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Soil Knowledge Embodied in a Native American Runoff Agroecosystem

J.A. SANDOR, J.B. NORTON, R.R. PAWLUK, J.A. HOMBURG, D.A. MUENCHRATH, C.S. WHITE, S.E. WILLIAMS, C.I. HAVENER, and P.D. STAHL. Iowa State Univ., Zuni Conservation Project, Univ. of New Mexico, Univ. of Wyoming.
J. Sandor address: Agronomy Department, Iowa State University, Ames, IA, 50011, USA

Abstract

Traditional cultures hold valuable knowledge about sustainable management of land resources. A study of a Native American runoff agroecosystem is presented to illustrate this knowledge and its relevance to current work on soil quality, land resource conservation and sustainable agriculture. Runoff agriculture is a venerable agricultural system adapted to arid and semiarid environments, and knowledge of soils and geomorphology is essential to the system. A general function that the several kinds of runoff agriculture share is to increase water for crops by using stormwater flow generated from watersheds. Soils and their management play key roles in this agriculture, both in the watershed that serves as the source of supplemental water and nutrients and in the cultivated fields connected to their source watersheds. A multidisciplinary study of traditional runoff agriculture was conducted in cooperation with the Zuni Indian Tribe in the southwestern USA. The objective of the study was to evaluate nutrient and hydrologic processes, management, productivity, and long-term soil quality in Zuni runoff farmlands, which contain some of the oldest (at least 1000 yr) recognized crop fields in the U.S.A. Maize has been grown in this arid to semiarid land for over 2000 yr. Data about soil knowledge come from two approaches: 1) knowledge inferred from soil, geomorphic, and crop investigations of this agricultural system, and 2) by more direct ethnopedology studies through interactions with contemporary traditional farmers and evaluating historic ethnographic sources. These studies provide information about field placement criteria, modification and management of natural soils and geomorphic processes to enhance soil hydrology and fertility for crops, and soil conservation. Fields are deliberately placed on alluvial fans and other valley margin landforms to intercept runoff and associated sediment and organic debris transported from small watersheds in adjoining mesa uplands. Key hydrologic soil properties are depth and texture as they affect infiltration and retention. Another aspect is the soil's role in contributing nutrients through runoff, from sediment and organic debris entrained from exposed soil mineral and organic horizons. Within fields, soils and slopes are modified to enhance properties for crop water and nutrient uptake, and crop protection. Although ethnopedological investigations indicate relatively few Zuni terms for soils, each term holds rich meaning that extends beyond description of material to insights about the origin of these materials and soil-geomorphic relationships and processes. Most of these soil terms also have functional significance for runoff agriculture. One term that translates as "tree soil" encapsulates the process of sediment and organic matter transport in runoff from forested watersheds, which replenishes soil fertility in fields downslope. Other terms convey knowledge of fluvial and eolian processes involved in runoff and sediment cycling on alluvial fans, and farmers' awareness of the value of sediments for soil tilth and erosion control. Zuni knowledge of soils and geomorphology encompasses a dynamic process that equips farmers with decision-making tools to respond to a complex, dynamic environment.

Key Words: indigenous soil knowledge, ethnopedology, runoff agriculture

Introduction

Among traditional agricultures, runoff agriculture is a venerable system adapted to arid environments, and knowledge of soils and geomorphology is critical to system function and management. Runoff agriculture has been practiced for many centuries by past and present agriculturalists in arid to semiarid regions of Africa, the Near East, central Asia, and the Americas (review in Sandor, in press). It represents an adaptation to arid environments where precipitation alone is commonly insufficient for consistent crop production. The common purpose of runoff agriculture is to increase water for crops by retaining surface storm water flow generated from watersheds. A remarkable feature of runoff agriculture is that it functions by directly tapping into natural watershed and ecosystem processes. Although runoff agricultures share characteristics, they also have a diverse range in geography, utilization of environmental niches, management practices, and crops. Besides the importance of runoff agriculture as a viable technique for coping with aridity and drought, research on ancient fields can provide a long-term perspective on soil change needed to evaluate agricultural sustainability. These soils, and the knowledge accumulated by farmers over many generations carry important lessons, providing examples of successes and failures in agricultural management, land stewardship, and resource conservation.

