The Evolution of Agricultural Adaptations in the Sierra Tarahumara

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Abstract

Often viewed as one of the most isolated and intact indigenous groups in Mexico, the Tarahumara have been neither isolated nor intact for almost 400 years. Similarly, agriculture that is traditionally envisioned as adapted to the steep canyons and uplands of the Sierra Madre Occidental in southwestern Chihuahua has undergone a series of changes over four centuries. Underlying these changes, however, one constant remains — the need to overcome the lack of organic matter in the stony mountain soils. From the time of the Spaniards' arrival until the twenty-first century, large amounts of animal manure compensated for deficiencies in organic matter. Recently, this has begun to change; the Tarahumara are increasingly adopting commercially available fertilizers due to the pressures of globalization and drought. Tarahumara agriculture today involves many traditional techniques, but it also contains techniques that are anything but native or indigenously developed. This study includes in-depth interviews with 28 Tarahumara farmers to better understand the adoption of modern agricultural techniques, their motivations, and overall sustainability. Soil samples taken from these farmers' fields are analyzed to determine the sustainability of Tarahumara agriculture. The analyses show that traditional Tarahumara agricultural practices appear to be the most efficient and sustainable options, but should not necessarily be viewed as a panacea.

Keywords: Tarahumara, sustainable agriculture, soil analysis, farmer interviews

1. Introduction

For many years, geographers and anthropologists have been fascinated with the Tarahumara. Lumholtz (1902), Bennett and Zingg (1935), Pennington (1963), Kennedy (1978), and others conducted ethnographies of the Tarahumara. These studies looked at their unique agricultural practices, the making of *tesguino* (a fermented corn beer) and their ultra-running prowess. Cultivation of illegal drugs has been part of the Sierra Tarahumara for decades, but with harsher federal drug laws, the Tarahumara are now caught in the crossfire among warring cartels and government forces (Perramond, 2004). Tarahumara are also being pushed out of their ancestral home due to an influx of tourism and industry into the region, as mestizos look to take advantage of the beautiful landscape and abundant timber resources. Further exacerbating their predicament, a major drought, and now famine, in much of northwestern Mexico has put many Tarahumara at risk of starvation (BBC, 2012). The myriad of pressures on the Tarahumara has forced them to adopt more modern agricultural strategies that may threaten their unique cultural practices and independence.

Building on previous scholarship on the Tarahumara's traditional agricultural strategies, this article looks to fill a research gap and analyze these techniques in relation to modern pressures. The primary goal of this research is to examine the changes in agricultural strategies of the Tarahumara, and while doing so, broaden understanding of indigenous perspectives and decolonize the production of knowledge (Shaw et al., 2006). The author is aware of the power of his own political positioning, as a researcher from a Western university, and did not enter this research with the intention of prescribing specific agricultural remedies to the Tarahumara or to governmental and non-governmental organizations. The author also understands the inherent risks of simply replicating colonialist representations and thus attempted to integrate indigenous voices into the research methodology. Through farmer interviews and soil analyses, this article examines current Tarahumara agricultural practices including new chemical fertilizers that can decrease the reliance on traditional practices.

2. Physical environment

A thorough knowledge of the Sierra Tarahumara's physical environment is crucial to understanding the Tarahumara's distinctive agricultural techniques. The Sierra Tarahumara encompasses the narrow ridge of the Sierra Madre Occidental mountain chain in the Mexican state of Chihuahua and its valleys and canyons to the west. The elevation ranges from a high of 2,400 meters at the town of Creel to a low of 460 meters at Batopilas (Kennedy, 1978). At the time of contact with the Spanish in the seventeenth century, the Tarahumara were spread across five physiographic regions, but today they reside only in the upland and canyon country (Figure 1; Pennington, 1963).

The highest elevations of the Sierra Tarahumara are found in the upland country and average 1,800 meters. In addition to its mountains, the upland country contains a heavily dissected rolling plateau (Kennedy, 1978). The majority of the Tarahumara and mestizo populations are found in this physiographic region. Located to the west, the canyon country includes the drainage systems of Río Urique, Río Batopilas, Río Otero, and Río Verde. Elevations range from highs of around 1,500 meters to lows of 460 meters (Kennedy, 1978). Moving down the canyons, one quickly passes from pine and cedar into oaks and down to nopal, cacti, and thorn forests (Brown, 1982).

The climate of the uplands permits only certain vegetation adapted to harsh winters, primarily pines, along with certain species of juniper and oak (Brown, 1982). Due to a paucity of temperature and precipitation data, it is difficult to properly evaluate the climate of southwestern Chihuahua, though it is possible to get general details of the climate based on available data stations and its location in relation to the Intertropical Convergence Zone (ITCZ) (Pennington, 1963). Tarahumara agriculture has adapted to strong seasonal patterns that are appropriate to the climate of southwestern Chihuahua, as farmers take advantage of the summer rains and keep crops in storage throughout the cold and dry winters.

Seasonal variation characterizes the annual precipitation of southwestern Chihuahua. Up to 75 percent of the rainfall occurs in the rainy season during the months of July, August, and September, while only 3 percent occurs during the two driest months, February and March (Pennington, 1963). The water levels in the streams of Chihuahua reflect the seasonal character of the annual precipitation; during the late summer months, streams are generally flooded, whereas they may run completely dry during the winter.

