UTILIZING MICROCATCHMENT SYSTEMS TO INCREASE TREE ESTABLISHMENT RATES IN THE BOLIVIAN HIGH PLAINS

By

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The thesis: "Utilizing Microcatchment Systems to Increase Tree Survival Rates in the Bolivian High Plains" is hereby approved in partial fulfillment of the requirement for the Degree of MASTER OF SCIENCE IN FORESTRY.

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PREFACE

In 1998 I graduated from the University of California, Davis with a Bachelor of Science degree in Wildlife, Fisheries, and Conservation Biology. During my last year at Davis, I decided that I wanted to spend some time working and living abroad in a completely different culture from the one I had grown up in. The Peace Corps Masters International Program offered at Michigan Technological University seemed to fit perfectly with my desire to have a unique cultural experience while continuing to further my education and career goals. Following a year of forestry related classes at Michigan Tech, I was assigned to serve in the Peace Corps Natural Resource Project as a forestry and soil conservation Volunteer in the country of Bolivia.

In my two years in the Peace Corps, I spent my time bouncing between two separate jobs. The site to which I was assigned to work at was a small university research station located in the high plains of Bolivia. As a Volunteer at this station I worked on a variety of different projects from soil conservation extension work with local Aymara farmers to teaching nursery management courses at the university. In the second year of my service, my counterpart Jesús Cárdenas and I implemented a UN funded project to construct 10 rainwater catchment ponds benefiting 40 farm families in a community near our station. While at this station, I experimented with a number of different water harvesting techniques to increase crop production. After repeated failures in establishing trees in our area, I decided to initiate a study whereby water-harvesting techniques were adopted to individual trees so as to increase their survival through the harsh high plains winters.

In my other capacity within the Peace Corps, I worked as the Roving Technical Assistant to the Associate Director of the Natural Resource Project in Bolivia. In this job I traveled throughout the country visiting other Volunteers within our project in order to assist them with project design and development. I also played an active role in organizing training activities for new Volunteers, helping with site development, and putting together various national workshops on the environment. While in my service, I was selected to participate on the Project Advisory Committee of Peace Corps Bolivia and helped reorganize and write the Natural Resource Project plan for the next five-year cycle.

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To my parents, friends, and family I want to say thank you for allowing me to go traipsing all over the world while letting me know that I always have a home to come back to. Finally, I want to thank my grandfather Saul Cohen. You are an inspiration to us all.

ABSTRACT

The Bolivian high plains is an area where forestry production is limited. A combination of high altitude, low rainfall, and variable climate all contribute to cause extremely high mortality rates among tree species. The use of microcatchment systems around the world has helped to significantly increase tree survival and establishment rates over time in a number of dry areas. Through the harvesting and collection of rainwater around a plant, these systems serve to moderate climate variations and increase the amount of water available for plant uptake.

The purpose of this study was to examine whether microcatchment systems can improve tree establishment rates in the Bolivian high plains. Five treatments were selected and laid out in a randomized block design of ten blocks along a hillside located on the Centro Experimental Agropecuaria Condoriri (CEAC) in the Bolivian Department of Oruro. Two tree species, one native (*Polylepsis tarapacana*) and one introduced (*Cupressus macrocarpa*), were planted in each of the treatments at the beginning of the rainy season. Survival data was collected every two and a half-months throughout the one-year study period.

Overall survival rates after the end of the study varied according to treatment. Treatment number two, the pit planting method, showed 80% survival while the control treatment had a survival of only 45%. Survival for the introduced species varied widely among treatments. In the case of the native species, survival rates did not show statistically significant variation among the treatments. Species adaptability and planting treatment structure played a large part in the overall survival of tree species in this study.

Chapter 1: Introduction

When I first arrived to the Bolivian high plains as an agroforestry and soil conservation volunteer, I had a lot of ambitious plans about stocking the entire region of San Antonio de Condoriri with trees. Initial meetings with the farmers of this area had convinced me that trees would be a valuable and highly desired resource. Farmers who had successfully grown trees in their home patios displayed them to me with pride and often asked me when they might be able to get some more trees to plant.

Although the previous volunteer at my site had planted thousands of trees, a large number of them had died by the time of my arrival. I was positive that I could do better. So, for the first year of my service I set to work undertaking traditional planting and seeding methods in my nursery. I was confident that by the time the next rainy season came, I would be ready to successfully transplant thousands of tree seedlings.

A year passed and the rainy season was returning. Knowing this, my counterpart Jesús Cárdenas and I outlined an ambitious tree-planting program where over 6,000 trees of two native and three introduced species would be planted in various locations around the valley. In order to get the entire project done in time for the rainy season, we enlisted the help of students, workers, farmers, and anybody else we could find to help with digging holes and planting trees. By the end of November, all the trees were planted in the ground and awaiting the rains to come.

Then, disaster struck. The rains which normally come in early December did not arrive. Although we did our best to irrigate the trees we could, late frosts swept through the valley and within less than a month, 90% of the trees we had planted were dead. Lack of water and extreme cold had devastated our well-laid plans.

Prior to the initiation of this project, I had been reading up on studies of water harvesting in arid lands. Since the previous fall, my counterpart and I had been busily working at constructing and testing different methods to prevent soil erosion and capture water runoff in cropping systems. After our failures in the first year's plantation, I decided to adapt water harvesting methods to tree systems using microcatchment systems.

My objectives for this study are to examine ways in which tree establishment rates on the Bolivian high plains can be improved upon. Through the application of microcatchment systems, I hope to provide a viable option to farmers and extension workers looking to promote forestry activities throughout this region.

In chapter two I will discuss the country of Bolivia where the study took place. I will begin with an overview of the country by discussing its various geography, people, and resources. Following this information, I will give a historical account of Bolivia up through the present day.

Chapter three will discuss the background on this particular study. I will begin by outlining the Department of Oruro and the Cercado province. I will then talk about the community of San Antonio de Condoriri as well as the Centro Experimental Agropecuaria, Condoriri (CEAC) where the actual trial took place. Finally, I will continue with climate data for the calendar year.

In chapter four I will give background information on microcatchment systems. This will include definitions, historical uses, and benefits associated with their use. I will also briefly discuss their adaptability to the high plains region of Bolivia.

Chapter five will outline my methodology as well as present the data collected during this experiment. I will begin with a discussion on experiment design and layout followed by a description of the soil type and the species used in this study. I will then present the various data I collected throughout the trial period

I will continue in chapter six with the results and discussion section of this experiment. I will start with an analysis of my study followed by a comparison of my results to other studies. Some discussion as to the results of my experiment will be covered toward the end of this chapter.

Chapter seven will cover conclusions drawn from this experiment. In this chapter I will define the results of this study as they relate to present day conditions in the Bolivian high plains. I will also discuss possible further studies that could be conducted based on the information gathered from this trial.

Chapter 2: Background Information on Bolivia

Few countries in the world are able to match the diversity that encompasses the present day nation of Bolivia. Covering 1,098,591 km^2 (INE, 2002), Bolivia is centrally located in South America (Figure 1) and straddles a region encompassing the Andes down through the lower valleys and foothills and eventually into the Amazon Basin. Landlocked since the 1880s and bordering Argentina, Brazil, Chile, Paraguay, and Peru, the varying ecosystems stretch over a territory slightly smaller than Alaska and more diverse than many other nations in the world.

Politically, Bolivia is divided into nine states or departments. The departments are La Paz, Oruro, Cochabamba, Beni, Pando, Tarija, Potosí, Santa Cruz, and Chuquisaca (Figure 2). The most populated departments are La Paz, Cochabamba, Santa Cruz, and Oruro. Largely due to their inaccessibility, Beni and Pando are the least populated departments.

