduced pH levels, which would have been beneficial for crop production due to increased plant availability for many essential nutrients. Nitrogen and available phosphorus content is consistently higher in the gridded and terrace alignments soils, and upper terrace positions immediately below terrace alignments. If these elevated nutrient levels are not the result of changes since field abandonment, then cultivation is associated with improved soil fertility. Compared to uncultivated controls, cultivated terrace and rockpile soils tend to have similar or slightly reduced organic carbon levels. Importantly, the grid alignment soils have significantly elevated organic carbon, nitrogen, and available phosphorus levels compared to the grid interiors. The precise cause of these chemical soil differences is uncertain, but they may reflect either direct cultivation effects or post-cultivation vegetation associations with agricultural features. Bulk density tests do not indicate that ancient cultivation practices caused soil compaction. In short, there is no indication that ancient farming activity seriously degraded the soil, and that is especially true for the grid features, the dominant type of agricultural feature.

An especially puzzling and elusive aspect of this study is determining what crops were, or might have been, cultivated. Soil data alone cannot answer this question, but it does provide important clues about potential crops, especially when evaluated in the context of modern soil and native plant associations relative to prehistoric agricultural features. The widespread occurrence of lithic artifacts that are commonly associated with agave processing (e.g., tabular knives and large flakes that may have served as cutting implements and steep-edged core tools/ pulping planes) in field areas and the recovery of charred agave remains from roasting pits in the alluvium of Big Spring Wash provide important, though indirect, clues that agave was the focus of cultivation. Colonies of Agave murpheyi, a domesticated species of agave, have been identified in many valleys of central Arizona (Hodgson et al. 1989; Homburg 1997), usually where traces of agricultural rock mulch features are found on cobbly, gently sloping alluvial fans and river terraces . No such colonies have been found in the Safford Basin, but it is possible that such colonies once existed but failed to survive without human aid or were completely harvested by later occupants. Agave thrives in cobbly, calcareous, droughty soils, even soils with low fertility in rugged terrain that support little other vegetation. Overall, soil nutrient levels in the Safford gridded field complex are sufficient to have supported maize agriculture, but the thin rooting zones, high temperatures, low rainfall, and low runoff throughout most landscape positions of the field suggest that crops such as agave or other drought-tolerant plants were likely the focus of agricultural production.

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APPENDIX A. SOIL PROFILE DESCRIPTIONS

Profiles were described by Jonathan A. Sandor and Jeffrey A. Homburg on March 10-13, 1997 in Locality 1, the westernmost part of the agricultural complex. The parent material of all profiles consists of gravelly alluvium derived from Gila Mountain conglomerates and miscellaneous volcanic rocks.

Profile Description 1: Grid interior, Prospector's Pit 1

Classification: Loamy, mixed, superactive, thermic Typic Petrocalcid (Cave series)

Geomorphic setting: Backslope of alluvial fan, elevation 901 m (2955 ft), 3-4% slope

Agricultural setting: Within grid interior; profile exposed in north wall of Prospector's Pit 1

A 0-2 cm. Pinkish gray to light brown (7.5YR 6/3) gravelly loam, brown (7.5YR 4.5/3) moist; weak medium and coarse plates plus weak to moderate fine and very fine subangular blocks; slightly hard, friable, slightly sticky, slightly plastic; common very fine and few fine roots; few fine and medium tubular pores; 10% gravel; slightly effervescent; moderately alkaline (pH 8.0-8.5; pH 6.5-8.0 under creosotebush); abrupt smooth boundary. Mantled by 80-85% gravel pavement cover, with gravel typically 0.8-2.0 cm in size; crust varies from 1 to 2 cm thick, with an algal crust on the surface, under creosote bush vegetation; some soil is noncalcareous and some thin carbonate coatings noted on parts of the surface.

ABk 2-12 cm. Light brown (7.5YR 6/4) gravelly loam, brown (7.5YR 4/4) moist; weak fine and medium subangular blocks; soft, friable, slightly sticky, slightly plastic; common very fine, fine, and medium roots, with some pockets of many fine to very fine and few large roots; few fine tubular pores; 5-10% gravel and 20% cobbles; strongly effervescent; strongly alkaline (pH 8.0-8.5); clear smooth boundary.