Soils play a key role in runoff agriculture from watershed to field. In the watershed ecosystem that is the source and pathway for runoff transport to fields, soil properties such as depth, texture, and structure influence water infiltration, hydraulic conductivity, and storage. Another aspect is the soil's role in contributing nutrients through sediment and organic debris entrained in runoff from exposed soil mineral and organic horizons. Soils indirectly influence runoff through watershed vegetation types and distribution, and vice versa. Strategic field placement on certain landscape positions and soils adjoining upland watersheds is needed to intercept and manage incoming runoff. Existing soil and slopes are modified through small dams and other techniques to enhance properties for water use, nutrient uptake, and crop physical stability and protection.

Our project studied American Indian runoff agriculture in the arid to semiarid southwestern USA, specifically traditional Zuni agriculture. Zuni fields are among the oldest identified in the USA. The agriculture is remarkable in that it does not rely on conventional irrigation or fertilization. Two initial questions in this study were: 1) how have farmers been able grow maize in this arid land, and 2) how has soil fertility been maintained for centuries without direct fertilizer application? These observations and questions formed the basis for studies of soils and crops in runoff agricultural fields, watershed geomorphology and ecology, and ethnopedology. Interaction and technological exchange with Zuni farmers was essential to the project (Norton et al., 2001). One research outcome has been to learn about Zuni knowledge of soils and landscapes in relation to traditional agriculture. Documentation and exploration of that knowledge forms the objectives of this paper. Two approaches presented are direct study of soil knowledge through ethnoscience research, and knowledge inferred from studying the soils and agriculture themselves. Many ancient runoff agriculture sites have been abandoned for centuries, so that only indirect studies are possible. Both approaches are possible at Zuni because runoff agriculture has been practiced from the archaeological past through the present.

Materials and Methods

Environmental and Cultural Context

The Zuni Indian Reservation is located in the mesa country of the southeastern Colorado Plateau, at 1838-2347 m elevation. Topography is controlled by mainly flat-lying to gently dipping strata of uplifted, mostly Mesozoic sedimentary rocks with variable resistance to erosion. Mesas are separated by narrow canyons to broad alluvial valleys. Traditional runoff agriculture is practiced mainly on alluvial fans where tributary ephemeral streams emerge from mesa uplands. Vegetation is dominated by pinyon-juniper (*Pinus edulis-Juniperus* spp.) woodlands on mesa uplands and semiarid grasses and shrubs in valleys. Precipitation is extremely variable, averaging 300-400 mm annually. May and June are usually dry, while over half the annual precipitation falls from July to September, often as intense localized thunderstorms. It is upon these monsoonal rains that runoff agriculture depends. Soils grade from Aridisols and Alfisols in the drier western area to Mollisols and Alfisols in higher eastern valleys. Soil temperature regime varies from thermic to mesic and soil moisture regime from aridic to ustic from lower to higher elevations.

The Zuni are among several southwestern American Indian tribes known for runoff agriculture. They have a record of arid land agriculture extending well back into prehistory. Maize radiocarbon dated to about 2200 yr B.P. has been found, and archaeological ceramics indicate that many Zuni runoff fields are at least 1000 years old. Agricultural features dating to 2000-3000 yr B.P. were recently found at Zuni. Historic records provide evidence of agricultural productivity and attest to Zuni agricultural skills (Ferguson and Hart, 1985). Besides the staple maize, a variety of native (e.g., beans, squash) and introduced crops are grown. Zuni also mastered other forms of agriculture, ranging from gridded gardens, to peach production in sand dunes, to floodwater farming of larger watersheds, and irrigation agriculture (Ferguson and Hart, 1985; Kintigh, 1985). Sheep and cattle production became important during the historic period and continues today. As with other Native Americans, Zuni population declined substantially mainly due to introduced European diseases; the population has rebounded to about 9,000 today. The current size of the Reservation is 1656 km^2, though the traditional Zuni land use area was many times greater. With the intent to assimilate Zuni into the irrigated agriculture norm of the western US, early 20th century government programs initiated irrigation projects that shifted agriculture from primarily traditional valley margin fields to floodplains, which tend to have poorer soils (including highly clayey or sodic soils) and are more freeze-prone. A lawsuit by Zuni against the US government for land damages was settled with the Zuni Land Conservation Act of 1990. Although greatly reduced in scope, traditional agriculture is still practiced at Zuni and revitalization efforts have been undertaken by the Zuni Conservation Project and the Zuni Sustainable Agriculture Project.