Figure 1: Map of South America, CIA, 2002

Figure 2: Political Map of Bolivia, INE, 2002

Bolivia is considered to be a country with a high birthrate (27.12 Births/1,000 individuals). Rural birthrates tend to be higher than those in urban areas (INE, 2002). The average Bolivian home consists of 4.5 members with the male as the nominal head in 81% of the cases. The infant mortality rate has decreased significantly in the last twenty years, down from 151 per 1000 live births in 1970 to and estimated 59 per 1000 births in 2001 (CIA, 2002; INE, 2002).

Bolivia has a young population. Of the total population of 8,300,463 people, those under the age of fifteen number 3,192,446 (38.46%). The economically active age group (ages 15-64) constitutes 4,727,085 people (57.07%) (CIA, 2002).

The official languages in Bolivia are Spanish, Quechua, Aymara, and Guarani. Approximately 87.4% of the population over six years of age speak Spanish as their primary language. Other languages spoken are Quechua (34.3%), Aymara (23%), various foreign languages (3.1%), Guarani (1.0%), and various other indigenous languages (0.6%) (INE, 1993). Albo (1989) estimates that within the overall population of Bolivia there are approximately 2,500,000 Quechua speakers, 1,600,000 Aymara speakers, and 60,000 Guarani speakers.

Women's involvement in the economy has grown from 18% in 1976 to 38% in 1992. The number of women economically active has risen 300% during the intervening period from 337,000 to 986,000 women. This increase has taken place in both rural and urban areas, but especially in the rural areas where the percentage has risen from 15% in 1976 to 48% in 1992 (INE, 1993).

Of the economically active male population in Bolivia, the major fields of employment are agriculture, business, clerical, forestry, machine operators, and manual labor. In the case of women, agriculture, forestry, service industry, middle level technicians and professionals, and manual labor are all sectors which serve as major areas of employment (Montes de Oca, 1997; Valdivia, 1996).

Geography of Bolivia

Bolivia can be divided into three main geographic regions, the high plains (*altiplano*), the valleys (including subtropical foothills), and the tropical lowlands (Figure 3). Although the lowlands of Bolivia cover approximately 60% of the surface area of Bolivia, they remain relatively unpopulated as a result of their inaccessibility. Approximately 74% of the current population is located in the valleys and high plains regions (INE, 2002).

Figure 3: Geographic Map of Bolivia's Three Zones (adapted from CIA 2002)

High Plains Region:

The high plains region consists of an enormous flat expanse of land located at high altitudes. This region, stretching from its northernmost reaches along the banks of Lake Titicaca to some 805 km (500 miles) south, is located at an average altitude of 4,000 meters (13,000 feet). Geologically speaking, the high plains represents a sediment filled valley formed when the Andes split into two separate mountain chains known as the Occidental and the Oriental ranges (*Codillera Real*). This large, flattened region varies in width from a few kilometers at the northernmost point to a few hundred kilometers in the central areas. This expansive landform is also within Argentina, Chile, and Peru. Approximately two thirds of the 31,250 km^2 (50,000 miles^2) of the high plains fall within Bolivian territory (Hudson and Hanratty (ed.), 1989, 52; Sweaney 2001, 13-15).

The high plains region is delineated by three major lake systems. Lakes Titicaca, Poopo, and Uru Uru are connected to each other by the Desaguadero River which runs from Lake Titicaca on the Peruvian border to Lake Poopo within the Department of Oruro. Lake Titicaca, the more important of these three systems, has been the historical focal point for most Bolivian Pre-Columbian civilizations. The highest navigable lake in the world, its waters irrigate some of the most productive farming lands in the whole region and moderates local weather patterns through the creation of a huge microclimate resulting from evaporation of the Lakes' vast surface area of 9,064 km^2 (5,665 $miles^2$). Lake Titicaca has a depth of 457 meters (1,500 feet) with an approximate surface length of 230km (144 miles) and width of 97 km (60 miles). The smaller Lakes Poopo (Figure 4) and Uru Uru are fed primarily from the Desaguadero River which functions as the only outlet for Lake Titicaca. These two lakes represent an important fishing resource to the people of the central and southern high plains region but are largely shallow, salty puddles measuring at most only a few meters deep at their deepest points (Sweaney 2001, 15; Hudson and Hanratty (ed.), 1989, 53).

Figure 4: Pink Flamingos on Lake Poopo

Traditional agriculture and domestic systems in this area are based primarily on potatoes (*Solanum sp.*) and other nutritional root crops (fam. *Solanaceae*). Potatoes were originally domesticated in the Lake Titicaca region thousands of years ago and were central to the development of the Andean civilization. Since they can be dehydrated and naturally frozen so as to be available for consumption at a later date, these root crops provide an important year round food source to local inhabitants. Some other important crops to this area are quinua (*Chenopodium quinoa* Willd.), a high-protein grain, and introduced grain crops such as wheat (*Triticum sp.*) and barley (*Hordeum sp.*). Vegetables such as onions (*Allium cepa* L.) and carrots (*Daucus carota* L.) are also widely planted. Andean cameloids have traditionally played an important role in the high plains society and their wool and meat has provided sustenance to the inhabitants of the region since time immemorial. The introduction by the Spanish of old world livestock into this region has led to the widespread use of sheep and a more limited dispersal of other animals such as cattle, pigs, and chickens. Today, the high plains farmers use most of their production for subsistence with only 30% of their harvest going to markets in cities and local towns. Cultivation is done on an annual basis during the fall months of April-June. According to the 1992 census, 45.0% of the total population of Bolivia can be found in this region (Montes de Oca, 1997, 75-78).

The western part of the high plains run into the Occidental range. This rather narrow and relatively unbroken range averages around 5,000 meters (16,500 feet) in altitude and rises to over 6,400 meters (21,000 feet). Moving westward, the Occidental mountain range descends into the Atacama Desert, one of the driest deserts in the world, along the coasts of Chile before disappearing in the Pacific Ocean. Lacking major water sources, fertile soil, and any substantial mineral deposits outside nitrate and copper concentrations in the Atacama Desert, the altiplano region leading up to this range is relatively uninhabited (Cuzmar, pers. com., 2001).

Andean Inter-Mountain and Valley Regions:

At the eastern edge of the high plains the Oriental or Cordillera Real range begins. This range, more broken and expansive than the Occidental range, consists of numerous fertile valley systems and river drainages which run from an altitude of 4,300 meters (14,000 feet) down to just a few hundred meters above sea level. A dry, temperate climate, relatively stable water supply, and large open plains with fertile soils and accessibility to the high plains region generally characterize the higher valleys. The largest population concentrations are located in the areas of Cochabamba, Tarija, Chuquisaca, and Western Potosi (Hudson and Hanratty, 1989, 55; Lopez Levy, 2001,88)

Traditional agricultural systems in these areas include crops such as corn (*Zea sp.)*, fish, fruits, tomatoes (*Lycopersicon lycopersicum* L.), and beans (fam. *Fabaceae*) as well as a variety of introduced crops such as wheat, barley, and vegetables, particularly onions. Livestock systems in this area rely predominantly on the use of old world species such as sheep, goats, cattle, chickens, and pigs. In the valleys of Bolivia farmers cultivate biannually in small plots averaging between five and ten hectares per family. According to the 1992 census, 28.9% of the total population of Bolivia can be found in these regions (Montes de Oca, 1997, 78).

Stretching down from these highland valley areas the Cordillera Real begins to descend into sub-tropical and tropical foothill regions fed by rains and humid winds from the Amazonian basin. These lush areas comprise a number of small, vertically oriented ecosystems with high rates of biodiversity and have historically represented the frontier of most highland human intrusions into the tropics. They are divided into two main regions known as the Yungas and the Chapare.