Bk 12-30 cm. Light brown to (7.5YR 6.5/3.5) very gravelly sandy loam; brown (7.5YR 4.5/4) moist; weak fine subangular blocks; soft, friable to very friable, slightly sticky, slightly plastic; common very fine and fine roots; few fine tubular pores; 20% gravel and 25% cobbles; violently effervescent; strongly alkaline (pH 8.0-8.5); abrupt smooth boundary.

Bkm1 30-31 cm (2 to 3 cm thick in places). Matrix is weakly cemented by white (10YR 8/1) carbonate, pink to pinkish gray (7.5YR 7/3) moist (no texture estimate due to cement, but is gravelly/very cobbly); contains some clayey zones of reddish yellow (7.5YR 6/6) stained by iron oxide (?), strong brown (7.5YR 5/6) moist; 20% gravel; root mat on top; strongly effervescent on top to slightly effervescent below, carbonates noted on all sides of gravel and cobbles, but often thickest on top; moderately alkaline (pH 8.0-8.5); abrupt smooth to slightly wavy boundary.

Bkm2 31-71 cm. Matrix is weakly cemented by white (10YR 8/1) and pinkish white (7.5YR 8/2) carbonate, pink to pinkish gray (7.5YR 7/3) moist (no texture estimate due to strong cement, but is gravelly/very cobbly); contains some clayey zones of reddish yellow (7.5YR 6/6) stained by iron oxide (?), strong brown (7.5YR 5/6) moist; 35-40% gravel; rare fine and very fine roots; strongly effervescent, carbonate coatings up to 4 mm thick on the bottom of gravel; moderately alkaline (pH 8.0-8.5); clear smooth boundary.

Bkm3 71-118 cm. Matrix is weakly cemented by white (10YR 8/1) and pinkish white (7.5YR 8/2) carbonate, pink to pinkish gray (7.5YR 7/3) moist (no texture estimate due to strong cement, but is gravelly/very cobbly); contains some clayey zones of reddish yellow (7.5YR 6/6) stained by iron oxide (?), strong brown (7.5YR 5/6) moist; 25% gravel and 15% cobbles; rare fine and very fine roots, but occasionally clustered in pockets; violently effervescent carbonate matrix and effervescent clay plus iron (?); moderately alkaline (pH 8.0-8.5); clear smooth boundary.

B’k 118-125 cm. Light brown (7.5YR 6/3) very gravelly sandy loam, pink to pinkish gray (7.5YR 7/3) moist; massive structure; slightly hard, friable, slightly sticky, slightly plastic; few very fine and fine roots, often in clusters; 15% gravel and 10-15% cobbles; violently effervescent, carbonate coatings on all sides of gravel; moderately alkaline (pH 8.0-8.5); clear smooth boundary.

BCk 125-142 cm. Light brown (7.5YR 6/4) very gravelly sandy loam to very gravelly loamy sand, pink (7.5YR 7/4) moist; massive structure; soft, very friable, slightly sticky, slightly plastic; few very fine and fine roots; 25% gravel and 10% cobbles; strongly to violently effervescent, few carbonate coatings on gravel; moderately alkaline (pH 8.0-8.5); abrupt smooth boundary.

2C 142-162+ cm. Pink (7.5YR 7/3) loamy sand, strong brown to reddish yellow (7.5YR 5.5/6) moist; massive structure; soft, very friable, nonsticky, nonplastic; few very fine and fine roots; 5% gravel; effervescent; moderately alkaline (pH 8.0-8.5).