3. Historical adaptations and transformations

3.1 Pre-Hispanic setting

The Tarahumara share with mestizos approximately one quarter of the southwestern portion of the state of Chihuahua, Mexico and fall within a culture area called the Greater Southwest. They belong to the Uto-Aztecan language group, which is distributed, with the exception of a few breaks, from Utah to Mexico City (Kennedy, 1978). The word *Tarahumara* is a mistranslation, though it is the name that predominates. Most Indians refer to themselves as Rarámuri, "the people of the swift running feet" (Smith, 2008, 6). Prior to contact with the Spanish, the Tarahumara were primarily hunters and gatherers that relied on a wide variety of edible plants scattered throughout the region. They hunted game, especially turkey, hare, and deer, fished mountain streams, and cultivated small amounts of corn along riverbanks to take advantage of the rich alluvial soil. This early agriculture supplemented their hunting and gathering, allowing them to remain mobile and independent (Kennedy, 1978).

3.2. Spanish era

The encroachment of Spaniards into the region came in two forms: those who searched for wealth, mainly in the silver mines in the deep canyons, and those who desired to save souls, reflected in the work

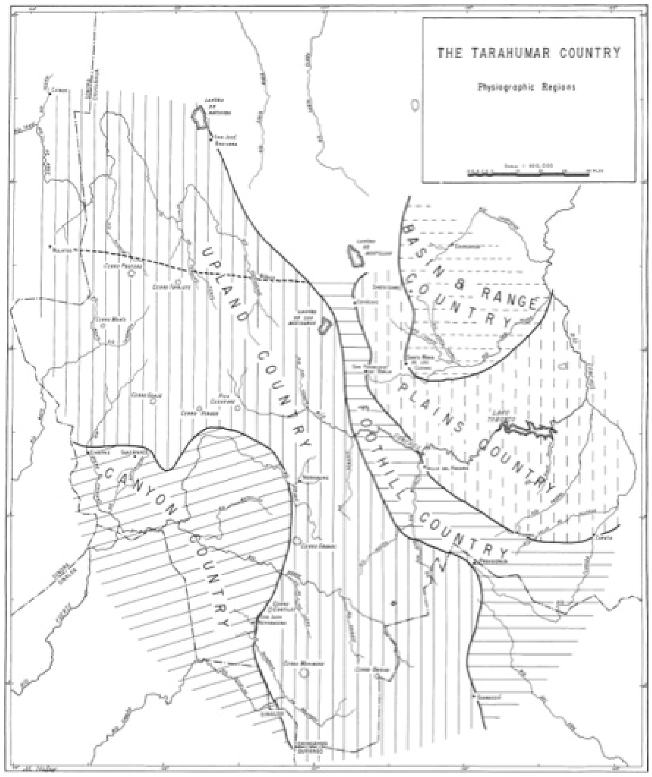

Figure 1. Physiographic regions of the Sierra Tarahumara (Pennington, 1963).

of early Jesuits in the area. Agricultural land was usurped from the Tarahumara to feed the new settlers (Kennedy 1978). Along with the Spanish explorers and Jesuits came several different types of livestock, including goats, sheep, cows, horses, and pigs, that are now crucial to the Tarahumara's existence. The agricultural success of the Tarahumara is predicated on the use of animal fertilizer to increase the organic matter content of the shallow stony soils. Livestock allowed them to shift away from hunting and gathering to a more sedentary agricultural existence, which stabilized their food supply (Kennedy, 1978).

3.3. Modern times

Regional economic and demographic change has exposed the Tarahumara to the effects of modern society and globalization. The estimated Tarahumara population is 75,545, but they are now significantly outnumbered regionally by the mestizo population (INEGI, 2005). With the swell of mestizos came logging, tourism, mining, and significant impacts on the environment and Tarahumara culture. The infrastructure of these encroaching industries reduced the once immense buffer between the two groups. New paved roads now enable development to invade the Sierra Tarahumara more deeply. Although the roads can bring access to education and better health care, they also carry cheap goods and disrupt animal herding. Threats to traditional agriculture lead Tarahumara to supplement their subsistence strategies through wage labor, pulling them out of a previously independent existence.

The effect of globalization is further seen in the impacts of the war on the illicit drug trade. Drug cultivation has been common in this region for decades, as evidenced by landing strips located throughout the Sierra Tarahumara, which have aided large-scale operations since the 1960s (Perramond, 2004). Historically, few Tarahumara participated in the drug trade, though some Tarahumara have been forced into production ventures with threats and violence. As more Tarahumara rely on the cash economy to buy fertilizer and other modern agricultural additions, growing illicit drugs provides the potential for substantial increases of their incomes. One kilogram of marijuana was worth about $280 in 2002, which is 100 to 200 times more than similar corn and wheat harvests in the region (Perramond, 2004).

The Mexican government tolerated illegal drug production in the Sierra Tarahumara for decades. This production has always been illegal, but corruption and a lack of drug enforcement allowed it to flourish. Recently, a government crackdown and feuding cartels have changed the nature of the business. The state of Chihuahua is now at the center of the drug war, as rival cartels fight over territory. Though the majority of violence takes place in the larger cities of Ciudad Juarez, Chihuahua, and Cuauhtémoc, it is increasing in the Sierra Tarahumara (Linares, 2008). A larger police and military presence does little to diminish the violence, and the drug war remains a threat to the Tarahumara and the other residents of the region.

