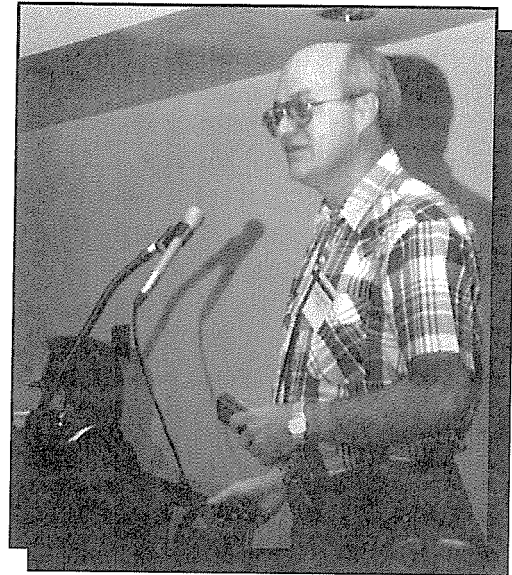


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COBBLE MULCH: AN ANASAZI WATER-CONSERVATION GARDENING TECHNIQUE

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ABSTRACT

Prehistoric Native American agriculturalists practiced successful dryland farming on large areas of arid and semiarid lands in Central and Northern New Mexico. Their dryland farming techniques involved the use of gravel and/or cobbles applied as a mulch on the soil surface. Apparently, the primary function of these mulches was to reduce direct evaporation,

which left more moisture available for crop growth. If these techniques could be successfully applied to current gardening and agricultural practices, water requirements could be significantly reduced. Also, a detailed understanding of their techniques may allow the revival of dryland farming practices in the water-limited Southwest.

Experimental garden plots (four cobble-mulched and four unmulched, or bare) were established at the

Plant Materials Center in Los Lunas, New Mexico. Soil temperature and moisture were monitored during the first year when all plots received only direct precipitation and weeds were removed to minimize soil moisture loss from transpiration. Three days after plot construction, soil moisture was not significantly different between plots; however, soil moisture was significantly higher on the cobble-mulch plots relative to the bare plots at every subsequent sampling. Daily maximum and minimum soil temperatures were moderated throughout the year in the cobble-mulched plots relative to the bare plots.

In the second year, all plots were planted with seedlings of native Hopi corn (ten plants), two Hopi squash plants, two Hopi bean plants, and one each of the following plants: New Mexico Olive, Three-Leaf Sumac, Fernbush, Mormon Tea, Rabbitbrush, Apache Plume, Indian Ricegrass, Giant Sacaton, Purple Prairieclover, Purple Coneflower, and Blackfoot Daisy. Each plant was watered equally during periods of limited rain to promote survival. At the time of harvest in early September, all the plants had higher average weight on the cobble plots than on the bare plots, with many of these differences significant ($P < 0.05$). Also, the total plant harvest from the cobble plots was nearly 4 times greater than from the bare plots (746 to 193 grams, respectively) and the plants had higher water content on the cobble plots than on the bare plots (1.87 ml water per gram plant material on the cobble compared to 1.05 on the bare). Thus, cobble mulch promoted plant growth by reducing direct evaporative loss of soil moisture and creating a more moderate soil environment.

INTRODUCTION

Water is the most important single factor controlling all facets of life in arid and semiarid regions. The availability and quality of water will influence growth within these regions, if not already, in the foreseeable future. Prehistoric Native American agriculturalists successfully farmed large areas of arid and semiarid lands. Their farming techniques included supplementation of water through irrigation, but they also used other dryland farming practices that relied solely upon direct rainfall. The success of some dryland practices involved the use of gravels and/or cobbles applied as a mulch on the soil surface. Apparently,

the primary function of these mulches was to reduce direct evaporation, which left more moisture available for crop growth. If these techniques could be successfully applied to current landscaping and gardening practices, this could substantially reduce the amount of water consumed by these land uses. Also, a detailed understanding of the Anasazi's successful techniques, and when or if they failed, may allow the revival of dryland farming practices in the water-limited Southwest.

As with all study of past cultures without a written history, much of what we "know" about cobble mulch gardens is derived from interpreting the "record" preserved in and around the gardens. The current basis of our knowledge is founded upon the records associated with excavated gardens, which are limited in number. Studies of cobble (or gravel) mulch gardens occurred in 1985 when soils were collected from sites located along the highway between Española and Abiquiu (NMSHD Project No. F-052-1(15), or the Medanales North Project, Rio Arriba County, New Mexico) and analyzed for the Museum of New Mexico (Anschuetz et al. 1985). Later studies analyzed additional cobble mulch gardens along US-285 north of the Rio Chama. Additional work near Ojo Caliente excavated trenches across the border of three prehistoric cobble mulch sites (C.S. White, S.R. Loftin, and R. Aguilar, unpublished report). Cobble mulch gardens in the Galisteo Basin have been studied by D. Lightfoot (1994). At this time, we are aware of no direct experimental evidence surrounding the functioning of these gardens.

Research on the three cobble mulch gardens near Ojo Caliente yielded initial hypotheses concerning the soils upon which gardens were developed. It appears that Native Americans placed cobble mulch gardens in areas with coarse or loamy-sand surface horizons (Figure 1). These sandy horizons extend from about 20 cm in depth to a maximum of 50 cm deep. Beneath this upper soil horizon, other horizons acted to interrupt the downward movement of soil moisture. Such horizons included either a bed of finer textured alluvium, or unsorted sands, gravels and cobbles, an argillic (clay-rich) horizon, or a caliche deposition. Native Americans aligned larger cobbles to form "cells" or compartments within the larger garden plots, and then filled the cells with a mixture of gravels and cobbles. Native Americans concentrated