Methods

Agroecological research concentrated on the eastern part of Zuni to reduce geologic and soil variability; other areas were studied but to a lesser degree. To characterize runoff agricultural soils and test for soil changes, presently cultivated and abandoned agricultural soils documented to have been farmed during the 20th century were compared with soils not farmed during this time. Agricultural land use information was obtained from archaeological records, historical documents, aerial photos (1934-present), inventories of agricultural sites, and interviews with farmers. To compare soils at both detailed and broad scales, a dual sampling method was used. For wide coverage, an "extensive" sampling consisted of 29 sites across the study area, including 9-10 sites each of cultivated, abandoned, and uncultivated soils. For more controlled, detailed comparisons within agricultural sites, an "intensive" soil sampling was undertaken at three adjacent pairs of cultivated/uncultivated sites located near traditional farming villages. Watershed ecosystem, meteorological, and maize production research was also conducted at "intensive" study sites. Altogether, study sites represent an approximately 30% sample of known runoff fields. Detailed field and lab methods used in this multidisciplinary study are given in Norton (1996, 2000), Havener (1999), Homburg (2000); Sandor et al. (2000), and Muenchrath et al. (in review). Knowledge of soils, geomorphology, and agriculture was studied through interviews with a number of Zuni farmers over several years. Ethnoscience methods used to conduct interviews and evaluate data are reported in Pawluk (1995).

Results and Discussion

Zuni Knowledge Inferred from Agroecosystem Studies

1. Watershed Composition and Processes Relative to Agriculture

Zuni runoff agricultural fields, which mostly occur on valley margin landforms such as alluvial fans, are directly connected to naturally vegetated watersheds. Studies were conducted to test the hypothesis that these watersheds are important sources of water and nutrients for agricultural fields downslope. Data were collected to characterize watershed geomorphology, soils, and vegetation, and to monitor runoff processes and composition. Findings are summarized from Norton (1996, 2000). Watersheds of agricultural fields consist of two general components: small valleys (upper alluvial fans) with grass and shrub vegetation, and 2) upland mesas and hillslopes with forest and shrub cover. Runoff pathways to fields are by overland flow and valley channels. Several characteristics impart effective runoff production to these watersheds, including extensive steep hillslopes, bedrock outcrops, patchy vegetation cover, and common argillic horizons. Soil morphology and sediment transport data suggest that while subsurface soil horizons in these watersheds mostly remain stable, surface horizons are more mobile, and episodically contribute organic matter and sediment to fields downslope. Backslopes are especially major sources of sediment and organic matter for runoff transport. Runoff measured by sediment traps ranged up to 8% of precipitation, within the lower range reported in other studies.

Small frequent hillslope runoff events incrementally move sediment and organic matter downslope, where they accumulate on mesa footslopes. Larger, less frequent runoff events episodically flush accumulated materials from uplands, through mesa canyons by ephemeral stream and overland flow, and on to alluvial fans. Storms that generate watershed-wide runoff and flush sediments occur in the time range of a few times per summer to once every several years. Farmers report that major runoff events can cause crop damage but recognize the long-term benefits of soil renewal. With active management of runoff that was practiced traditionally, it is possible that many runoff events could be controlled and were more immediately beneficial in supplying water to crops. The mineral sediment and organic debris deposited in fields varies greatly in amount and composition. Runoff sediments tend to be rich in organic C, N and P compared to soils, supporting the idea that runoff is an important source of nutrient replenishment for agricultural soils. Besides tree litter, cryptobiotic crusts and N-fixing shrubs common in these watersheds are also potential N sources for fields downslope. Several ethnographic and historic reports on runoff agriculture among Southwest Native Americans discuss the importance of flood deposition in maintaining soil fertility, and farmers' knowledge of this function.

2. Agricultural Fields: Landscape, soils, and production

Locational patterns of the ancient runoff fields indicate deliberate placement with respect to geomorphic and soil criteria in response to factors that limit crop production in this environment. These criteria are mostly consistent with contemporary traditional farmers judgments about field location. Subtle variation in landscape and soil setting patterns create a diversity of niches among and within fields. Most runoff fields in the central to northern Southwest occur at relatively high elevations, higher than most modern conventional agricultural fields. Eastern Zuni fields range from about 2000-2150m (some to 2250m), relative to 2000-2750m elevations in the immediate region. Field location with respect to elevation is likely an optimization between precipitation and temperature, which are inversely related variables with elevation. The maize-based agriculture is practiced at relatively high elevations to maximize precipitation, but low enough to permit a sufficient frost-free period. Other factors may also come into play, e.g., elevation increase correlates with increased proportion of precipitation that becomes runoff.