As mestizos and industry intrude further into Tarahumara land and the effects of the drug war continue, the Tarahumara are left with two main options: retreat further into the canyons and uplands of the sierra or leave their homeland and find jobs in the nearby cities of Creel and Cuauhtémoc. The younger male Tarahumara usually chooses to do the latter. If they do not possess land to cultivate, or if they lack the necessary resources, they frequently move to urban areas in pursuit of wage labor.

4. Current agricultural strategies

The mixture of disparate sources for the agricultural practices of the Tarahumara has shaped their agricultural techniques. The origins of their practices include traditional Tarahumara cultivation of traditional crops employing intimate knowledge of the environment, Spanish influences, such as use of the plow and husbandry of livestock, and more recent practices of reliance on modern agricultural inputs. The trifold combination allows the Tarahumara to take advantage of their unique environment, but without proper use and foresight, some of the applications may not be viable over the long-term.

Corn is the predominant and most traditional Tarahumara crop. It is the source of the vast majority of their calories, it stores well, and it is central to the making of *tesguino*, the fermented corn beer that plays a central role in social interaction. Other crops, in order of importance, are squash and beans, potatoes, peas, oats, and fruit trees.

The earliest planting date in the agricultural calendar is 20 April, though most farmers report that they plant their corn in the middle of May. If a farmer plants early, he risks losing the crop to a late frost, but if they sow late, then they increase their risk of insect destruction. The planting dates for beans and squash often coincide with the planting of corn. However, some farmers plant their beans later than their corn, often delaying seeding until late June.

Tarahumara farmers cultivate their crops on stony mountain soils with the help of plows, a strategy borrowed from the Spanish. Many Tarahumara still use the traditional wooden plow, or *arado* (Figure 2), while others employ the more efficient iron *arado*. The *arado* breaks up the soil, allows for the planting of seeds, and helps prevent weed growth. On many bean fields and on crops located on steeper slopes, farmers will instead use an *azadón*, or garden hoe, to plant and weed. Though it takes more energy and more time, the *azadón* causes less soil disturbance and thus prevents soil erosion and desiccation.

Two important agricultural strategies used by the Tarahumara that deserve greater focus are the use of fertilizers and erosion-control structures. Both allow the Tarahumara to adapt to the unique topography and soil, and are central to their survival.

4.1. Fertilizer

The Tarahumara have a distinctive approach to agriculture. The majority of Mexican farmers that graze livestock on non-arable landscapes gain sustenance from the environment by milking their animals and eating their meat. In contrast, the Tarahumara use livestock primarily for their manure for fertilizer. The Tarahumara only slaughter and eat livestock for festivals or if they die prematurely, but these are rare occasions. They even refrain from milking their livestock, although, if they did, it could provide a consistent source of protein.

The Tarahumara herd livestock along the steepest sections of the canyon walls. Goats are the most common livestock and are the best suited for the harsh environment. Other common livestock include cattle, sheep, horses, and pigs. Each night, a farmer may pen up a herd of 15 to 50 goats in an area of about 6 square meters. Farmers construct their pens with light interlocked pine logs, which they move and reassemble, usually doing so about every four days, in locations that are determined by a field's specific fertilizer needs (Kennedy, 1978). This slow and painstaking method is key to increasing soil fertility. It takes a farmer's herd about 45 days to fertilize an acre of land. During winter, farmers keep livestock in a more permanent enclosures. Work parties are organized to sweep the accumulating manure from the bottoms of corrals and then spread it on the fields (Kennedy, 1978).

Tarahumara communities cooperate in the collection and use of manure for fertilizer. Some Tarahumara do not have sufficient livestock to apply fertilizer, so they borrow from family or friends. Those with a surplus lend out their livestock, expecting that they will be well cared for while providing their manure. The care of the animals is a family affair with many

Figure 2. A traditional wooden *arado.*

shared tasks. The countryside provides little in the way of pasture, so shepherds, often women or small children, are responsible for moving large herds of livestock across the uplands and canyon country to find suitable foliage (Bennett and Zingg, 1935). That task may last for days and even a week at a time, but all Tarahumara understand its importance. Without the combined biomass of the surrounding countryside converted into manure, they will be unable to grow an adequate supply of food. If there were no access to livestock, the fields would become barren within a few years and traditional agriculture would no longer be possible (Bennett and Zingg, 1935).

Over the past 20 to 30 years, the Tarahumara shifted away from exclusively traditional and organic agricultural practices, and began to rely on both organic and chemical fertilizers. Some Tarahumara farmers now use chemical fertilizers that are available due to the mestizo influx in order to maintain a substantial harvest. The addition of chemical fertilizers presents new challenges for Tarahumara farmers and may diminish their agricultural independence as acquisition of industrial chemicals requires participation in the cash economy.

4.2. Erosion control structures

The Tarahumara's homeland landscape requires agricultural strategies that differ from those developed for flat terrains. Steep slopes are more susceptible to erosion, especially when vegetation declines and when soils are exposed. Agriculture is a common cause of soil erosion, particularly during periods during which vegetation and rocks are removed (Harden, 2001). Erosion is detrimental to soil quality because nutrients and sediment lost downslope may not be regenerated (Knox, 2002). Without essential soil nutrients, agricultural fields on slopes remain unproductive for years and they are often abandoned (Denevan, 1989). The loss of a field can be disastrous to a farmer whose family's sustenance and livelihood depend on it. In response, the Tarahumara have developed numerous strategies to allow for cultivation of steep slopes while still preventing erosion. They have long employed traditional environmental awareness to develop techniques adapted to local topography and to changing environmental conditions. The techniques enacted will be determined by available resources and capital (Wilken, 1987).