The Yungas region extends from the north of the La Paz region. More easily accessible by humans to the high plains regions, these areas provided important crops such as coca and maize during Pre-Columbian times and coffee and citrus fruits following colonization by the Spaniards. The Chapare region remained relatively uninhabited until the late 20th century and is located as the interrogatory land space between the high valleys of Cochabamba and the lowland areas of Santa Cruz. (Lopez Levy, 2001, 13; Klein, 1992, 6-8)

Lowland and Amazonian Basin:

The lowland and Amazon Basin represent around 60% of the total landmass of Bolivia. Yet until the twentieth century they remained largely unpopulated. This area encompasses the present day Departments of Santa Cruz, Beni, and Pando and are dominated by two great river systems which function to drain this vast area into Amazonian tributaries in Brazil and also via Paraguay into the Atlantic Ocean. Characterized by hot, flat, expanses of forested lands, these areas contain some of the highest biodiversity in the world and the world's eighth largest contiguous landmass of natural forests according to the World Resources Institute (Mittermeier and Oates, 1985, as cited in Mittermeier, 1988).

To the south of the country, the Chaco region hosts a variety of forest ecosystems from the lush tropical regions of Monteagudo in the Chuquisaca department to the dry shrubby forests near the Paraguayan and Argentine borders.

Agricultural systems in the lowland areas are generally more commercialized than in other regions of the country with the extensive development and use of large monoculture and mechanized agricultural systems. The principle crops of this region are soy and sugar with production occurring on a year round basis. According to the 1992 census, 26.1% of the total population of Bolivia can be found in these areas (Montes de Oca, 1997, 78).

Natural Resources:

The natural resources of Bolivia are the property of the Bolivian state which has a duty to administer them for long-term sustainability. The state assumes the position of principle regulator over the exploitation and use of these resources in order to guarantee their proper use. The use of renewable natural resources within Bolivia cover agriculture, livestock production, water, wildlife management, and forestry.

The forestry resources within Bolivia constitute forested lands and all the natural resources that exist within it to form the forest ecosystem. In Bolivia in 1975 there was 564,684 km^2 (352,865 $miles^2$) of forested land (approximately 51.4% of its territory). In 1993 the total forested land consisted of 534,492 km^2 (334,058 $miles^2$). Deforestation within Bolivia does not yet present a serious problem relative to other Latin American countries as it accounts for less than one percent of its total lands per year (Montes de Oca, 1997, 471). However, clearing of forested lands are becoming more and more common and lead directly to land degradation in many cases. Forested lands range from humid tropical forests in the Amazon basin to sparse open forests located at more than 5,000 meters (16,400 feet) above sea level in the high plains, the highest forests in the world (Argollo *et al.*, 2001). These forests cover more than 50% of the total landmass and play central roles in the environmental and economic aspects of Bolivian life.

Bolivia contains some 20,000 species of plants and 10,000 species of animals (Montes de Oca, 1997). Some 316 species of mammals from ten orders and 36 families and representing 35.5% of the fauna species of South America have been described (Ergueta and De Morales, 1996). According to Hershkovitz (1972 as cited in Ergueta and Sarmiento, 1992) South America contains 810 species of mammals which represent 20% of the species in the entire world. The eighteen species of primates found within Bolivia place it within the top fifteen countries in the world for primate diversity (Anderson, 1985; Mittermeier, 1988).

Approximately 3,100 species of resident and migratory birds exist in South America. Because of the diversity of its ecological regions, Bolivia has one of the richest avifaunas in the world with more than 1,274 species recorded, representing 41% of the total bird species in South America (Arribas *et al*., 1995). Bolivia has the sixth largest number of birds in the Neotropics and seventh worldwide (Mac Neely *et al*., 1990, 90).

In addition to 112 species of amphibians, Bolivia contains 220 species of reptiles including 125 species of snakes and five species of crocodiles. (Ergueta & Sarmiento, 1992; Ergueta & Pacheco, 1991; King & Videz-Roca, 1989; Fugler & De La Riva, 1990; Fugler, 1989; Peters and Donoso-Baros, 1986; De La Riva, 1990).

History of Bolivia

Early Human Settlement:

The first humans came to the high plains of Bolivia more than 10,000 years ago. It is presumed they had arrived via the Bering Strait from Siberia and migrated from North and Central America or by boat via the Pacific Ocean. Due to the relative openness and ease of travel that the high plains provide, as well as the fertile grasslands that produced game in abundance, the high plains became an obvious point of settlement for various nomadic groups. Beginning in 8,000 B.C. these people began to experiment with the domestication of various plants (Roman, 1993).

Around 2,500 B.C. the first settlements and relatively urban areas arose in the high plains region. Traditional agriculture was practiced for the first time on a more permanent scale with crops such as potatoes (*Solanum sp.*) and Quinua (*Chenopodium quinoa* Willd.*)* forming the basis of their diet. In order to improve agricultural production, complex irrigation, soil conservation, and water catchment systems were developed and widely used. During this time the first domestication of Andean cameloids began with llama and alpaca (Klein, 1992, 12-13).

Around the year 1200 A.D., seven different kingdoms arose which were loosely connected by a common language and origin. Presumably originating from the shores of Lake Titicaca, the Aymara kingdoms were to become the dominant force in the high plains region of Bolivia up to the time of the Spanish Conquest (Gisbert *et al*., 1996).

The class structure of the Aymara peoples was well defined into a number of ayllus, or kin groupings with each grouping divided into nobility and commoner castes. Slaves and serfs appeared outside of these classifications (Klein, 1992, 16-17).

Each group of ayllus had colonies working for them in the coast and valley regions, supplying them with goods unobtainable in the high plains regions. Movement within these various zones by the ayllus was common with a member having properties in a number of the different zones. A barter system organized along kinship lines developed between the colonists and high plains kingdoms in which llama meat, wool, potatoes, and other products were exchanged for maize, coca, fish, and fruits. This barter system formed an essential part of the Aymara culture and helped to establish their supremacy within many different ecological zones (Klein, 1992, 15-17). Their distribution and relationship of vertical trade was to remain the dominant system in Bolivia up through the present day.

Around the beginning of the fifteenth century, a new group began to conquer the high plains region of Bolivia. Arriving from the Peruvian region of Cuzco, these people became known as the Incas, named after their king. Although they had existed as a people since the twelfth century, their status up until the fifteenth century was one of a minor chiefdom. At around the year 1440 the Incas began their conquest of neighboring regions and within a span of 50 years managed to bring under control most of the central Andes (Lopez Levy, 2001, 11) (Figure 5).

Known for their highly organized society and craftsmanship, the Quechua speaking Incas established a complex system of roads and storehouses throughout their realm and ruled their conquered peoples through a system of taxation and strict moral codes. Best described as a system of social welfare, the Incas collected tribute in the form of foodstuffs and trade goods from the prosperous regions of their empire and distributed them evenly to the poorer regions (Brundage, 1963).

Figure 5: Traditional Quechuan Dress

With the arrival of the Incas into Bolivia, surprisingly little changed within the Aymara structure. Known as the Kollasuyo region (one of four Incan regions), the Incan conquerors retained the ayllu system and local rulers extracted tribute for them. Until the revolt by Aymara rulers around 1470, Inca rulers maintained an indirect control over the Aymara regions. Following this revolt however, a number of Quechua speaking colonies were established in Aymara areas with Quechua eventually supplanting Aymara as the dominant language in many of these regions. Today, the Aymara people maintain pride in the fact that they were the only indigenous group never to be fully conquered and assimilated by the Incas (Figure 6). Only eighty years after the rise of the Incan empire, their rule came to an end with the arrival of the Spanish empire (Aymara, 2002).

Figure 6: Aymara Women Parade in Traditional Dress Displaying the Aymara Flag

Colonial Conquest and Society:

Without a doubt, the most profound impact on Bolivian society came in the year 1531 when the Spanish conquistadors, headed by Francisco Pizarro and Diego de Almargo, arrived in present day Ecuador. Less than two years later the Incan Empire had been defeated and dissolved with the spoils being divided up among the conquering Spaniards.