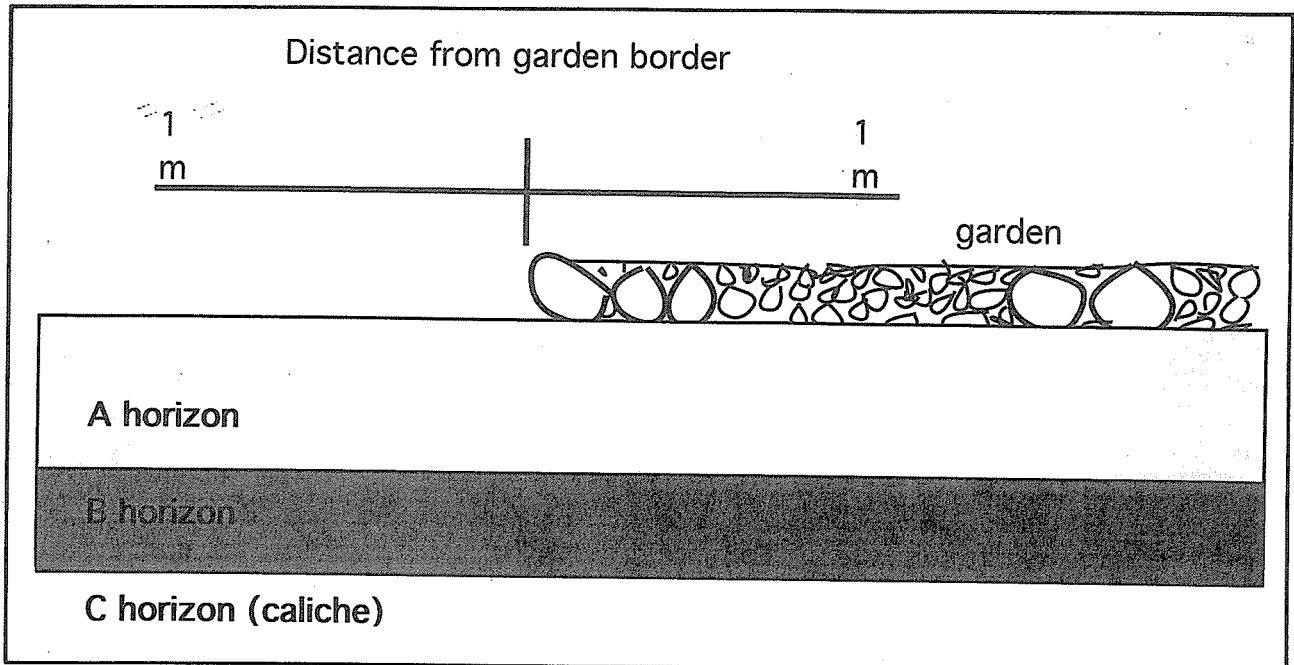


Figure 1. Diagram of general soil characteristics of cobble mulch gardens that were excavated in the lower Rio Chama basin, NM. Surface cobbles are concentrated in the gardens, which overlie a sandy-loam A horizon, an argillic or more clay-rich B horizon, and a calcic C horizon (often with visible caliche).

locally occurring surface cobbles into smaller areas or obtained cobbles and gravels from nearby “borrow pits” to place on the gardens. The greater concentration of cobbles within these gardens lends a patchwork quilt appearance to these areas with patches of gardens containing native grass species surrounded by shrub-dominated sandy areas.

The hypothesized primary function of the cobble is to reduce direct evaporative loss of soil moisture. In research focused on increasing recharge to groundwater, Kemper et al. (1994) determined that gravel mulches 5 cm thick resulted in accumulation of 80 to 85% of the annual precipitation in the soil beneath the mulch. This research, which was conducted near Fort Collins, Colorado, attributed less accumulation of moisture beneath thinner mulches and unmulched soils to evaporative loss.

Additional functions of prehistoric cobble mulches are to control weeds and raise soil temperatures, as hypothesized by Lightfoot (1994). In certain areas, like the Galisteo Basin studied by Lightfoot (1994), increased soil temperatures could be advantageous to promote germination and growth of crops and to extend the growing season. A current landscape practice in arid regions is to lay a sheet of plastic on the soil surface, and then apply cobbles to

hold the plastic and control weeds. Public concern has been expressed about possible adverse effects of the cobbles on above-ground plant growth because of the additional energy (heat) reflected from the rock surfaces. Additional reflectance could cause greater transpiration water-loss, which could override the benefit of additional soil water. Thus, the beneficial or detrimental effects of cobbles on plant growth is unclear.

Cobble gardens could have affected areas much larger than the immediate gardens. Periman (1996) investigated the possible role of cobble gardens on the greater landscape. The cobble protects the soil surface from erosive forces of rainsplash, which could reduce erosion and, together with promoting infiltration, reduce total runoff. Thus, questions about the function and net effect of cobbles on plant growth, and soil moisture in general must be answered before this practice can be implemented.

This study addresses three questions about the role of the cobble on plant growth. First, when water inputs (precipitation or irrigation) are equal, do cobble plots retain more soil moisture than bare plots? Greater soil moisture would indicate reduced evaporation since the plots would have an intercepting soil horizon that would minimize deep

percolation. Second, what effect do cobbles have on soil temperatures? If cobbles increase reflection, the soil temperatures may be lower on cobble plots relative to bare plots. However, if cobbles absorb more energy, the heat storage may be greater, which may prolong the growing season, but increase root respiration. Third, given the same, yet limiting, amount of water inputs, do plants grow better on cobble plots relative to bare plots? After all, plants are the ultimate integrators of the combined effects of a cobble-mulch on plant growth.

METHODS

Experimental cobble-mulch gardens were established at the Plant Materials Center in Los Lunas, New Mexico. The experiment contained four cobble-mulched gardens and four bare, control plots. The garden plots were constructed by first mechanically removing the existing vegetation and approximate leveling of the site. Two trenches, approximately 4 m wide by 24 m long, were excavated to a depth of about 30 cm. A layer of a clay loam soil was laid in the bottom of the trench and compacted, resulting in about a 3-cm thick layer. The purpose of this layer was to impede the downward movement of water, which mimics the function of similar features found in excavated cobble gardens. The trenches were filled with original topsoil to a depth of about 30 cm. Alternating cobbled and bare gardens, 2 each overlying each trench, were constructed. Each garden measured 3 by 4 m with a 1 m walkway between and at the end of each row of gardens. At the center of each plot, temperature probes with data loggers (HOBO™, Onset Instruments, Pocasset, MA) were set at 5 cm depth beneath the original soil surface. Construction of the plots was finished in February 1995.