Traditional fields are mainly located at valley margins, especially alluvial fans, but also footslopes, ephemeral stream terraces, and small drainageways near uplands. Slopes used for runoff agriculture are gentle, mainly ranging from 1-7 %. The prevalence of valley margin settings for traditional agriculture is consistent from prehistoric time through the present. However, government soil surveys generally do not recognize valley margins as arable, reflecting modern emphasis on irrigated agriculture on valley floors. Nevertheless, there are good reasons for farming valley margins as a diversification strategy for managing risk and maintaining crop production stability: 1) valley margin fields could remain productive during major valley floor flooding; 2) valley floors are more freeze-prone than valley sides due to cold air drainage; 3) salt-affected and sodic soils occur on valley floors. Also, many floodplain soils are clayey, and for this reason are rated poor for maize by Zuni farmers; and 4) soil fertility is more readily maintained on alluvial fans and footslopes by more frequent deposition of runoff sediments and organic matter from adjacent uplands.

Runoff fields connect to upland watersheds with relatively small drainage areas of mostly 5-200 ha. One benefit of smaller watersheds is less risk of high-magnitude runoff that can damage crops. Another is the inverse relationship between watershed size and runoff typical in arid regions; i.e., the smaller the watershed, the higher frequency of runoff and greater runoff per unit area. The fields themselves also tend to be small, mostly 1-15 ha, and often only parts of fields are cultivated each year. Ratios of field to drainage area average about 1:25, though highly variable. Other runoff field and modeling studies report similar averages, suggesting that the ratio is important in these systems worldwide in terms of runoff amounts generated to meet crop needs (e.g., Hack, 1942).

Soils in fields also have natural properties favorable for runoff agriculture, for example argillic horizons that help retain water within crop rooting zones. More than half the field soils have fairly shallow argillic horizons (within about 30 cm of surface), and other soils have subsurface clay increases in the form of non-argillic Bt horizons, buried argillic horizons, or finer textured strata (Table 1; Homburg, 2000). Previous work indicates that argillic horizons and other slowly permeable layers (e.g., duripans, petrocalcic horizons, bedrock) are associated with many Southwest prehistoric and contemporary runoff fields. Surface soil retention of runoff is greatest where sandy to loamy A horizons are underlain by strongly developed argillic horizons or analogous layers. Even in soils with less developed horizons, water retention within a deeper rooting zone is enhanced. Plant available moisture in weak-moderate argillic horizons was higher than A horizons (57% relative, 7% absolute) at two Zuni runoff fields tested. Besides increased water infiltration rates, sandy surfaces also act as a mulch to reduce evaporation.

Ethnoscience Investigations of Zuni Soil, Geomorphic, and Agricultural Knowledge

1. Knowledge of Soils and Geomorphology

Direct investigation of Zuni soil knowledge in an agricultural context indicates about 12 major soil terms (Table 2; Pawluk, 1995). Most terms initially distinguish soils on the basis of texture, color, and consistence. Textural terms include sand, clay, and gravel, and differentiate coarse and fine sand. Examples of color use are to distinguish clays, darkness of organic matter-rich soil, and whiteness of calcareous or saline soils. Consistence is commonly described, such as hard clays, and often linked to water movement (e.g., “water won’t go down”) and retention (e.g., “like a sponge but dries quickly” or “stays wet longer”). Property change with depth is sometimes stated (e.g., “clay loose on top, hard below”). Soil term descriptions often reflect primary concern with water in this arid environment. Sandy soils associated with runoff sediments are described as “better for catching water,” and transport of organic matter or sediment in runoff is indicated by phrases such as “rich soil from far away-forest” and “sand that comes with the water.” Agricultural soil evaluation is also provided for most terms, ranging from the “the best one” to “can’t grow anything.” Spatial information, both on geographic location and geomorphic setting, is also given for certain soils, illustrating traditional peoples’ knowledge of local environments. Regarding the preference for valley margins versus floodplains for maize agriculture, recognition of favorable alluvial deposition and better soils on alluvial fans than on floodplains is evident from interviews (Table 2; Pawluk, 1995; Norton, 2000).