One of the reasons that the Tarahumara construct *trincheras* (Figure 3), a term used by the Tarahumara to refer to all forms of erosion-control structures, is to and prevent erosion while farming steep slopes (Treacy and Denevan, 1994). Large rocks are the primary construction unit for these structures which can reach upwards of 2 meters high while the majority are comprised of one to two rock levels and are 0.5 to 1 meter in height. Tall vegetation, both dead and alive, may be added as reinforcement to this structure. The specific purposes of specific *trincheras* vary based on the goals of the specific farmer, but the general purpose is to maintain soil fertility (Doolittle, 2000).

It may appear that their agricultural strategies are changing, and, in fact, they are. One must not forget, however, that in Tarahumara agriculture, change is normal. What appears to be change is part of a long transformation of Tarahumara livelihoods occurring over centuries. Challenges to agriculture and subsequent adaptations are nothing new; Tarahumara farmers believe they will adapt just as they always have. To gain insight into their adaptations interviews of Tarahumara farmers and analysis of soil quality have been undertaken.

Figure 3. A *trinchera*, the Tarahumara erosion-control structure.

5. Methods

5.1. Qualitative interviews

To understand agricultural practices and perceptions of Tarahumara farmers, 28 interviews were conducted across the Sierra Tarahumara, primarily in the towns of Cusarare, Guacajípare, Choguita, Basíhuare, and Norogachic (Figure 4). Each farmer responded to the same set of questions, but the interview were conducted semi-formally. The results reflect the general sentiment and answers of the Tarahumara farmers interviewed. All those interviewed relied heavily, often entirely, on the production from their fields for their subsistence. Within the Sierra Tarahumara, men are those primarily responsible for agricultural decisions. Thus all of the interviewees were men. Each had little or no formal education and all had minimal financial wealth. Interviews of Tarahumara women should (at some future time) also be conducted, as they are chiefly responsible for grazing livestock, as their views may yield significant complementary perspectives, as they also have experiences with and perceptions of the changes in agricultural techniques and outputs even though they do have decision-making authority. Interviews were conducted by the author at elevations between 1,815 and 2,338 meters during the summer of 2010, a particularly dangerous time in the Sierra Tarahumara due to on-going conflicts between drug traffickers and the Mexican government. Two months before the author began his research a shootout between rival cartels killed nine people in the city of Creel, the selected base of operations for this work (Tuckman, 2010). This conflict limited the duration of the fieldwork and also the degree to which the author could enter isolated areas.

5.2. Quantitative soil analysis

To better understand Tarahumara agriculture, a comparison of soil quality with farmer strategies and