During the first year following their establishment, all plots received only direct precipitation. All plots were periodically weeded to minimize transpirational loss of soil moisture. Soil temperature was downloaded from the data loggers periodically during the course of the study. Climatic data was provided from the weather station at the Plant Materials Center, which is less than a quarter of a mile from the experimental plots. Soil samples were taken with a 2-cm diameter corer to a depth of 15 cm to avoid damaging the compacted clay loam. At each sampling,

four cores were taken from each plot to obtain representative coverage, composited, and analyzed for moisture content. For soil texture and other initial soil characterizations, four additional cores were taken from each plot at the beginning of the experiment and composited. Soil samples were transported to the laboratory, where they were sieved and the portion passing the 2-mm sieve was retained for analyses. Field water content was determined by loss-upon-drying at 105° C for 24 hours. Water holding capacity (WHC) was determined by first saturating a portion of each sample contained in a funnel with water, then allowing the sample to drain by gravity for 30 minutes (White and McDonnell 1988). The amount of water retained by the sample was determined gravimetrically by drying the drained sample at 105° C for 24 hours. Total nitrogen and phosphorus was determined by Kjeldahl digestion (Schuman et al. 1973), followed by analyses on a Technicon Auto-analyzer (White 1986). Soil texture was measured by the hydrometer method (Day 1965).

Nitrogen mineralization potential (N Min, Table 1) was determined by first determining water-holding capacity. Then, a portion of each sample was adjusted to 50% of determined WHC and up to 11 subsamples were apportioned into plastic cups. Each cup contained approximately 30 g dry-weight mineral soil. One subsample of each sample was immediately extracted with 100 ml 2 N KCl for NH_4^+ -N and NO_3^- -N analyses. The remainder of the cups were covered with plastic wrap, sealed with a rubber band, and incubated in the dark at 20°C. The plastic wrap minimized water loss during incubation, yet exchange of CO_2 and O_2 was sufficient to keep the subsamples aerobic during incubation. Moisture content was monitored by mass loss and replenished as needed. At weekly intervals, one subsample of each sample was removed and extracted with KCl for 18-24 hours. The clarified KCl was filtered through a Kimwipe® and analyzed for NH_4^+ -N and NO_3^- -N+ NO_2^- -N on a Technicon AutoAnalyzer (Technicon, Terrytown, NY) as described in White (1986).

After more than a year's data on soil moisture and temperature on plots without plants, all gardens (cobbled and bare) were planted with a variety of crop plants, ornamental perennials, and shrubs (Figure 2). The same planting pattern was used for the four cobbled and four bare garden plots. The plants included

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Table 1. Initial soil characterizations of cobble and bare plots at the Plant Materials Center.

Characteristics	Units	Cobble	Std. Error	Bare	Std. Error
50% WHC	g water/g soil	0.158	0.003	0.16	0.004
Sand	%	89.5	0.045	89.5	1.323
Silt	%	1.25	0.629	1.25	0.946
Clay	%	9.25	1.109	9.25	0.854
Total N	ug/g	186.5	33.7	147.5	13.7
Total P	ug/g	136.5	14.9	108.5	5.3
N Min	ug/g	20.7	3.2	22.1	4.1

Note: No characteristics were significantly different ($P > 0.05$)