The initial conquest of the Incan Empire came about rather easily. In the late 1520s a civil war had broken out in which an Incan nobleman named Atahuallpa overthrew his king half-brother Huascar and assumed the throne as the descendent of the Sun God. This led to massive civil war within the empire with the Aymara section of the empire siding with the Huascar factions. Utilizing this knowledge and their superior technological capacities, a few hundred Spanish soldiers were effectively able to maneuver themselves into both camps and eliminate all organized resistance. This, tied with local beliefs in white bearded gods, made conquest fairly easy. Consequently, a population of around a million inhabitants was easily subdued (Brundage, 1967).

In 1572-1576 Lima Viceroy Francisco Toledo visited the region of Bolivia (then known as Upper Peru) and completely reorganized the communal structure. Toledo ordered all communities to be concentrated into fixed villages and town in order to facilitate taxation. This style, evidently adapted from the Mediterranean system of communal organization, had the effect of ending all vertical movement of peasants and placed them more firmly under the control of the Spanish crown. Through these decrees, Toledo created a system of rural and social organization which continues today (Klein, 1992, 38-39).

Revolution and the Formation of a Republic:

In 1809, with the Spanish empire waning, Bolivia became the first country to formally declare independence from Spain. In the twenty years that followed, Bolivia would be liberated and recaptured a number of times by armies from both sides of the conflict with each change followed by massive destruction and looting. Finally, in December of 1824, Bolivia was liberated by Simón Bolívar as the last remnants of the Spanish Army were defeated in two decisive battles in the areas of Ayacucho and Junin in Peru. On August 6, 1825 the Republic of Bolivia was formally established with the capital located in the city of Sucre (then known as Chuquisaca). In honor of their liberator Simon Bolivar, Upper Peru adopted the name Bolivia (Lopez Levy, 2001, 14; Van Lindert and Verkoren, 1994, 13).

In the year 1879, Bolivia entered into the War of the Pacific with Chile over nitrate rich fields in the Atacama Desert. Poorly led and trained, Bolivia was forced to sue for peace in December 1879 leaving Chile all of Bolivia's previous coastal territories. Although Bolivia has lost an estimated 1,274,695 km^2 (796,684 $miles^2$) to Brazil, Chile, Paraguay, and Peru, the 120,000 km^2 (75,000 $miles^2$) lost during this war to Chile remains the hardest and most remembered. To this day, Bolivian school children sing songs about reclaiming the coast, the country has a national day of remembrance for this lost territory, and the department seal for that region remains on all national maps (Van Lindert and Verkoren, 1994, 14).

Throughout the late nineteenth and early twentieth centuries, the Bolivian government progressed into a more stable and democratically functioning body.

However, this transition was in no way inclusive of all sectors of society. The Bolivian government grew to cater to the elite Spanish descendants (Creole) who lived in urban areas and spoke Spanish. This effectively excluded the large rural Aymara, Quechua, and other populations from all national participation and largely barred them from the electoral process. Political parties were formed only to represent those Creole or Mestizo (Spanish/Indian mixed descendant) elite who lived in the cities or functioned as plantation or mine owners in the countryside.

On June 14, 1935, a devastating war with Paraguay ended that had resulted in huge loses on both sides. As a result of the internal chaos imposed by this war, the Bolivian military assumed power through a revolt. However, the excesses of the army and discontent among the labor movements at the pace of government reform soon led to open revolution and hostility. On April 9, 1952, the city armories were opened to the public and the army led government met its defeat at the hands of the armed movement (Hudson and Hanratty (eds.), 1989, xxix).

The revolution of 1952 brought about new long waited reforms for the indigenous population. Led by president Victor Paz, the government seized and nationalized the mining sector, instituted broad educational reforms, gave universal suffrage rights to all its citizens, and took part in an aggressive agrarian reform program which distributed all plantation land to its peasants. Until that point, most indigenous peasants lived and worked on lands owned by wealthy men of Spanish descent. The seizure and redistribution of this land led for the first time to widespread land tenure and freedom from oppression for the long suffering indigenous population. The universal suffrage further helped to vastly increase the political power of the revolutionary parties as the voting public increased from 200,000 to just under 1,000,000 people (Molloy, 1970).

However, despite reforms initiated following the revolution, little economic and social progress was made in Bolivia. In November 1964 the military performed a relatively bloodless coup and placed power into the hands of Vice President General Rene Barrientos. In the following eighteen years, a series of dictatorships and weak military backed governments would vie for power while achieving little actual progress in the area of economic or social development (Molloy, 1970).

Weary with long periods of authoritarian rule the populace began to demand a return to democracy. In 1982, General Celso Torrelio Villa was forced to resign. Later in the same year, Congress elected Harnan Siles Zuazo as the president of Bolivia. From that point on, democracy and open market programs have steered Bolivian government policy (Klein, 1992, 70-73).

Throughout the 1990s heavy foreign investment has helped spur development programs. Although the economy suffered a recession and national protests as a result of the U.S. imposed coca eradication programs, the country has maintained a democratic process and developed its national economy. Large sectors of the economy became privatized and in order to spur rural development, the law of popular participation mandated that 51% of all profits from national industries would be steered toward infrastructure development and the building of medical facilities and schools in rural areas (Aguabolivia 2002).

Although recent widespread protests have hindered economic growth, Bolivia nonetheless stands poised to maintain its progress and development well into the next century. New programs aimed at educational reform and social development in the areas of gender relations have recently begun. National free vaccination campaigns and yearly pensions to the poor have helped to create greater stability.

Sectors of the government which have recently received much attention have been those that deal with the environment and sustainable agriculture. Within the last ten years, a flood of new laws including the Law of Popular Participation and the Law of the Environment have provided new resources to farmers and technical trainers wishing to promote greater environmental stewardship. New efforts aimed at reforestation of degraded lands, reducing erosion and flooding, and land reclamation have begun to see widespread use in rural areas. One such example where these methods are being introduced is at the Centro Experimental Agropecuaria, Condoriri in the Department of Oruro.

Chapter 3: Background on the Area of Study

The study was conducted in the community of San Antonio de Condoriri, located within the Cercado province in the Department of Oruro (Figures 7 and 8). This area is classified according to Montes de Oca as the Eastern Central Rangelands and is characterized by "porous volcanic rocks, sparse grassland vegetation, and high rates of erosion" (Montes de Oca, 1997, 156). According to the Preliminary Map of Soil Erosion, the region is distinguished as having levels of erosion between 101-200 tons/hectare/year (Ministerio de Des. Sos., 1998, 28). The trial was conducted at the Centro Experimental Agropecuaria Condoriri (CEAC) or Agricultural Research Station at Condoriri (Figure 9).