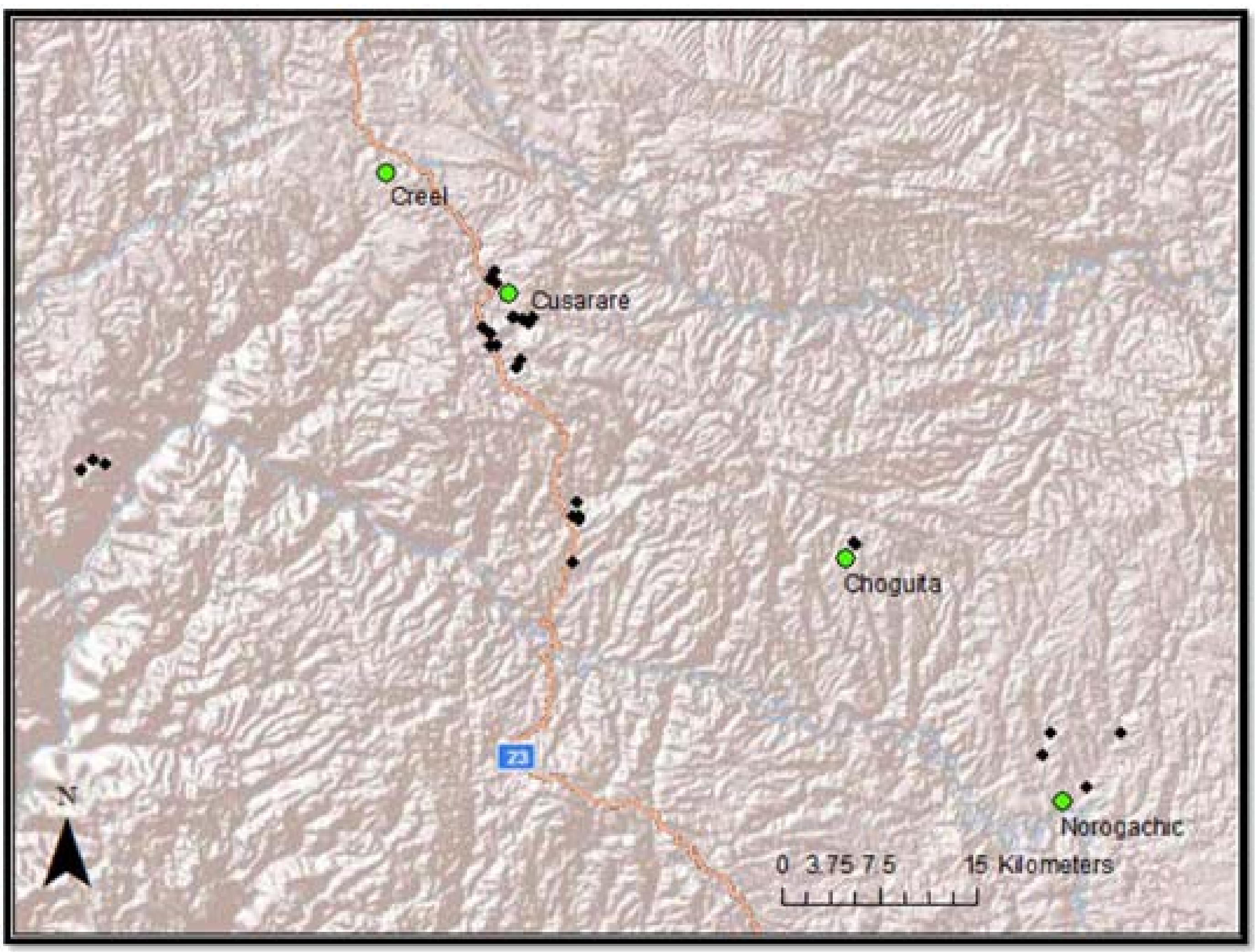

Figure 4. The locations of the interview sites.

perceptions is beneficial to discern how recent changes in Tarahumara agricultural alter soil quality and future sustainability of their communities. The reason for soil analysis is to determine soil quality and attempt to infer the effects of specific agricultural techniques through a simple comparison of agricultural practices. Due to the small number of soil samples taken, a more thorough statistical analysis of soil fertility in relation to agricultural practice will be left to future work. Past research in the Sierra Tarahumara has examined agricultural techniques but has paid little attention to soil quality. A better understanding of agricultural soil quality will help elucidate the risks to Tarahumara agriculture.

Soil samples were collected from each farmer's field at each interview site. The 43 samples were taken from the uppermost 10 centimeters of the profile and consisted entirely of topsoil. Each sample weighed between 500 and 1,000 grams when dried. The samples were sent via courier from Chihuahua, Mexico to the Soils Laboratory at the Department of Geography and the Environment of the University of Texas at Austin. To determine the percentage of organic matter in the samples, a loss-on-ignition determination was conducted. Soil samples were processed and sent via courier to the Texas A & M University Agrilife Extension for basic chemical analysis to determine acidity and quantities of primary macronutrients.

6. Results

6.1. Qualitative interviews

The interviews consisted of three primary questions that prompted additional discussion with farmers. These discussions generally regarded fertilizer availability, abundance, decision-making rationale, and the perceived quality of the land for agriculture. Each question is discussed below.

I. How many and what types of animals do they have?

Many Tarahumara still have livestock, but the numbers are dwindling. A major reason for this change is the shift in climate that has occurred over the last 12 to 15 years which has generated a lingering drought and killed many animals. Of the 28 farmers, 13 of them owned goats and had herds that ranged from 5 to 50 animals. Cows were also important. Twelve farmers owned cows, and their herds ranged from 1 to 25 head. Less numerous were horses, sheep, chickens, donkeys, and pigs. Several of the villages, such as Basíhuare, grazed significant numbers of cattle and goats, but now only a small number of animals remain and this seems to be primarily due to the long drought.

II. What type of fertilizer do they use and why?

Of the 28 farmers interviewed, 8 stated that they either currently apply fertilizer on their fields or they have in the past. One farmer said, "We use chemical fertilizer today because the soil is not as good as before. Chemical fertilizers replaced the use of animal manure." They apply a chemical fertilizer known as "El 18" and it contains 18 percent nitrogen, 46 percent phosphorus, and 0 percent potassium by weight. It is sold to farmers for 480 pesos (38 $U.S.) per 50 kilograms and is brought to isolated villages on large trucks. Farmers recognize that it can increase crop yields but also notice the fertilizer's detrimental effects on long-term soil quality. Apparently, there is no commonly known historical date when farmers in the region started using chemical fertilizers, but several stated that this process began roughly 20 years ago.

III. Were the agricultural fields better before?

The answer to this question is subjective, as there are few records that document the annual yields. It, therefore, can be easy for farmers to exaggerate previous harvests and give imprecise and inaccurate representations of overall trends. Despite these possibilities, there is value in the of farmers' perceptions of changes in their agriculture, particularly in decadal terms. Nearly all of the farmers interviewed claimed that the harvests were superior when their father or grandfather cultivated the land and they needed less fertilizer to achieve those harvests. A small number of the farmers that had worked their fields for ten years or more claimed that they saw no difference in productivity. Others claimed that the fields are better now because of the use of chemical additives.

The farmers that perceived that their yields were declining assigned the absence of erosion-control structures as the primary reason. These farmers recognized that without soil erosion-control structures they lost topsoil, but they rarely undertook efforts to stop the loss due to shortages of labor and capital. One farmer explained that decreased agricultural production was primarily due to heavy rain events and said, "The soil was much better before. Without erosion control structures, we lose a lot of soil to the rivers and creeks." Others simply stated that soil erosion was something they could not control. Previous generations had constructed virtually all of the erosion-control structures that are now in place.

The farmers also believed that the recent on-going drought was another reason for decreased productivity. However, recent climate data are unavailable to substantiate this claim. The drought they are experiencing is said to have begun 12 to 15 years prior to this study. It has affected the crops and killed a large number of their animals. Some farmers blamed significant deforestation in the Sierra Tarahumara for the genesis of the drought. Mestizo businesses that sell lumber outside of the Sierra Tarahumara cut down extensive swaths of pine forest. Without trees, there is less water stored in the local vegetation and soils and that has intensified the effects of the drought. Other Tarahumara note different drought consequences and lament the lack of snow and snow pack. One farmer said, “The fields were much better before because there was more snow. This would kill many of the insect larvae which helped produce larger harvests.”