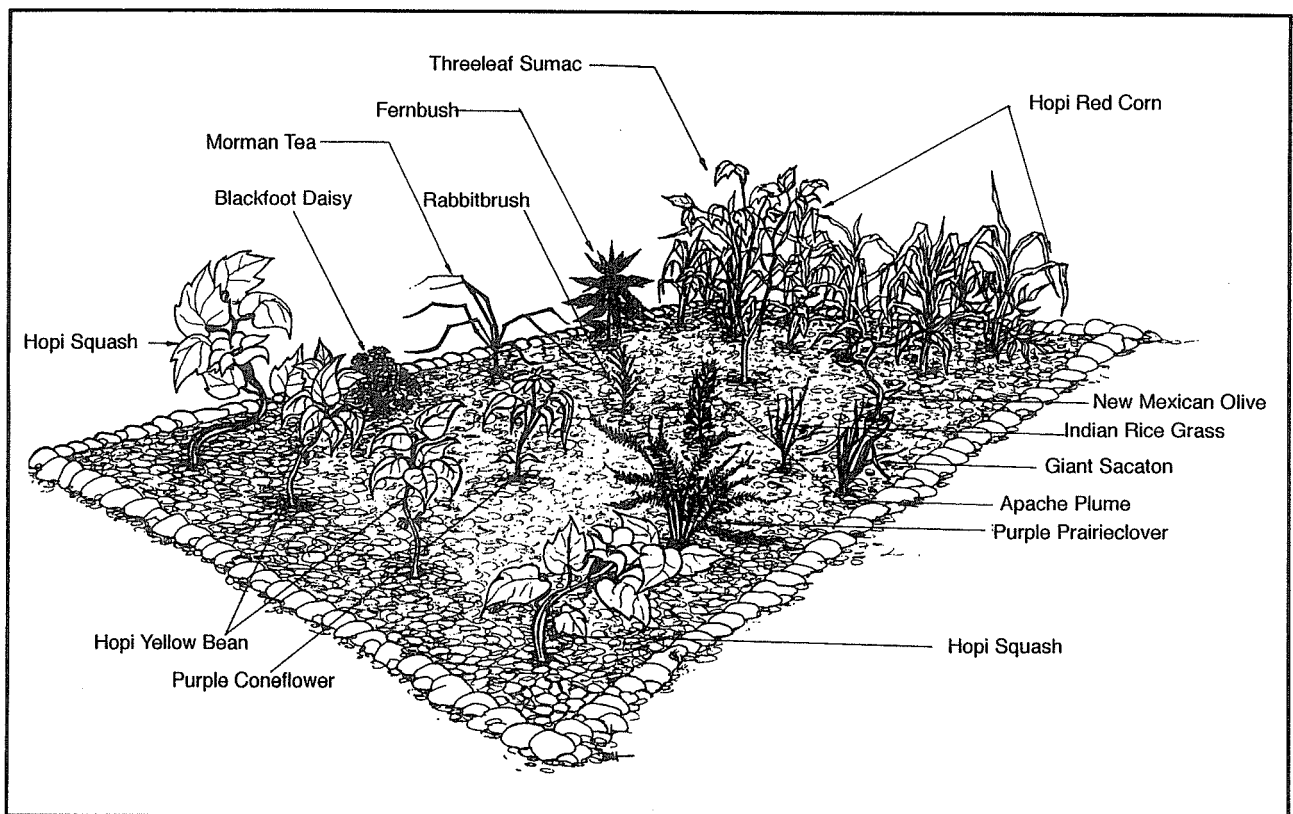


Figure 2. Drawing of experimental cobble garden indicating the placement and types of plants.

two rows of native Hopi corn (ten plants), two Hopi squash plants, two Hopi bean plants, and one each of the following potential landscape plants: New Mexico Olive, Three-Leaf Sumac, Fernbush, Mormon Tea, Rabbitbrush, Apache Plume, Indian Ricegrass, Giant Sacaton, Purple Prairieclover, Purple Coneflower, and Blackfoot Daisy (common and scientific names are given in Table 2). These plants and vegetables exhibit a wide range of watering requirements from low to high water use (City of Albuquerque).

All plants were grown from seed at the Plant Materials Center and transplanted to the gardens. The seedlings were planted on June 26, 1996, except Giant Sacaton and Indian Ricegrass, which were planted a few days later. Each plant was watered equally from a watering can at the time of planting. Throughout the summer, each plant was watered equally, regardless of its water-use or whether it was in a cobbled or bare plot. Within the first two weeks, plants that died or fared poorly were replaced. After

Table 2. Names of plants, water requirements, and total harvest from cobble mulch experiment.

Plant	Scientific Name†††	Water Req.††	Average (mean) dry weight of 4 plots			
			Cobble		Bare	
			grams*	S.E.†	grams	S.E.
Fernbush	Chamaebatiaria millefolium	Low/Med	2.84**	0.54	1.24	0.18
Rabbitbrush	Ericameria nauseosa	Low	4.2*	0.54	1.8	0.6
Purple Coneflower	Echinacea purpurea	High	3.9	0.9	2.4	0.94
Mormon Tea	Ephedra viridis	Low	1.19*	0.08	0.53	0.18
Apache Plume	Fallugia paradoxa	Low	3.64	1.03	1.11	0.66
New Mexico Olive	Forestiera neomexicana	Med.	5.98*	0.89	3.38	0.44
Blackfoot Daisy	Melampodium leucanthum	Low	16.5***	0.3	4.12	1.53
Purple Prairieclover	Dalea purpurea	Low/Med.	4.67	2.12	0.37	0.18
Indian Rice Grass	Oryzopsis hymenoides	Low	1.07***	0.12	0.035	0.018
Three-leaf Sumac	Rhus trilobata	Low/Med.	17.7***	0.89	10.6	0.72
Giant Sacaton	Sporobolus wrightii	Med.	34.6**	8.34	0.7	0.54
Hopi corn (stalk)		Low	34.8*	8.0	13.2	0.94
Hopi corn (cob)		Low	14.4*	4.0	1	0.27
Hopi yellow bean (plant)		Low	9.8*	2.37	1	0.45
Hopi squash (plant)		Low	60	23.7	11.5	6.8
Hopi squash (fruit)		Low	20.3	12.4	1.2	0.69
Total dry harvest			746**	145.0	193	20
Total water (ml)			2710**	439.0	696	148
Water content per gram plant			1.87**	0.015	1.05	0.078

†S.E. = standard error of mean

††Water requirements based upon "Albuquerque Plant List", City of Albuquerque.

†††Scientific name based on Roalson and Allred (1995).

Means with asterisks are significantly greater than bare plots (= P < 0.05; ** = P < 0.01; *** = P < 0.001)

the first two weeks, plants that died were left in place, but still were watered. If rain did not occur and the plants showed signs of water-stress, a maximum of two cups water per week were given to all plants (or the equivalent of 1/8" of rain over the entire plot per week). Thus, all plots received the same amount of water at all times, regardless of the number of live plants.

All plots were weeded to retain all soil water for the growth of the experimental plants only. Additionally, blood meal was spread around the perimeter of each plot to deter animals from eating the garden plants. Twice in early August, an insecticidal soap solution was sprayed on the squash plants to reduce aphid attack. No fertilizer or other pesticides were used in this experiment.

All plants, live or dead, were harvested on September 11, 1996. Although some plants may have continued growth, many were changing colors (senescing) by this time. The above-ground portions

of all plants were removed at the ground or about 2" above the ground for the woody perennial trees and shrubs. The plants were taken to the laboratory on the University of New Mexico campus and weighed (wet weight). After cutting into about 4" sections to allow more rapid drying, the plants were placed in a forced-air oven set at 60°C until they reached a stable weight (about 3-4 days). All plants were reweighed, thus providing both wet and dry weight for each plant, or type of plant when more than one planting occurred in the same plot.

RESULTS

Year 1

The cobble and bare plots were not significantly different for any soil characteristics at the beginning of the experiment (Table 1). Three days after completion of the cobble plots, soil moisture was not significantly different between plots (Figure 3). How-

ever, throughout the remainder of the experiment, soil moisture was significantly higher (range from $P < 0.05$ to $P < 0.001$) on the cobble mulch plots relative to the bare plots. Except for the day after completion of the cobble mulch plots, the cobbled plots were more moderate in temperature than the bare plots, which had higher daily maximum and lower daily minimum temperatures (figures 4a, b, c, d, and e). This "buffering" of soil temperatures occurred throughout the year, but was particularly noticeable in the summer months. During the hottest period, the bare plots had daily maximum temperatures in excess of 46°C (the maximum for the data loggers) and minimum temperatures below 20°C (Figure 4c). In comparison, the cobble plots averaged maximum and minimum temperatures of 38° and 25°C , respectively. There did not appear to be earlier warming or later cooling of the cobble plots relative to bare plots.