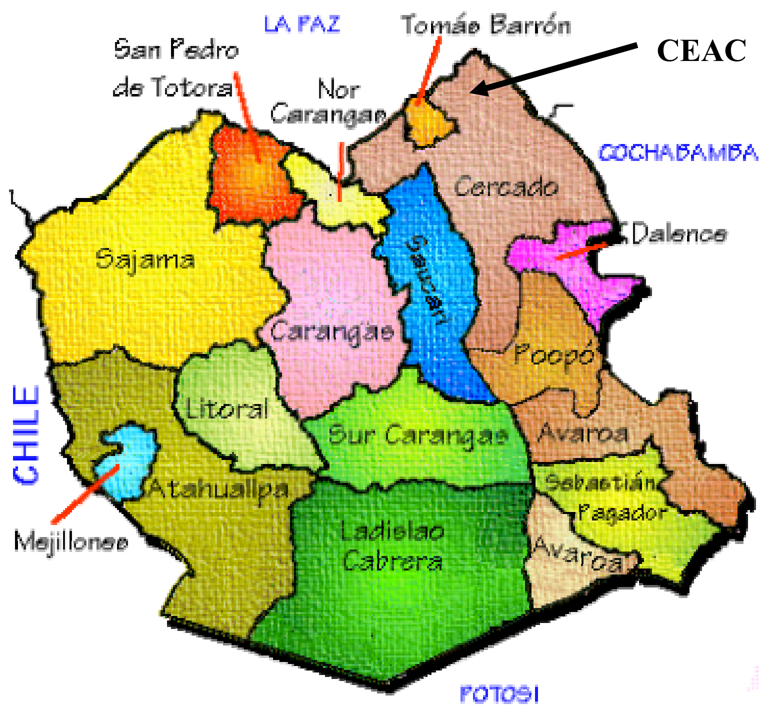


Figure 7: Map of the Department of Oruro, INE 2002

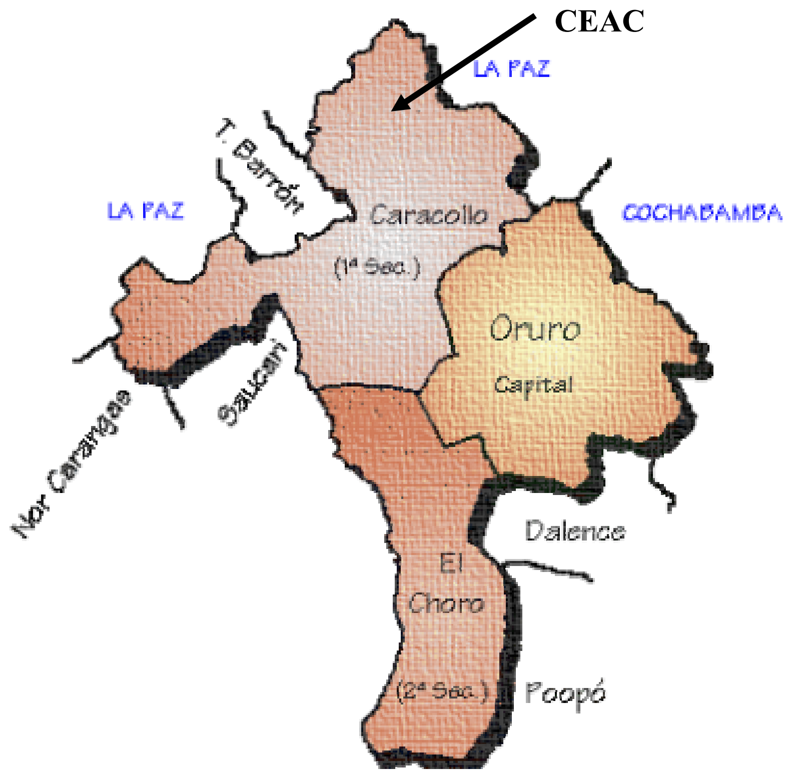


Figure 8: Map of Cercado Province, Oruro, Bolivia INE 2002

CEAC is located on the Bolivian central high plains region approximately 56 km north-northeast of the capital city of Oruro (pop.183, 422) (INE, 1993). The center spans approximately 2,084 hectares and is located at an altitude of 3,830 meters (12,562 feet) above sea level. Average rainfall is approximately 350 mm/year (14 inches/year) and average temperatures range from -18°C to 15 °C (0°F to 60°F). Rainfall is unimodal in its distribution with the majority arriving in the summer months of December through March. Natural vegetation consists largely of prairie grasslands intermixed with shrubs and bushes.

The station is funded and operated by the Oruro Technological University (Universidad Tecnicá de Oruro) as a research and extension center. A variety of researchers (*técnicos*), students, and farm hands work at the center and focus their efforts on a range of agricultural sectors. My main function at the center was to act as a liaison within the local communities to promote agricultural practices aimed at increasing sustainability of farm production.

Figure 9: CEAC

Surrounding CEAC are a number of smaller communities collectively known as the Center (Central) of San Antonio de Condoriri. These communities consist largely of the original ayllu kin groupings normally dominated by one or two families. The Center of San Antonio de Condoriri is made up of four separate village groupings (Q'aqani, Ocovinto, Cala Cruz, and Antiloco) which each elect representatives to participate in the larger political entity of San Antonio de Condoriri. The leader of the Center is known as the general secretary (secretario general) who is elected by the larger community on two-year cycles.

San Antonio de Condoriri is a poor community without access to running water or electricity. The average farmer has a life expectancy of 64.06 years (INE, 2002).

According the National Statistical Institute (INE, 1993), the population density for the Cercado province is between 5.0 and 14.9 people per hectare with sparser populations being located in the rural regions. The Cercado province has a population growth rate of 2.04% per year (Montes de Oca, 1997, pg. 89-95) and the sectional capital of Caracollo has an estimated population of 11,547 inhabitants including the nearby Center of San Antonio de Condoriri. The most widely spoken languages in this region are Aymara (63%) and Spanish (71%) with most people speaking only Aymara until they reach school around six years of age (INE, 2002).

Agricultural Production:

Of the 65,000 different family farms within the central high plains zone, 66% of them are less than five hectares in size. The average farmer in this area earns around $250 a year from his crops and animals with only ten percent of their total land considered cultivable. The rest of their lands are dedicated to grazing systems (Cárdenas, pers. com., 2000; Montes de Oca, 1997, pg. 406). Most farm production relies heavily on animal draft systems for plowing as well as manual labor. Small family farms are the norm with most families managing an integrated system of livestock and agriculture. When possible, animal fertilizer from sheep, cattle, and llamas are added to the fields to increase production. Green fertilizers are not commonly used in this area.

The majority of agricultural production in the surrounding area lies in seasonal rain-fed crop systems that produce a limited variety of crops such as potatoes, wheat, onions, barley, and quinua (Tables 1 and 2). These systems are small scale and limited to areas where soil productivity remains relatively high. However, because of problems with erosion and climate variability, this method gives variable yields depending on the farming parcel and weather characteristics for that year.

The preferred but more costly system of farming in the area is irrigation. This system relies on water pumps to remove water from sub-terranean aquifers or from a nearby river system for watering in traditional furrow agriculture. This system allows for larger and more variable crop production including carrots, beets (*Beta vulgaris* L.), lima beans (*Phaseolus lunatus* L.), and alfalfa (*Medicago sp.)*. However, given the cost of running and obtaining the pump, this method is not available to all families. Only approximately 1000 ha. of land within the Caracollo province are currently under irrigation with a large portion of that number (400) falling under CEAC lands (Cárdenas, pers. com., 2000). Local farmers rarely utilize soil conservation practices. However, in recent years there has been a slight increase in the adoption of basic soil conservation practices such as trenches and contour farming in the areas surrounding the research station (Figure 10).

Figure 10: Soil Conservation Work in San Antonio de Condoriri

Table 1: Principle Crops of Oruro

Crops	**1995 (Metric Tons)**
Potato	31,582
Berza Barley	25,400
Alfalfa	20,300
Quinua	6,200
Lima Bean	5,600
Sweet Potato	3,100
Barley	2,290
Onion	2,000
Total	**96,472**

Source: Valdivia, 1996

Table 2: Oruro: Surface Area, Yield and Production/Year/Crop 96/97

	Area (Ha.)	Yield (kg/ha)	Production (m.t.)
Potato	8,540	4,370	37,320
Alfalfa	5,596	5,282	29,557
Quinua	10,045	755	7,584
Lima Bean	4,771	1,521	7,255
Grain Barley	5,039	616	3,104
Wheat	842	580	488
Pea	112	1,118	125

Source: INE, 1998

Livestock Production:

Most families within the area rely heavily on livestock production to augment their income. Pasturing is primarily on communal lands and controlled by the women or children (Figure 11). Sheep, llamas, swine, and cattle are the most common species. Of these four animals, only llamas are native to Bolivia. The other species were introduced by the Spaniards during colonial times and have since become an integral part of Bolivian agriculture. In a preliminary survey of farmers from the community of San Antonio de Condoriri, the average farmer was found to have approximately 68 sheep, six llama, and five cattle (Appendix 1).