Profile Description 2: Next to rock pile, Trench 2

Classification: Fine-loamy, mixed, thermic Calcic Paleargid (similar to Pinaleno series; would be classified as a Typic Petroargid if petrocalcic horizon is present in 100-150 cm zone)

Geomorphic setting: Alluvial fan terrace, elevation 899 m (2950 ft), 4% slope

Agricultural setting: Desert pavement near rock pile feature; adjacent to west side of Prospector's Pit 2

A 0-4 cm. Light brown (7.5YR 6/4) loam, brown to strong brown (7.5YR 5/5) moist; moderate medium plates; slightly hard, very friable, slightly sticky, slightly plastic; few fine and very fine roots; many fine to very fine vesicular pores; 10-20% gravel, mainly on the surface; effervescent; moderately alkaline (pH 8.0-8.5); abrupt smooth boundary. Contains few filaments and faint spots of carbonate.

Btk1 4-17 cm. Light brown to reddish yellow (7.5YR 6/5) clay loam, brown to strong brown (7.5YR 4/5) moist; moderate fine subangular blocks; slightly hard, friable, sticky, plastic; many moderately thick clay films on ped faces and pores; common very fine and fine roots; few fine tubular pores; 5% gravel; strongly effervescent; moderately alkaline (pH 8.0-8.5); clear smooth boundary. Contains common small (~1mm) masses of carbonate, and the matrix consists of 5-10% carbonate filaments.

Btk2 17-40 cm. Light brown to reddish yellow (7.5YR 6/5) clay loam; strong brown (5YR-7.5YR 5/6) moist; moderate fine subangular blocks; slightly hard, friable, sticky, plastic; many moderately thick clay films on ped faces and pores; few very fine and fine roots; few fine tubular pores; 5% gravel; strongly effervescent; moderately alkaline (pH 8.0-8.5); gradual smooth boundary. Contains common to many soft powdery masses, with few moderately hard masses; several are 5-10 mm across and some are cylindrical in shape.

Btk3 40-59 cm. Light brown to reddish yellow (7.5YR 6/5) loam, strong brown (7.5YR 5/6) moist; moderate fine and medium subangular blocks; hard, firm, sticky, plastic; common thin clay films on ped faces; few very fine and fine roots; few very fine tubular pores; 5% gravel; strongly effervescent matrix, and violently effervescent carbonate masses; moderately alkaline (pH 8.0-8.5); clear smooth boundary. Contains few to common (5-10%) masses of carbonate and some finely disseminated carbonates; some consist of 6-10 mm cylindrical carbonate concentrations, possibly formed in old insect burrows.

2Btk4 59-77 cm. Pinkish gray to light brown (7.5YR 6/3) clay loam, brown to yellowish brown (7.5-10YR 5/3 and 5/4) moist; hard, firm, sticky, plastic; many moderately thick clay films on ped faces; few very fine and fine roots; few very fine tubular pores; <1% gravel; strongly effervescent matrix, and violently effervescent carbonate masses; moderately alkaline (pH 8.0-8.5). Contains few to common moderately hard masses of carbonate.

2Btk5 p 77-100+ cm. Pinkish gray to light brown (7.5YR 6/3) clay loam to clay, brown (7.5YR 5/3 and 5/4) moist; weak fine prisms parting to moderate fine and medium subangular blocks; very hard, very firm, very sticky, very plastic; some possible clay coatings on peds; rare fine roots; rare fine tubular pores; strongly effervescent; moderately alkaline (pH 8.0-8.5); clear smooth boundary. Contains few to common seams and filaments of carbonate.

Profile Description 3: Agricultural terrace, upslope of rock alignment, Trench 1c

Geomorphic setting: Backslope of fan terrace scarp, 10-11% slope

Agricultural setting: Terrace, 20 cm upslope of rock alignment

A1 0-5 cm. Pinkish gray to light brown (7.5YR 6/3) very gravelly sandy loam to loam, brown (7.5YR 4.5/3) moist; weak to moderate fine and medium subangular blocks and some weak medium plates; soft, very friable, slightly sticky, slightly plastic; few to common very fine roots; few very fine tubular pores; 35% gravel, mainly on the surface; not effervescent; mildly alkaline (pH 7.5); abrupt smooth boundary. This horizon has formed in the upper terrace fill deposit, and it is covered by a patchy gravel pavement.