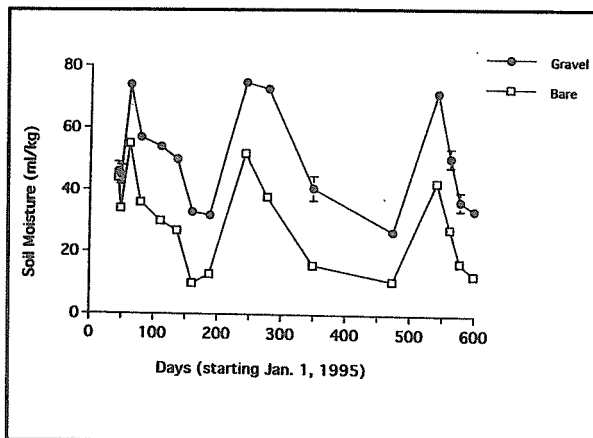


Figure 3. Changes in soil moisture within cobbled and bare experimental garden plots, beginning on February 17, 1995, and ending on August 22, 1996. When visible, bars represent standard error of the mean (four replicate plots).

Year 2

All plants were given about 1,000 ml of water when planted. During the five days following planting, the area received about 1.5" of rain (Figure 5). Over the duration of the growth experiment, pan evaporation exceeded precipitation by about 16", which indicates that potential evaporation exceeded water inputs. Supplemental water was given in equal amounts to all plants (alive and dead) over the remainder of the study, except during the period in late August when about 1" of precipitation occurred.

With only a few exceptions, all plants on the cobble plots survived and increased their growth during the summer. After the first two weeks, the only plants to die on the cobble plots were two bean plants and a single squash plant. In contrast, many of the plants on the bare plots died or showed little further growth after surviving the first two weeks.

Without exception, every plant had equal or higher average weight on the cobble plots than on the bare plots (Table 2). Also, the total plant harvest from the cobble plots was nearly 4 times greater than from the bare plots (746 to 193 grams, respectively). The most dramatic difference between plots occurred in the Giant Sacaton, which grew to 3' or more in the cobble plots and only 8-12" in the bare plots. The average dry weight of the Giant Sacaton was nearly 50 times greater in the cobble than in the bare plots (34.8 grams to 0.7 grams average weight). Other plants showed similar but smaller differences. Among the landscaping plants, the Blackfoot Daisy did especially well in the cobble plots, and in all plots in general. In contrast, Indian Ricegrass did not grow much after planting in the gardens, but still had more growth in the cobble plots. Indian Ricegrass grows best during cool seasons, so it was not expected to grow well during this study period.

In addition to every plant showing better growth, on average, the plants had a higher water content on the cobble plots than on the bare plots; 1.87 ml water per gram plant material on the cobble compared to 1.05 on the bare. The total amount of water in the plants on the cobble plots was nearly 4 times greater than in the plants on the bare plots (2710 to 696 ml, respectively). Thus, regardless of how the results are compared, the results support the beneficial effect of cobbles on plant growth and plant water content.

DISCUSSION

Since the plots were similar in all measured soil characteristics and were above the same compacted material, evaporation and minimal transpiration were the only sources of soil moisture loss. Transpiration, if any, was probably higher on the cobble plots (although not directly measured), given that weeds appeared to grow better on those plots (personal observation). Thus, the soil moisture results are clear

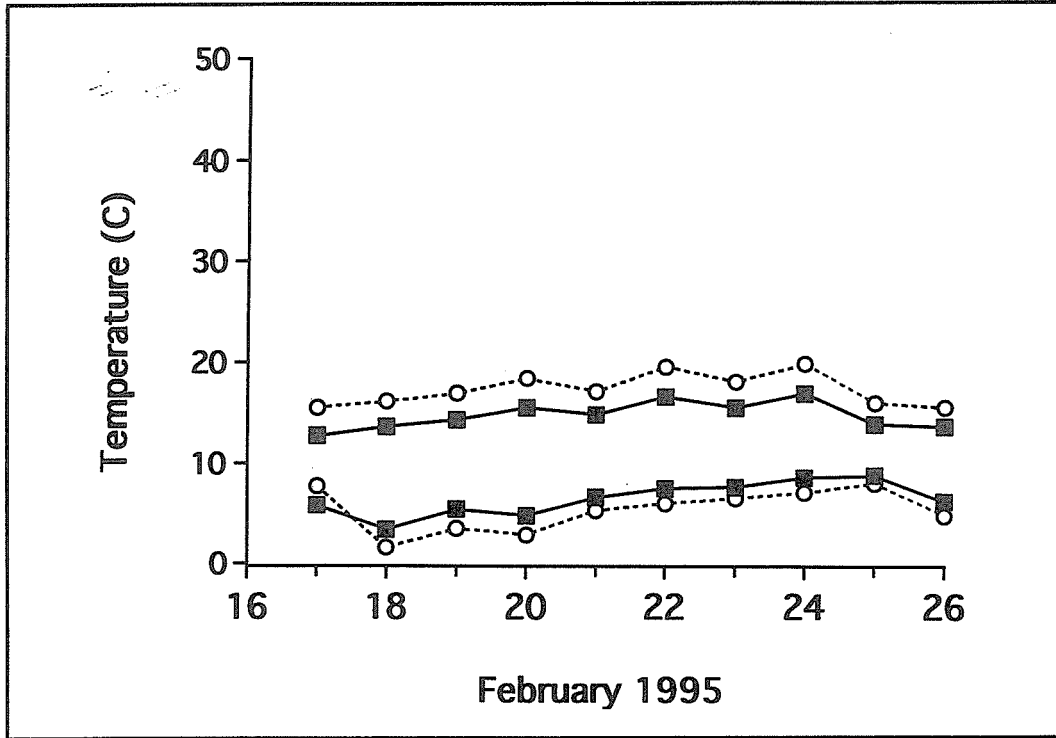


Figure 4a. Average daily maximum and minimum temperatures on cobbled (filled squares) and bare (circles) experimental plots beginning after plot establishment.