6.2. Interview trends

The Tarahumara were not only concerned about their specific plots of land but also about the dwindling number of young Tarahumara who choose to work in the fields. Few Tarahumara farmers interviewed were under the age of 35. Most of the younger Tarahumara do not participate in traditional agricultural practices and have instead either taken jobs in surrounding towns or work for wages in the timber industry. After experiencing a more materialistic lifestyle, few return to the solitude and tranquility of the canyon, that leaves a small number of farmers behind to carry on traditional agriculture and insufficient workers for large projects, such as for the building erosion-control structures. The lack of *trincheras* worried Tarahumara farmers, but there was no sense of urgency or panic apparent during the interviews. The Tarahumara farmers believed they would adapt, as they always have, and continue on with their lives. Agriculture in the Sierra Tarahumara is continuing its transformation as modern technologies are added to traditional strategies. These interviews provide critical insight into farmers’ perceptions and the reasoning behind their agricultural strategies, but to more deeply understand the results of their methods an analysis of soil quality has been performed.

6.3. Quantitative soil analysis

I. Fertilizer

A rather simple analysis of fertilizer use shows that natural fertilizer produces a higher soil organic matter (SOM) percentage than does chemical fertilizer. SOM plays several important roles that foster increased agricultural productivity. As a general rule, the higher the SOM, the more productive and stable the soil (Brady and Weil, 2004). The 27 samples that consisted of natural fertilizer, primarily animal manure, had an average SOM of 5.12 percent (Table 1). There is higher SOM found in this sample than in samples from the fields to which chemical fertilizer was applied. The latter had an average of 4.22 percent. One sample taken from an area where the farmer claimed to not use any fertilizer had an even higher percentage of 9.3. The data reveal that the use of animal manure for fertilizer creates higher SOM than chemical applications.

The relationship of fertilizer choice and average pH levels is not so direct. Corn, the dominant crop in the Sierra Tarahumara, does well in soil that has pH levels between 5.8 to 7 (Espinoza and Ross, 2006). Fields to which only natural fertilizer has been added have an average pH value of 5.9, whereas the fields with chemical fertilizer have an average value of 5.7 (Table 1). Chemical fertilizer of the type used in in this region has a tendency to lower soil pH, or perhaps does not raise it as natural fertilizer does; the plot on which no fertilizer has been applied had a similar value to the fields with added chemical fertilizer. The fields on which natural fertilizer has been applied have pH values that fall within the desirable range for corn, while the chemical fertilizer creates a soil pH that is slightly too acidic. Without amelioration, the fields can become less productive of corn.

The fields which received natural fertilizer had the highest levels of nitrate, a constituent of chlorophyll and involved in nearly all plant growth processes ((Maddox 1974), at 99.3 ppm, and the field with no fertilizer had a similar value at 92 (Table 1). The chemically treated fields had an average value of 72.43 ppm which suggests that the natural fertilizer provides more essential macronutrients. Fertilizer raises the nitrate levels and make cultivation possible. However, it must be noted that chemical fertilizers have low residence time in soil, so tests may indicate inadequate levels of nutrients for crops. For more accurate results, samples should be taken immediately after chemical fertilizer applications to best measure available nutrients.

Table 1. Values for soil samples based on fertilizer application.

	Number of Samples	SOM %	Soil pH	Nitrate (ppm)	Phosphorus (ppm)
Chemical Fertilizer	14	4.22	5.72	72.43	60.64
Natural Fertilizer	27	5.12	5.97	99.3	91.11
No Fertilizer	1	9.3	6	92	39

The fields with natural fertilizer had an average phosphorus value of 91.11ppm, and the fields with applied chemical fertilizer had a value of 60.64 ppm (Table 1). Phosphorus is essential for early plant growth and is later transferred to the seeds, where it is vital for growth. It shortens the growing season and hastens maturity, and, in this respect, it acts in opposition to nitrogen (Maddox 1974). The naturally fertilized fields had eight samples having below-critical levels of phosphate of 50 ppm. These 8 represent fields that comprise 29.63 percent of the samples. In the chemically treated fields 42.86 percent of the samples did not meet the critical levels of phosphorus. The fields receiving no fertilizer also did not reach the critical levels necessary for phosphorus. There is insufficient phosphorus in the soil naturally, so the only way to maintain high levels of phosphorus is through fertilization. Chemical fertilizers will raise soil phosphorus, but apparently not to the same degree as natural fertilizer does.

II. Erosion control structures

Soil taken from erosion control structures had an average SOM value of 5.14 percent (Table 2). This is higher than the 4.54 percent value of the fields, which did not utilize erosion control techniques. The stabilization of the soil provided by erosion control structures allows for the generation of higher levels of SOM, which in turn further secures the soil and crop harvests.

There is a discrepancy between pH values of fields with erosion control structures and those with none. Fields that contain some type of erosion control structure have a 6.03 pH average, which is slightly acidic (Table 2). Those fields with no erosion control structure had a moderately acidic 5.63 pH average. By this comparison, erosion control structures have a higher pH than those without. The slightly acidic soil is best for corn, and fields with erosion control structures are the most appropriate for cultivation.