The relatively low number of Zuni soil classes is common among indigenous soil taxonomies, belying the rich knowledge they hold. During interviews and in working with farmers over several years, it became clear that these terms contain meaning beyond describing discrete material. They incorporate knowledge of soil material and agronomic properties, coupled with awareness of geomorphic and ecological processes that create and distribute earth materials. Some terms are related to processes involved in sediment transport and soil properties relating to tilth and fertility. Fluvial sediment transport is emphasized, as are eolian processes. This especially includes knowledge of watershed processes and their role in runoff agriculture. In this sense the soil terms, although few, are windows into in-depth understanding of geomorphic processes connecting erosion and sedimentation from watershed to field.

Knowledge of the watershed’s role in contributing sediments and organic matter to replenish agricultural soil fertility is encapsulated in the Zuni term *danaya so:we*, which translates into forest sand or soil, or simply “tree soil.” Tree soil describes the plant litter and topsoil (O and upper A horizons) transported by runoff from uplands to fields. In our studies, organic-rich materials from runoff events were observed in clusters and various stages of decomposition en route to and within agricultural fields. Other Southwest Native Americans practicing runoff agriculture have parallel terms to tree soil, including terms for different components and states of organic runoff debris. The significance of sediment transport and deposition in this agroecosystem is also evident in two other Zuni terms: *sotanna* and *heyalo:we*. Both terms refer to runoff sediments, the first referring to coarser sediment (literally “big sand”) associated with channel deposits and the latter to finer sandy or silty overbank deposits. Both were described in terms of material, origin, and depositional process, and reworking/cycling of fluvial deposits by wind were included. Farmers related that the fresh sediments and their location on alluvial fans are highly valued for enhancing water retention and fertility (Pawluk, 1995; Norton, 2000).

Discussions with farmers also revealed basic differences in soil concepts between Zuni and researchers. For example, concerning organic matter effects on soil, a farmer stated “... so when you add all that forest soil and manure you change the clay into sand...?” To Zunis, “sand” refers not only to a coarse texture, but also to “soil”, and can include other particle-sizes such as silt. Sand also connotes soil tilth and productivity, the ideal soil for maize and other crops. Conceptual differences between cultures make it difficult to accurately evaluate local soil knowledge and compare knowledge systems (Norton et al., 2001).

2. Agricultural Management through Landscape and Soil Modification

Knowledge is also expressed through traditional management practices that modify natural landscapes and soils to enhance conditions for runoff agriculture. Crop management adapted to arid high elevation environments, e.g., deep planting of special maize cultivars in widely spaced clusters, are covered elsewhere (Muenchrath et al., in review; Sandor et al., 2000). Emphasized here are some soil practices relating to runoff management. Small permeable dams in traditional Zuni agriculture served to intercept, partly retain, and distribute runoff and sediments. They functioned as agricultural terraces, decreasing slope angle and length, thereby encouraging runoff retention and sedimentation, and replenishing soils. The ephemeral dams constructed of brush and stones could be readily reconfigured, enabling farmers to respond quickly to dynamic conditions of runoff events. Traditionally farmers prepared new fields by building dams a year or more before cropping, allowing time for soil incorporation and decomposition of fresh sediment and organic matter inputs. This illustrates the emphasis on runoff as a soil resource as well as a water resource. Although dams are not used much today, runoff input is still important and partly managed by tillage.

Through runoff sediment management, soil properties in agricultural fields change. This study investigated soil morphological, physical, chemical, and biological properties and changes, though it is difficult to clearly distinguish runoff management effects from those of natural sedimentation, soil variability, and cultivation, especially given the complex long-term land use imprints at Zuni. Property changes inferred to most directly reflect runoff sediment management are upper horizon thickness, stratification/structure, particle-size, particle-size/organic matter relationships, carbonates, and pH. A distinctive property of runoff agricultural soils is increased surface horizon thickness (Table 1). Detailed grid soil mapping at two sites indicate that runoff field locations correspond closely with maximum A horizon thickness (Homburg, 2000). Depth to B horizons typically ranges from about 5-15 cm outside fields to 15-40 cm inside fields. Thickening is primarily attributed to field placement and enhanced sedimentation, though plowing may also be a factor. Fine sand and silt laminations were observed in surface horizons at some runoff fields. Such stratification results from runoff sediment deposition, and while this occurs naturally on alluvial fans, it is intensified in runoff fields. Textural changes observed in some soils partly reflect runoff sediment input. Silt and organic matter are positively correlated to a higher degree in runoff agricultural soils (Table 1; Norton, 1996; Homburg, 2000). In most soils where texture/organic matter relationships have been measured, clay-organic matter association is more typical. The silt/organic matter relationship found here probably reflects co-transport of silt and organic debris in runoff. Organic coatings on mineral grains and aggregates observed in micromorphological studies of agricultural soils are also attributed to runoff sedimentation. Overall, comparisons of properties (e.g., organic matter, microbial biomass) among cultivated and uncultivated soils suggest that long-term agriculture has altered but not degraded soils (Table 1; Havener, 1999; Homburg, 2000; Norton et al., 2001).