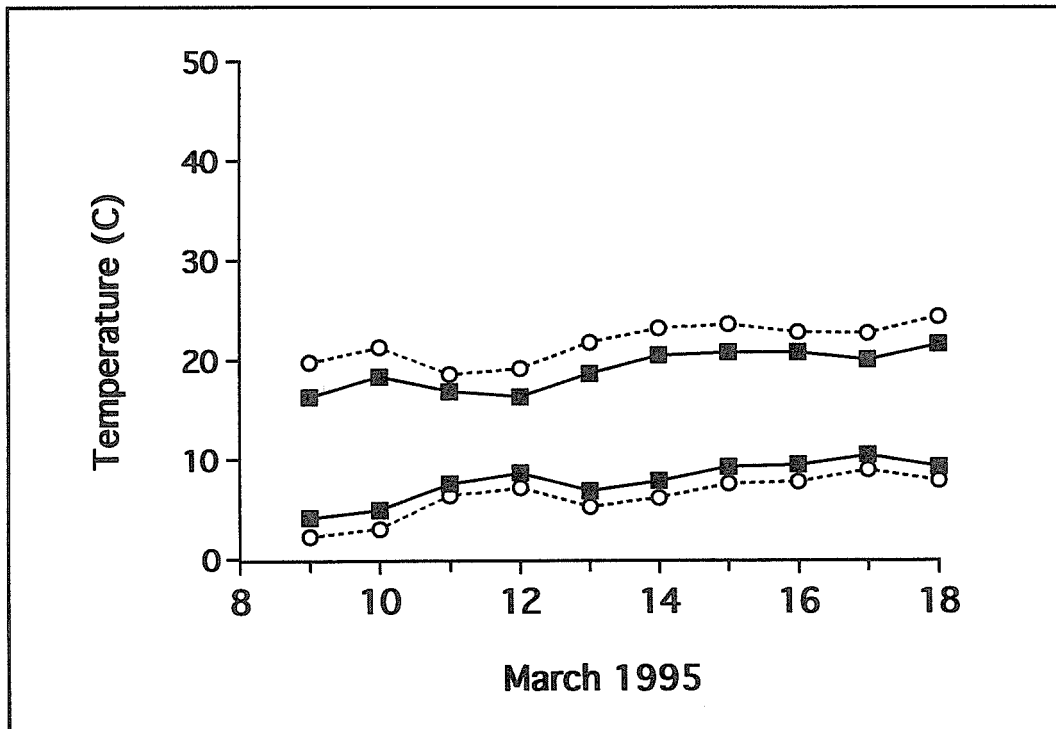


Figure 4b. Average daily maximum and minimum temperatures on cobbled (filled squares) and bare (circles) experimental plots at onset of soil warming.

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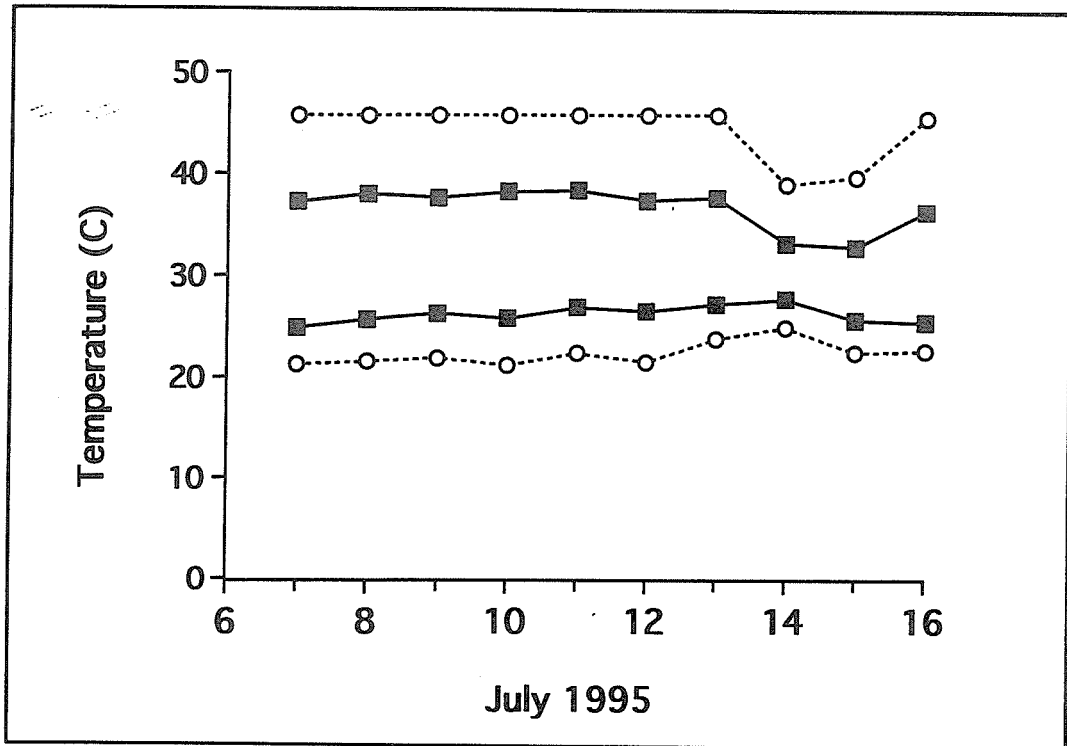


Figure 4c. Average daily maximum and minimum temperatures on cobbled (filled squares) and bare (circles) experimental plots during period of maximum temperatures.