Owing to overstocking and overgrazing problems associated with a dense population, animal quality and net annual production are relatively low. These problems could and are being addressed by local extension agents who are currently working at better animal selection and more selective grazing practices with local farmers. However, the economic benefits of owning many animals rather than fewer (livestock act as stored wealth) has limited the adoption of these methods.

Figure 11: Sheep and Llama Grazing in Condoriri

Forestry Resources:

Largely due to human land degradation, only small relic patches of open Quenua forests remain in the Department of Oruro. The main woody plant found within the region is *Baccharis dracunculifolia* L. which exist as a low-lying shrub and is used primarily for cooking wood (Figure 12). "Thola", as it is more generally known, is found in more humid soils and is an indicator species for soil moisture. Due to its short height and crooked trunk, this shrub is undesirable in terms of plantation cropping and is often treated as a pest plant by farmers wishing to use the more fertile, humid soils for cultivation.

Figure 12: Harvesting of "Thola" for Firewood

Most attempts at forestation within this area involve the use of a few species such as native Quiswara (*Buddleja diffusa* Ruiz & Pav.), Sauce Mimbre (*Salix humboldtiana* Willd.), and Retama (*Senna chloroclada* Irwin.). Non-native trees commonly used in the region are Monterrey Pine (*Pinus radiata* D. Don), Elm (*Ulmus campestris* L.), eucalyptus (*Eucalyptus sp.)*, aspen (*Populus sp*.), and various cypress species (*Cupressus sp*.). Owing to a variety of climatological obstacles, mortality rates among newly planted trees are very high. Because of these challenges, farmers tend to plant trees in areas only where they can be protected from the harsh climate and provided with adequate water.

The areas in Condoriri where trees are most widely planted are home patios or village squares (Figure 13).

Figure 13: Farmhouse in Condoriri with Trees in Front Patios

Climatological Data:

Since 1964, Centro Experimental Agropecuaria Condoriri (CEAC) has been regularly recording meteorological data. The weather monitoring station, located approximately 0.5 km (0.3 miles) from the experimental plot used in this study, records daily maximum and minimum temperatures, relative humidity, precipitation, evaporation rates, wind velocity, cloud cover, and soil temperature.

Table 3 shows a report of the climatological conditions broken down per month over an agricultural season. Because of their direct influence on agricultural production and tree survival, we pay the closest attention to the numbers on precipitation and temperature.

Average rainfall taken over a twenty-year period for the high plains region is 356mm. The rainfall patterns of the Cercado province do not vary greatly from this information (Table 4).

Table 4: Maximum and Minimum Precipitation Rates from Various Weather Stations (in millimeters)

Agricultural Year	High Plains Region Average	Min. Precip. High Plains Region	Max. Precip. High Plains Region
Jul. 93-Jun. 94	378.1	211.6	582.8
Jul. 94- Jun. 95	360.4	199.0	603.0
Jul. 95- Jun. 96	348	169	605
20 year average for Oruro	356		

Source: Valdivia, 1996

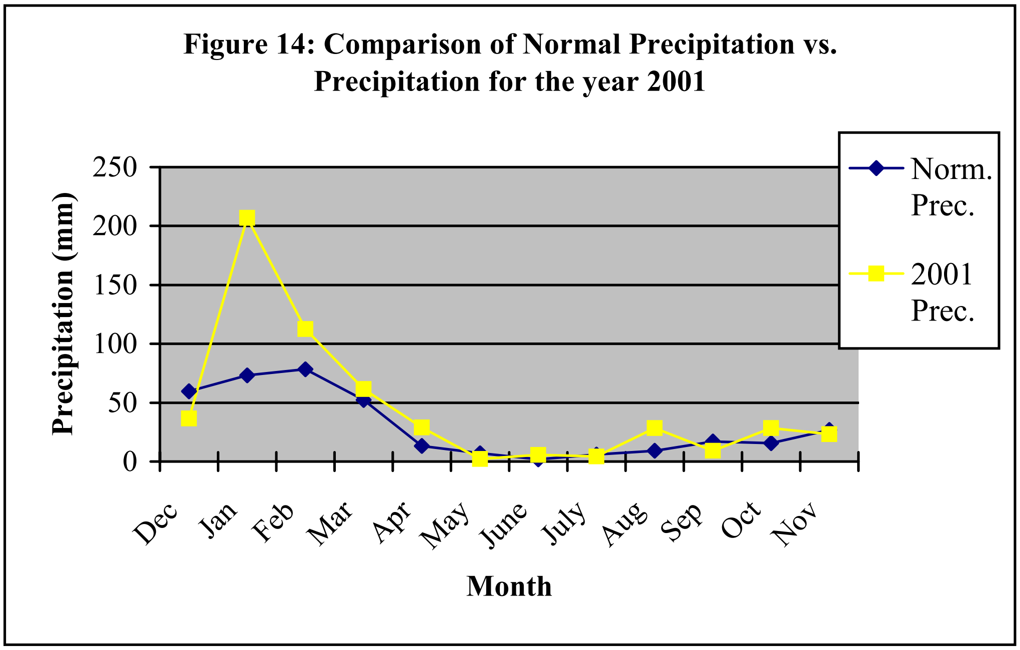
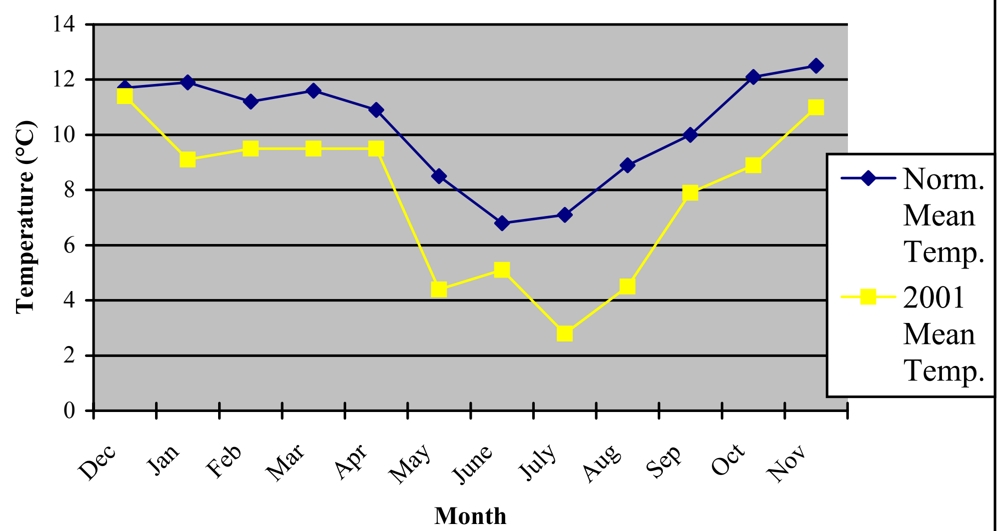


Figure 14 shows a break down of the precipitation rates at CEAC during the study period of December 2000 to November 2001 versus the 35-year observed average. Precipitation for the months of January thru March was much higher than normal. The total precipitation accumulated during the study period was 448 mm. The rains that fall within the months of January-March correspond with the agricultural growing season.

Figure 15 shows the average temperature at CEAC during the study period of December 2000 to November 2001 versus the 35-year observed average. The mean temperature for this period was slightly lower than the normal with the largest difference occurring in the month of July when temperatures were on average 4 degrees colder. The relative humidity was approximately 45% and the average evaporation rate was 4.2 mm/day. The dominant wind pattern was from the north.

Figure 15: Comparison of Normal Mean Temp. vs. Mean Temp. for the year 2001



Climate factors such low rainfall, fluctuating temperatures, frost, high altitude, and high winds all serve to inhibit the establishment of many non-native plants. In addition to establishment, growth over the long term may be retarded by these factors further serving to complicate agricultural and silvicultural efforts in this region. The introduction of a technology that could help overcome such obstacles would benefit the local communities.