There is little difference between the average nitrate and nitrate range values of the soil categories. Where the field with erosion control structures has a value of 88.68 ppm, the fields with no erosion control structures have a value of 90 ppm (Table 2).

The fields with erosion control structures have a phosphorus value of 93 ppm, which is 62 percent higher than the fields that have no erosion control structures. The fields without erosion control structures have a value of 57.56 ppm (Table 2). The stabilization of soil provided by the erosion control structures appears to allow for higher phosphorus content.

6.4. Soil trends

The soil analyses values do not portray a degraded landscape that cannot support agriculture, but instead high values of soil macronutrients and organic matter. The average pH value of 5.87 is low though it still fits within the desirable range for corn. There is an inherent irony when using soil analysis designed for large

Table 2. Soil values for sites with and without erosion control structures.

	Number of Samples	SOM %	Soil pH	Nitrate (ppm)	Phosphorus (ppm)
Erosion-control Structures	14	4.22	5.72	72.43	60.64
No Erosion-control	27	5.12	5.97	99.3	91.11

-scale commercial agriculture to determine the success of traditional agriculture. Tarahumara farmers know little of the Western scientific knowledge, such as soil macronutrients or pH levels. They do understand the importance of having fertile soil, but looked at the crop output and health as the best way to determine it. However, to quantifiably determine soil quality and examine specific agricultural techniques, a soil analysis is appropriate. The results of the soil analysis confirm important patterns in Tarahumara agriculture that may already have been known by individual farmers. The combination of both soil analyses and farmer interviews provides a unique perspective on Tarahumara agriculture.

Because of the recent addition of chemical fertilizer by Tarahumara, it is crucial to understand the effects on overall soil fertility. On nearly all of the soil analyses, natural fertilizer showed more desirable effects. SOM content in fields with added natural fertilizer demonstrated noticeably higher SOM percentages than chemical fertilizer. Soil pH was more acidic in soil with chemical fertilizers than natural fertilizer application, which could limit corn cultivation that needs a slightly acidic soil. Both nitrate and phosphorus values were significantly higher in the fields with only natural fertilizer.

The presence of erosion control structures was universally beneficial to soil fertility. The percentage of organic matter in the soil is higher among fields that have erosion controls. In addition, fields with erosion control structures have more desirable soil pH. Nitrate values are similar between fields with or without erosion control structures. Phosphorus is higher with erosion control structures. Tarahumara farmers understand the importance of erosion control structures for their agriculture. They serve numerous purposes, and, though they have a large upfront cost and need maintenance, the benefits can last for decades.

7. Discussion

The basic soil analysis appears to show that traditional agricultural techniques of the Tarahumara enhance the long-term soil quality, which may increase agricultural output, but a more detailed analysis is still needed. Chemical fertilizers must have some efficacy or Tarahumara farmers would not use their limited resources to buy them, however, this study was not able to measure the impacts of chemical fertilizers on the soil quality immediately following their applications. The soil analyses may also reflect the short residence of the chemical fertilizers in the soils. Farmers that apply chemical fertilizers are not necessarily improving long-term soil quality, but instead are only gaining a larger harvest for a particular season. Several farmers stated that chemical fertilizers increased crop production, but did not indicate whether the increases were sustained.

The romanticization of indigenous knowledge, that it will always provide the most appropriate and sustainable solution, causes it to be adopted as the hegemonic knowledge system that replaces Western science, a belief system that makes its own claims to superiority (Briggs 2005, 19). Cleaver (1999, 605) reflects on the danger of "swinging from one untenable position ('we know best') to an equally untenable and damaging one ('they know best')." It may appear that the switch from the traditional use of animal manure to chemical fertilizers marks the beginning of the end of Tarahumara agriculture, but that is a stereotyped and static view of this knowledge set. Tarahumara agricultural practices have always been evolving as they have adapted to a multitude of agricultural challenges before and have the ability to do so again. The use of chemical fertilizers and other types of modernization can still be seen as "indigenous" because they have been integrated with traditional techniques, and they support the overall objective to increase food sovereignty that sustains the local populations and helps to prevent migration. Migration is a much more serious threat to indigenous identity than is the embrace of new technologies (Bebbington 1993, 286).

8. Conclusion

Tarahumara agriculture has continually adapted as farmers shrewdly took what they needed from the Spanish techniques and used them alongside their traditional practices. Yet as recent famines show, the loss of livestock to drought and subsequent dispersal of young Tarahumara farmers present new tests to Tarahumara agriculture.

In response to these pressures, two trends developed to affect soil quality: the application of chemical fertilizers and the de-emphasis on the construction and maintenance of erosion control structures. An important foundation to maintain Tarahumara independence and their agricultural production is to protect soil fertility, a fundamental strategy of earlier Tarahumara agricultural practices. It is now more difficult to apply traditional agricultural strategies due to climate factors and globalization.