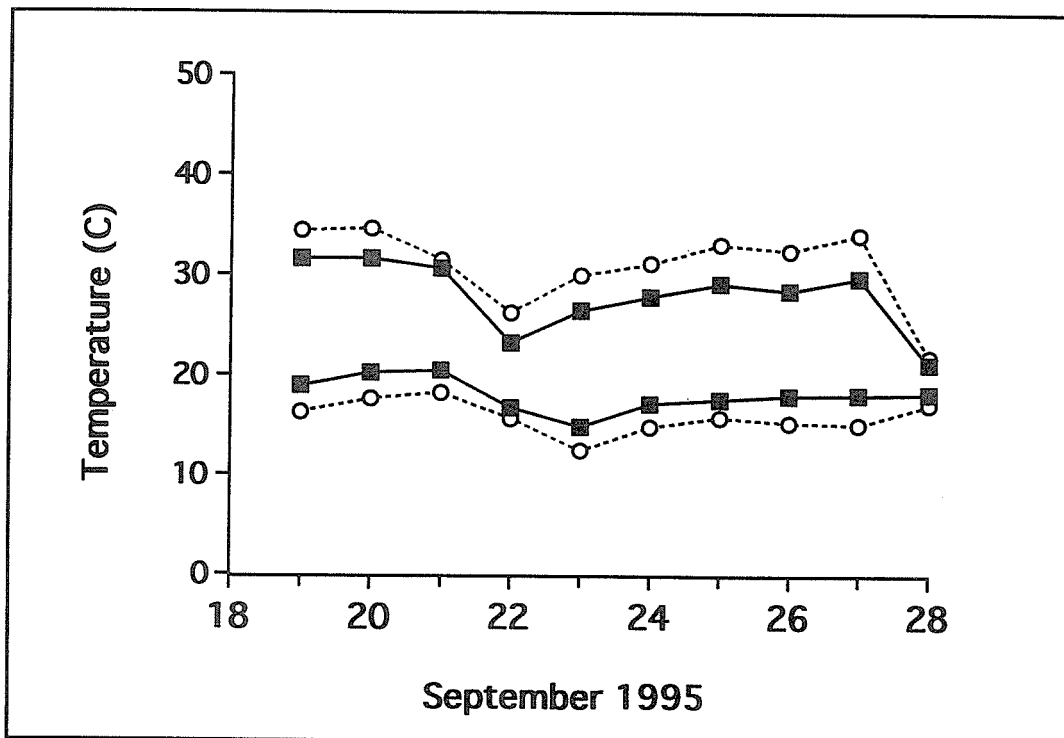


Figure 4d. Average daily maximum and minimum temperatures on cobbled (filled squares) and bare (circles) experimental plots during fall cooling.

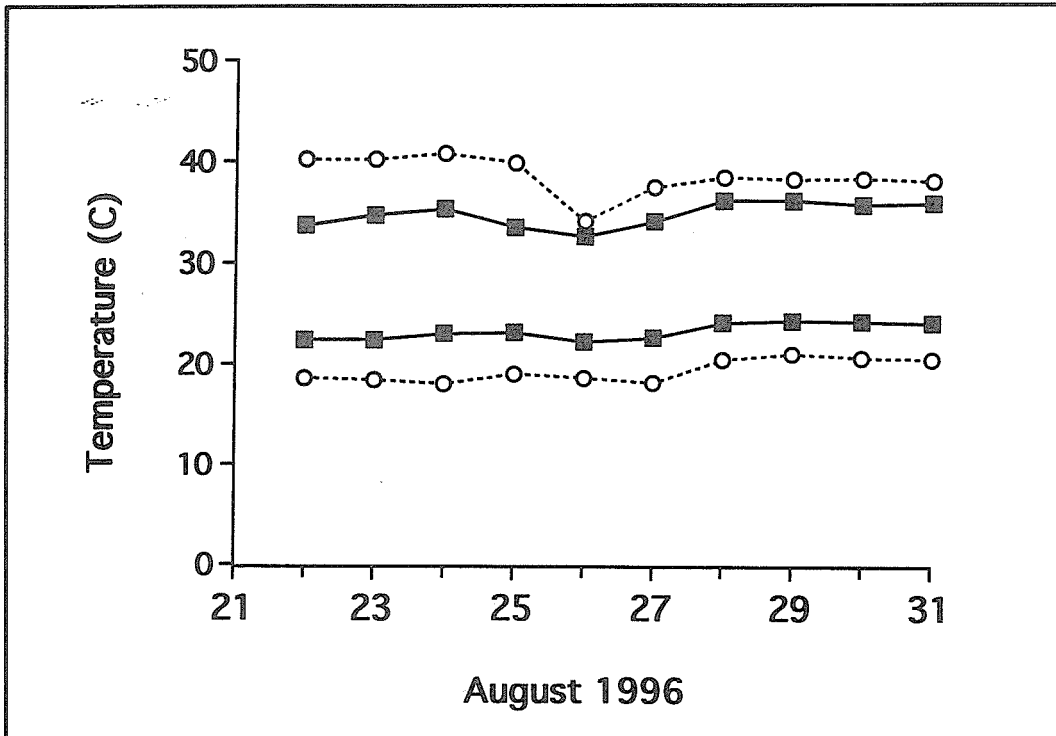


Figure 4e. Average daily maximum and minimum temperatures on cobbled (filled squares) and bare (circles) experimental plots during the plant growth experiment.