A2 5-16 cm. Pinkish gray to light brown (7.5YR 6/3) gravelly sandy loam to loam, brown (7.5YR 4.5/3) moist; weak fine subangular blocks and some weak medium plates at the top; slightly hard, very friable, slightly sticky, slightly plastic; common very fine and fine roots; few very fine tubular pores; 15-20% gravel; audibly effervescent; mildly alkaline (pH 7.5); clear smooth boundary. This horizon has formed in the lower terrace fill deposit.

Bk1 16-30 cm. Pinkish gray to light brown (7.5YR 6/3) gravelly sandy loam to loam, brown (7.5YR 4.5/3) moist; weak fine subangular blocks to massive; soft, very friable, slightly sticky, slightly plastic; common very fine and few fine roots; few very fine tubular pores; 25% gravel; strongly effervescent; moderately alkaline (pH 8.0-8.5); clear smooth boundary. Matrix is dominated by finely disseminated carbonates.

2Bk2 30-46 cm. Light brown (7.5YR 6/3.5) extremely gravelly sandy loam, brown (7.5YR 5/4) moist; weak fine subangular blocks to massive; soft, very friable, slightly sticky, slightly plastic; 65% gravel and some cobbles; common very fine and fine roots; strongly effervescent matrix, and violently effervescent; moderately alkaline (pH 8.0-8.5); abrupt smooth boundary. Contains both finely disseminated carbonates and gravel coatings on all sides.

2Bkm 46+ cm. Color of carbonate cement not described, but much lighter than above; massive, cemented; 60-70% gravel; violently effervescent; moderately alkaline (pH 8.0-8.5). This horizon has a laminar cap of carbonate above a massively cemented petrocalcic horizon.

Profile Description 4: Beneath rock alignment between two agricultural terraces, Trench 1b

Geomorphic setting: Backslope fan terrace scarp, 10-11% slope

Agricultural setting: Beneath rock alignment

A1 0-5 cm. Pinkish gray to light brown (7.5YR 6/3) gravelly/very cobbly sandy loam to loam, brown to dark brown (7.5YR 4/3) moist; weak fine subangular blocks and some weak medium plates; soft to slightly hard, very friable, slightly sticky, slightly plastic; few fine roots; few very fine tubular pores; 15% gravel, excluding surface gravel in rock alignment; not effervescent; mildly alkaline (pH 7.5); clear smooth boundary. Upper boundary is irregular between rocks.

A2 5-18 cm. Pinkish gray to light brown (7.5YR 6/3) gravelly/very cobbly sandy loam to loam, brown (7.5YR 4.5/3) moist; weak fine subangular blocks; soft, very friable, slightly sticky, slightly plastic; few to common very fine and fine roots; few very fine tubular pores; 25% gravel; not effervescent; mildly alkaline (pH 7.5); clear smooth boundary. Surface gravel in rock alignment extends about 13 to 15 cm below surface.

Bk1 18-27 cm. Pinkish gray to light brown (7.5YR 6/3) gravelly/very cobbly sandy loam, brown (7.5YR 4.5/3.5) moist; weak fine subangular blocks; soft, very friable, slightly sticky, slightly plastic; few to common very fine and few fine roots; few very fine tubular pores; 30% gravel; strongly effervescent; moderately alkaline (pH 8.0-8.5); clear smooth boundary. Carbonate coatings were noted on all sides of gravel.

2Bk2 27-40 cm. Light brown (7.5YR 6/4) extremely gravelly loam to sandy loam, brown (7.5YR 4.5/4) moist;

weak fine subangular blocks to massive; soft, very friable, slightly sticky, slightly plastic; 70% gravel and cobbles; few to common very fine and fine roots; strongly effervescent; moderately alkaline (pH 8.0-8.5); abrupt smooth boundary. Carbonate coatings were noted on all sides of gravel.

2Bkm 40+ cm. Color of carbonate cement not described, but much lighter than above; massive, cemented; 60-70% gravel; violently effervescent; moderately alkaline (pH 8.0-8.5). This horizon has a laminar cap of carbonate above a massively cemented petrocalcic horizon.