Further research that analyzes a larger sample size and that includes samples taken from less accessible areas in deep canyons and on rocky uplands is needed. Time is pressing for this vital work as Tarahumara out-migration continues, and those left behind use a diminishing amount of the traditional agricultural practices. Future works will aid the Mexican governmental and non-governmental organizations in the region to identify the most appropriate methods to provide assistance, if necessary, to the Tarahumara to maintain sustainable agricultural practices, to stem migration, and to maintain cultural traditions. Such assistance provided to the Tarahumara could focus on other aspects of their lives besides agriculture. The Comisión Nacional para el Desarrollo de Pueblos Indígenas, for example, promotes and supports projects to attain sustainable development and to achieve full rights for indigenous communities in Mexico. Their programs emphasize education, health, and infrastructure and are created to be sustainable, integral, and culturally pertinent in the long-term (CDI, 2014). They recognize that there are a variety of factors that can cause migration and the loss of cultural traditions, not just agriculture. Development that focuses on agriculture must be careful, however, so that it does not simply replicate hegemonic structures by reinforcing the binary perspective that only either modern agricultural technologies or traditional strategies can be correct. In an ever-changing world, the Tarahumara should be trusted to control their own agricultural future. If their unique agricultural strategies are still effective in a modern context and their other needs (e.g., education, health care, etc.) are also met, then their practice is likely to continue. A viable option for the development of Tarahumara agriculture might ultimately involve a combination of both modern and traditional agricultural strategies that takes the most effective of both approaches.

References

Bebbington, A. 1993. Modernization from Below: An Alternative Indigenous Development? *Economic Geography* 69(3): 274–92.

Bennett, W. and Zingg, R.M. 1935. *The Tarahumara: An Indian Tribe of Northern Mexico*. Chicago, Illinois: University of Chicago Press.

Brady, N. and Weil, R.R. 2004. *The Nature and Properties of Soils*. Upper Saddle River, New Jersey: Prentice-Hall Inc.

Briggs, J. 2005. The Use of Indigenous Knowledge in Development: Problems and Challenges. *Progress in Development Studies* 5(2): 99–114.

British Broadcasting Corporation (BBC). 2012. Food Aid Sent to Mexico Indians. (http://www.bbc.co.uk/news/world-latin-america-16593038). Accessed 10 Feb 2012.

Brown, D. 1982. Biotic Communities of the American Southwest: United States and Mexico. Desert plants, D. Brown (ed.), pp. 43-63. Salt Lake City, Utah: University of Utah Press.

Cleaver, F. 1999. Paradoxes of Participation: Questioning Participatory Approaches to Development. *Journal of International Development* 11(4): 597–612.

Comisión Nacional para el Desarrollo de Pueblos Indígenas (CDI). 2014. Quien Somos. (http://www.cdi.gob.mx/). Accessed 12 Nov 2014.

Denevan, W. 1989. Geography of Fragile Lands in Latin America. In *Fragile Lands of Latin America: Strategies for Sustainable Development*. J. Browder (ed.), pp. 11-24. Boulder, Colorado: Westview Press.

Doolittle, W. 2000. *Cultivated Landscapes of North America*. New York, New York: Oxford University Press.

Espinoza, L. and J. Ross. 2006. Chapter 4: Fertilization and Liming. In *Corn Production Handbook* Cooperative Extension Service, 23-45. Little Rock, Arkansas: University of Arkansas Press.

Harden, C. 2001. Soil erosion and sustainable mountain development. *Mountain Research and Development* 21(1): 77-83.

Instituto Nacional de Estadística y Geografía (INEGI). 2005. Tabulados de Población Mexico.

Kennedy, J. 1978. *Tarahumara of the Sierra Madre: Beer, Ecology, and*

Social Organization. Arlington Heights, Illinois: AHM Publishing Corporation.

Knox, J. 2002. Agriculture, erosion, and sediment yields. In *The Physical Geography of North America*, A. Orme (ed.), pp. 482-500. New York, New York: Oxford University Press.

Linares, F. 2008. Los Pueblos Indígenas de México. Mexico City, Mexico: Comisión Nacional para el de los Pueblos Indígenas.

Lumholtz, C. 1902. *Unknown Mexico: A Record of Five Years' Exploration among the Tribes of the Western Sierra Madre; in the Tierra Caliente of Tepic and Jalisco; and among the Tarascos of Michoacan*. New York, New York: C. Scribner's Sons.

Maddox, H. 1974. *Your Garden Soil.* Devon, United Kingdom: David & Charles Publishers.

Meyer, M., Sherman, W.L. and Deeds, S.M. 1995. *The Course of Mexican History.* New York, New York: Oxford University Press.

Pennington, C. 1963. *The Tarahumar of Mexico.* Salt Lake City, Utah: University of Utah Press.

Perramond, E. 2004. Desert Traffic: The Dynamics of the Drug Trade in Northwestern Mexico. In *Dangerous Harvests: Drug Plants and the Transformation of Indigenous Landscapes*, M. Steinberg, K. Mathewson, and J. Hobbs (eds.), pp. 209-217. New York, New York: Oxford University Press.

Shaw, W.S., Herman, R. and Dobbs, G.R. 2006. "Encountering Indigeneity: Re-imagining and Decolonizing Geography." *Geografiska Annaler: Series B, Human Geography* 88(3): 267–76.

Smith, J. 2008. Barranca del Cobre: North America's Other Majestic Canyon. *Focus on Geography*. 51(3): 1-10.

Treacy, J. and Denevan, W.M. 1994. The Creation of Cultivable Land through Terracing. In *The Archaeology of Garden and Field*, N. Miller and K. Gleason (eds.), pp. 91–110. Philadelphia, Pennsylvania: The University of Pennsylvania Press.

Tuckman, J. 2010. "Leaked Police Film Shows Mexico Drug War." *The Guardian*. (http://www.theguardian.com/world/2010/apr/15/police-video-mexico-drug-war). Accessed 10 Nov 2014.

Wilken, G. 1987. *Good Farmers*. Berkeley, California: University of California Press.