Conclusions

Traditional runoff agriculture represents a viable adaptation to arid and semiarid environments that relies on renewable sources of water and nutrients generated by natural watershed and ecosystem processes rather than on energy-intensive inputs of irrigation water and artificial fertilizers. A functioning runoff agriculture reflects in-depth knowledge of geomorphology, soils, and ecosystems. It is important that the knowledge and experience held in traditional systems be conserved, for the viability of the cultures, and to support the development of sustainable agriculture today.

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Table 1. Soils in Zuni agroecology study.

Agricultural land use	Mollisol	Alfisol	Inceptisol	Entisol	A horizon thickness (cm)	Org. C (g/kg)	Silt/Org. C correlation (r)
Cultivated	2	5	3	2	19.0 (5.6)a	12.2 (4.9)	0.88**
Abandoned	0	6	4	0	12.8 (2.5)b	13.2 (5.5)	0.42
Uncultivated	1	7	1	2	8.9 (4.2)c	13.1 (6.6)	0.26

Notes (For further information, see Homburg, 2000):

1. Soil classification data are numbers of cultivated, formerly cultivated (abandoned), and uncultivated (during 20th century and possibly before) soils at all eastern Zuni study sites. All Mollisols are Argiustolls, Alfisols are mostly Haplustalfs (two Paleustalfs), Inceptisols are Haplustepts with non-argillic Bt and/or buried Bt horizons, Entisols are Ustipsamments or Ustifluvents with buried Bt horizons. All soils in aridic subgroups.

2. For A horizon thickness and organic C data, means (standard deviations in parentheses) are shown for 29 extensive sample sites. Organic C and silt/organic C correlation for 0-15 cm depth at 29 extensive sample sites. A horizon thickness values followed by different letters are significantly different at the 0.05 probability level; the silt/organic C correlation coefficient followed by ** is significant at the 0.01 probability level.

Table 2. Examples of Zuni soil terms.

Ma:kose: Translation: white highly calcareous or saline soil Farmer comments: “white like salt on top” Researcher comments: In Zuni dictionary, makose means salt or salty. Includes calcareous and saline soils common in large valley basins
Lupopo Translation: gray clayey/dusty soil Farmer comments: “like dust”; poor for plant growth; requires much water; can form crust. Researcher comments: In Zuni dictionary, “lu” means ash, “lujo” means cloud of dust, “popo” means lump. Associated with irrigated land in valley basins.
Hepeka Translation: clay (can be red or gray) Farmer comments: “the clay area,” “…hard, really sticky…tight…” slow water movement.
Heyalo:we Translation: alluvial (primarily) or eolian-derived fine sand and silt; can be loamy. Farmer comments: “good soil,” “…sand that come with the water, soaks in the water and holds it,” “carried in the water over the bank…,” “finer sand,” “from up there [uplands]…when it rains, bring the soil down” “…windy soil…”
Sotanna Translation: sand (coarser than Heyalo:we) from runoff and streams, some from wind Farmer Comments: “real sand” “out of the riverbed…coarse,” “good rich soil” “sandy soil …easier and fertile to farm”; “better for catching water.” “come from the topsoil from above…washed down here.”
Danaya sowe Translation: forest floor material (O and upper A horizons), transported in runoff to fields. Farmer comments: “tree soil,” “forest sand,” “good rich soil,” “the best one,” “might have fertilizer” “like muje:we” (manure). “Rich soil from far away… forest,” dark color. Researcher comments: In Zuni dictionary, ta-na-ya means a surface collectivity of forest. Associated terms: “ts’I’bewi:we” (organic debris) and “ummo:we” (foam in runoff).

Note: Material in Table 2 is based on interviews with Zuni farmers. For more information, see Pawluk (1995).