Chapter 4: Description of Microcatchment Systems

The entire Cercado province and much of Bolivia are experiencing new challenges resulting from land degradation and increased population pressures. According to INE (1993), the overall population density for the high plains region has increased from 4.86 to 9.44 per hectare since 1950. As a result of these population pressures, land holding size is decreasing and previously marginal land is being cultivated. A vast majority of these lands contain poor soils, low vegetative cover, and slopes greater than or equal to 7% which lead to higher erosion rates. Coupled with low annual rainfall and increased overgrazing, the Andean farmer has seen a steady drop in soil quality and, as a result, farm production. In areas such as these, microcatchment systems may prove effective in increasing production and improving land quality.

Microcatchment systems vary greatly in design and size but generally follow the same basic principles. Beets (1990, 505) defines a microcatchment system as one in which “run-off from a small plot is captured at one side where it infiltrates and directly contributes to the available moisture in the rooted profile of an individual productive tree or shrub”.

Many examples of microcatchments have been constructed all over the world. Generally, they contain a catchment area in which rainwater is allowed to run off of a sloped surface and be channeled down to a certain area where a plant has been placed. Once channeled to that area, water begins pooling around an earthen bund or some other structure constructed at the desired angle and height (Figure 16). As the water pools, it then slowly infiltrates into the surrounding soil in order to provide more water to the plant within the microcatchment system. These systems generally are small in design and each support only a limited number of individual plants. They are relatively inexpensive to construct and with proper maintenance can last for many years.

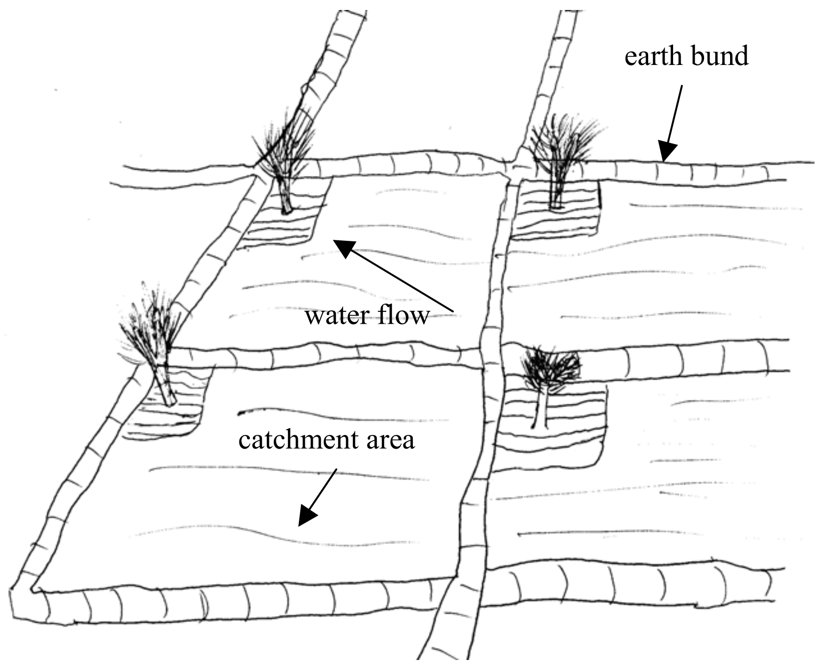


Figure 16: Example of Microcatchment System for Trees

Various microcatchment systems have been in use for thousands of years (Bruins *et al.,* 1986; Evenari *et al*., 1968; Harden, 1975; Meyer, 1975; Pacey and Cullis, 1986). Important publications on water harvesting systems include Shannan and Tadmor (1979); Dutt *et al.* (1981); Boers and Ben-Asher (1982); Rejj *et al*. (1988); Boers *et al.* (1985); and Ben-Asher *et al*. (1985). However, while there are numerous studies on the effectiveness of microcatchment systems in cropping systems (Anaya, 1988; Carmona and Velasco, 1988; Ehrler *et al.,* 1978; Flug, 1981; Hollick, 1982; Mielke and Dutt, 1981; Sharma *et al*., 1986; Slayback and Cable, 1970; Tabor, 1995) fewer studies exist for forestry catchments than for agricultural systems (Gupta, 1991; Gupta, 1995; Gupta and

Muthana, 1986; Pacey and Cullis, 1986). These studies have shown the benefit of using microcatchment systems over traditional planting methods in arid areas. In a study conducted in the Jodhpur region of India, Gupta (1995) showed that the use of microcatchment systems in forestry plantations can significantly increase soil moisture storage, tree growth, accumulated biomass, root growth, nitrogen uptake, and phosphorous uptake over traditional planting methods (Figures 17 and 18). Ojasvi *et al*. (1999) showed that *Zizyphus maurutuana* growth rates in the Jodhpur province of India were from 25-33% higher in shallow 1.0-meter diameter conical microcatchments than in the control in the first year of their study. In the Northern Negev Desert, *Atriplex halimus* seedlings planted within microcatchment systems showed establishment rates of 95% while those planted using traditional methods and receiving only direct precipitation had a 100% mortality (Shannan *et al*., 1970). In a design setup similar to this study, Suleman *et al.* (1995) achieved increases in soil moisture content of 59% from 0-15cm, 63% from 15-30cm, and 80% from 30-45cm in Ismail Khan, Pakistan through the use of micocatchment systems in soils with high clay and silt concentrations.

Figure 17: Tree Microcatchments in Niger

Figure 18: Tree Microcatchment in Niger

Microcatchment systems and the establishment of forested areas through their adoption increase nutrient and water retention capacity locally and throughout the entire region (Nabhan, 1984; Whisneant *et al*., 1995). Furthermore, these systems act to capture wind-blown organic materials (Tiedemann and Klemmedson, 1973; Virginia 1986) as well as improve the local environmental conditions by moderating wind and temperature patterns (Allen and MacMahon, 1985; Vetaas, 1992).

Microcatchment systems can lead to higher crop yields in areas where lands have been previously abandoned or considered unusable (Figures 19 and 20). Through the use of microcatchment systems, Rathore *et al.* (1996) achieved increases in rice yield in Madhya Pradesh, India from an average of less than 1 ton/ha to about 3.3 ton/ha. Other important studies on increased crop yields have shown similar results (Lewis, 1984; Slayback and Cable, 1970; Stern, 1979). Tabor (1995) used microcatchment systems on abandoned crusted soils in the Sahel to improve millet yields to 3,100 kg ha^{-1} compared to a yield of only 417 kg ha^{-1} on normal productive soils without microcatchments.

Figure 19: Construction of Earth Bund to Harvest Rainwater for Plant Production

Figure 20: Construction of Stone Walls in a Gully for Plant Production

Given the benefits of micro catchments in other areas, their adaptation in the Bolivian high plains may improve farm production of local farmers. Should their application become widely accepted, the utilization of these simple techniques can help bring about increases in production and yield of a variety of crops and tree species. Therefore, my objective was to develop a trial by which establishment rates of trees in the high plains region could be increased through the use of microcatchment systems. By testing whether microcatchment systems might help increase tree establishment rates, I can evaluate whether promotion of this technology for broader purposes could be undertaken. The original inspiration for this study came out of the work of Sheikh *et al*. (1984) in the arid lands of Pakistan.

Chapter 5: Methodology and Data

This experiment was designed to determine the best way to increase tree establishment rates in the Bolivian high plains. In order to overcome the climatological challenges of the high plains, creative solutions are needed. The impetus to test microcatchment systems came about after a long observation process in which various failed tree establishment methods were attempted on CEAC lands. In a project undertaken by my counterpart Jesús Cárdenas and former Peace Corps Volunteer Cotton Randle, approximately 1,000 native and introduced tree seedlings were planted on lands adjacent to the station. After a period of two years, less than 5% of those seedlings were still surviving despite being surrounded by protective structures. Water shortages seemed to be a critical factor in tree mortality.