Profile Description 5: Agricultural terrace, downslope of rock alignment, Trench 1c

Geomorphic setting: Backslope of fan terrace scarp, 10-11% slope

Agricultural setting: Terrace, 20 cm downslope of rock alignment

A 0-3 cm. Light brown (7.5YR 6/3.5) gravelly/very cobbly sandy loam, brown to dark brown (7.5YR 4/3) moist; weak to moderate fine and medium subangular blocks to massive; loose to soft, very friable, slightly sticky, slightly plastic; few very fine roots; few very fine tubular pores; 20% gravel, mainly on the surface; effervescent; moderately alkaline (pH8.0-8.5); abrupt smooth boundary. This horizon has formed in the upper terrace fill deposit, and it is covered by a gravel pavement.

Bk1 3-18 cm. Light brown (7.5YR 6/3.5) gravelly/very cobbly sandy loam, brown (7.5YR 4.5/4) moist; weak to moderate fine and medium subangular blocks; soft, very friable, slightly sticky, slightly plastic; few to common very fine and few fine roots; few very fine tubular pores; 20% gravel; strongly effervescent; moderately alkaline (pH 8.0-8.5); clear smooth boundary. Contains disseminated carbonates in matrix and coatings on all sides of gravel.

2Bk2 18-40 cm. Light brown (7.5YR 6/4) extremely gravelly sandy loam, brown (7.5YR 5/4) moist; weak fine subangular blocks to massive; soft, very friable, slightly sticky, slightly plastic; 70% gravel and some cobbles; few to common very fine and fine roots; few tubular pores; strongly effervescent; moderately alkaline (pH 8.0-8.5); abrupt smooth boundary. Contains few to common (5-10%) masses of carbonate and some finely disseminated carbonates; some consist of 6-10 mm cylindrical carbonate concentrations, possibly formed in old insect burrows. Contains disseminated carbonates in matrix and coatings on all sides of gravel.

2Btkm 40+ cm. Color of carbonate cement not described, but much lighter than above; illuvial clay is light brown (7.5YR 6/4), brown (7.5YR 5/4) moist; weakly cemented, massive, with some clay breaking out in blocks; many thick clay films on ped faces in clayey zones; 60-70% gravel; violently effervescent; moderately alkaline (pH 8.0-8.5). Contains few to common moderately hard masses of carbonate.

Profile Description 6: Grid interior, Shovel Pit 4

Geomorphic setting: Nearly level part of alluvial fan terrace, 1-2% slope

Agricultural setting: Within grid interior

A 0-3 cm. Pink to light brown (7.5YR 6.5/3.5) gravelly/very cobbly sandy loam, brown (7.5YR 4.5/3) moist; weak medium plates and weak fine subangular blocks; slightly hard, friable, slightly sticky, slightly plastic; few very fine roots; few very fine vesicular pores; 20% gravel; mildly alkaline (pH7.5); abrupt smooth boundary. This horizon has formed in the upper terrace fill deposit, and it is covered by a gravel pavement.

Bt 3-10 cm. Light brown (7.5YR 6/4) very gravelly/very cobbly sandy clay loam to loam, brown to dark brown (7.5YR 4/4) moist; weak fine to medium subangular blocks; slightly hard, friable, slightly sticky, slightly plastic; common thick clay bridges and colloidal stains on mineral grains; few to common very fine roots; few very fine tubular pores; 30% gravel and 10% cobbles; strongly effervescent; mildly alkaline (pH 7.5); clear smooth boundary.

2Bk 10-41+ cm. Light brown (7.5YR 6/4) extremely gravelly sandy loam, brown to strong brown (7.5YR 4.5/5) moist; weak fine subangular blocks; soft, very friable, slightly sticky, slightly plastic; few thin clay bridges; 40% gravel and 30% cobbles up to 12-15 cm in diameter; few to common very fine and fine roots, mainly in clusters; strongly effervescent; moderately alkaline (pH 8.0-8.5); abrupt smooth boundary. Contains disseminated carbonates in matrix, coatings on all sides of gravel, and some filaments.