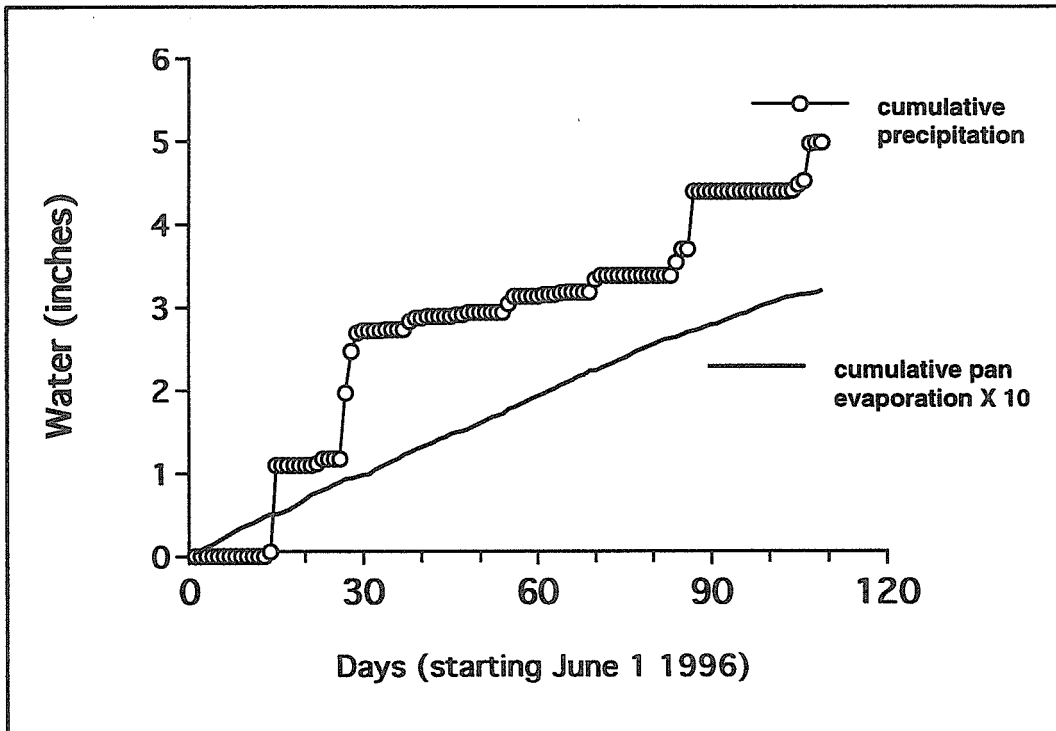


Figure 5. Cumulative precipitation volume (circles) and cumulative pan evaporation (actual values are 10 times indicated value) measured at the Plant Materials Center in Los Lunas, NM, starting June 1, 1996, ending September 15, 1996.

evidence that the cobbles reduced direct evaporative soil moisture loss.

Sandor et al. (1990) reported that areas used by Native Americans for agriculture in the Mimbres region of southern New Mexico had argillic (clay-rich) subsurface horizons. Argillic horizons would retard, if not eliminate, deeper percolation of soil moisture, which appears to be a feature common to the cobble mulch gardens. Apparently, argillic horizons or features with similar function were often used for semiarid agricultural practices to intercept the downward movement of water and retain moisture in the rooting zone. It is unknown how these subsurface features were detected by Native Americans, or what cue indicated that the area was satisfactory for agriculture.

The cobble plots had more moderate soil temperatures, which may, in part, be attributed to the greater soil moisture. Unlike the function proposed by Lightfoot (1994), there was no evidence that the cobble plots were warmer either earlier (Figure 4b) or later (Figure 4d) in the growing season than bare gardens. The differences in apparent results may be explained by the general color of the cobble; light in this study, and reddish at the Galisteo Basin area studied by Lightfoot (1994). The most beneficial temperature effect in this study may be the more moderate temperatures in the rooting environment, which would minimize root respiration. Both greater soil moisture and more moderate soil temperatures should favor plant growth.

Plant growth is the ultimate integration of the overall effects of the cobble. All plants fared as well or better on the cobble plots than on the bare plots. Given the same amount of water inputs, this indicates that the cobble plots were a more favorable environment for plant growth than the bare plots. The plants on the cobble plots were noticeably cooler, indicating potentially greater evaporative cooling on the cobble plots than on the bare plots (personal observation). Whether or not the plants suffered from excess solar reflectance is unknown, but there was no evidence of "sunburning." Reflectance would be expected to diminish as plants increase in size and provide greater shading. In this study, near maximum reflectance was expected given the late planting date and minimal shading, yet there was no visible damage.

Following plant harvest, no further watering was done. Many of the plants on the cobble plots resprouted later that same year, and many were actively growing during the next spring and summer (D. Dreesen, personal observation). Few plants on the bare plots survived the harvest and were present the next spring.

The apparent success of the cobble gardens relies on many aspects. The cobbles shed water to the sandy soils below, which have high infiltration rates, and minimize loss to overland flow. The cobbles then act as a mulch to reduce evaporation by reducing the surface area for evaporation. The cobbles may also reduce loss of soil moisture by creating a temperature gradient along which water vapor moves from hotter soils between the cobbles and condenses on the cooler surfaces on the bottom of the cobbles. This net movement of water to areas below the cobbles increases soil moisture, which attracts roots to that area. The roots, in turn, help initiate the carbonate coatings often found on the bottom of the cobbles. The sandy soils allow crop plants (or native plants) to remove a greater percentage of soil moisture relative to soils with higher clay content. The cobbles also moderate soil temperature, providing protection from both high and low temperatures. Thus, the gardens rapidly absorb precipitation, reduce evaporation from the soil surface, afford a higher proportion of soil moisture to crop plants, and provide a more moderate root environment.

Over time, the function of the gravel surface is expected to change. In the Anasazi gardens, the cobbles tended to stay on the soil surface and wind-blown particles fell through to the soil surface. Also, unwanted plants were probably removed, leaving the spaces between the gravel open. However, either before or after abandonment, the cobbles would favor eolian deposition (Gossens 1994) and the spaces between the gravel and cobbles became filled. Now, the cobbles are embedded with eolian material and plants, predominantly native grasses and cryptogamic crusts, fill the spaces between the rocks. This gravel- and cobble-imbedded surface has different hydrologic properties (Possen et al. 1990), with lower infiltration rates and probably greater runoff.

CONCLUSION

All types of plants grew as well or better on the cobble gardens than on the gardens without cobbles, regardless of their water-use requirements. Since plant growth is the ultimate indication of the effects of cobbles, this is very strong evidence that plant growth is enhanced through the use of cobble mulch. Soil moisture is increased under the cobble mulch by reducing water-loss through evaporation. Mulch also moderates soil temperatures, which makes for a less stressful rooting environment. If additional sunlight through reflection from the cobbles is stressful to the plants, there was no indication of this and any potential stress was obviously offset by the higher soil moisture and more favorable soil temperatures. Thus, we conclude that adding about a 3" depth of gravel or cobble to the surface of gardens will conserve water without harmful effects to the plants. The practical implication of this initial research is that gardens and landscaping would have to be watered less frequently if cobble mulch was utilized, which would reduce the total water consumption for this purpose.

Acknowledgements

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