The first part of this chapter will summarize the experiment. In this chapter I will discuss the design of the experiment, the statistical formulas used, soil data, and I will give a detailed history and description of the species chosen for this study. Following this information, I will present the data collected throughout the trial.

Land located on the Centro Experimental Agropecuaria, Condoriri (CEAC) was dedicated for use in this study. The experiment layout followed a randomized complete-block design (Steele and Torrie, 1960, 135) of ten blocks with five planting treatments each containing two commonly used species in this region, *Polylepsis tarapacana* Hieron. and *Cupressus macrocarpa* Hart. The experiment was organized and planned to begin at the start of the rainy season in Oruro and end at the end of the dry season. Data were collected throughout the study period.

Statistical methods:

The randomized complete-block design is a useful way of analyzing data when no external sources of variation (outside of treatment effects) are expected to interfere with various individuals of the experiment. Using a randomized complete-block design allows for larger levels of variation to occur within treatments within a certain block while still maintaining the independence of each block from other blocks (Steele and Torrie, 1960, 132). The response variable (y) for this study was the number of surviving individuals. The following formulas were used to analyze the statistical information from this study (Freese, 1984):

Source of variation	df
Blocks	n-1
Treatments	t-1
Error	(n-1)(t-1)
Total	(n-1)+(t-1)+ (n-1)(t-1)

Where n = the number of blocks and t = the number of treatments

1. The correction term

$$\text{C.T.} = \frac{(\sum^{50} X)^2}{n}$$

2. Total SS = $\sum^{50} X^2 - \text{C.T.}$

3. Treatment SS = $\dfrac{\sum^{5}(\text{Treatment totals}^2)}{\text{\# of plots per Treatment}} - \text{C.T.}$

4. Block SS = $\dfrac{\sum^{10}(\text{Treatment totals}^2)}{\text{\# of plots per block}} - \text{C.T.}$

5. $\underset{32\text{ df}}{\text{Error SS}} = \underset{45\text{ df}}{\text{Total SS}} - \underset{4\text{ df}}{\text{Treatment SS}} - \underset{9\text{ df}}{\text{Block SS}}$

Treatment Design

Each treatment within each block contained three individuals of each species. Ten blocks were laid out sequentially along on a hillside with a slope of approximately seven percent. Each treatment within each block was spaced ten meters down slope from the next treatment so as to provide for an adequate water catchment area (3:10). The trees were spaced 1.5 meters (5 feet) apart from each other to provide for a good rainfall catchment area. In order to exclude grazing animals from the study area, a barbed wire fence was set up around the outside perimeter of the study area. The five treatments were arranged within each block according to the following specifications:

1.) Treatment 1 was the **control**. There were no microcatchment systems used and the trees were placed directly into the ground without any protection from the elements. Holes were laid out in a transect line along a contour (Figures 21, 22, and 23).
2.) Treatment 2, known as the **pit planting method**, was a simple hole dug in the ground with one hole dug per seedling. The hole was dug to an additional depth of 30 cm. The seedling was planted 30 cm below ground to provide protection from the elements while still giving the seedlings access to sunlight. Holes were laid out in a transect line along a contour (Figures 21, 22, and 23).
3.) Treatment 3 was a **basic trench system** dug to a depth of 30 cm and localized along the contour to prevent excess water runoff. (Figures 21, 22, and 23).
4.) Treatment 4 consisted of a **widened trench basin** (approximately 60cm wide) with the trench depth still maintained at 30cm and laid out along the contour. The

increased width of the trench was constructed to allow for a larger collection area of runoff water within the microcatchments (Figures 21, 22, and 23).

5.) Treatment 5 consisted of a **slanted trench system** similar to trench number 4 with an additional trench dug 30cm deeper inside to provide further water collection and protection from the environment (Figures 21, 22, and 23).

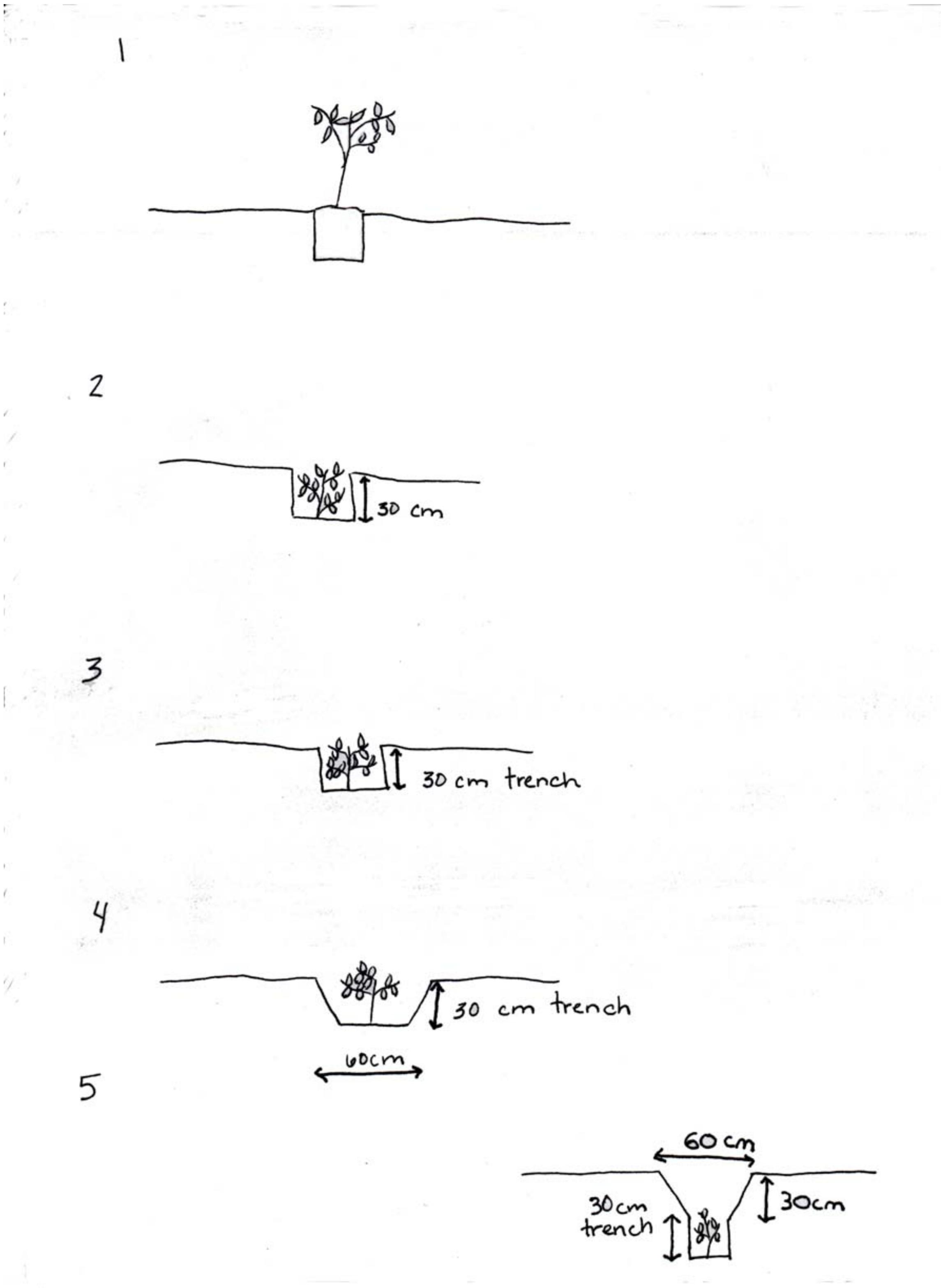


Figure 21: Treatment Design (side view) (drawing by K. Rahn)

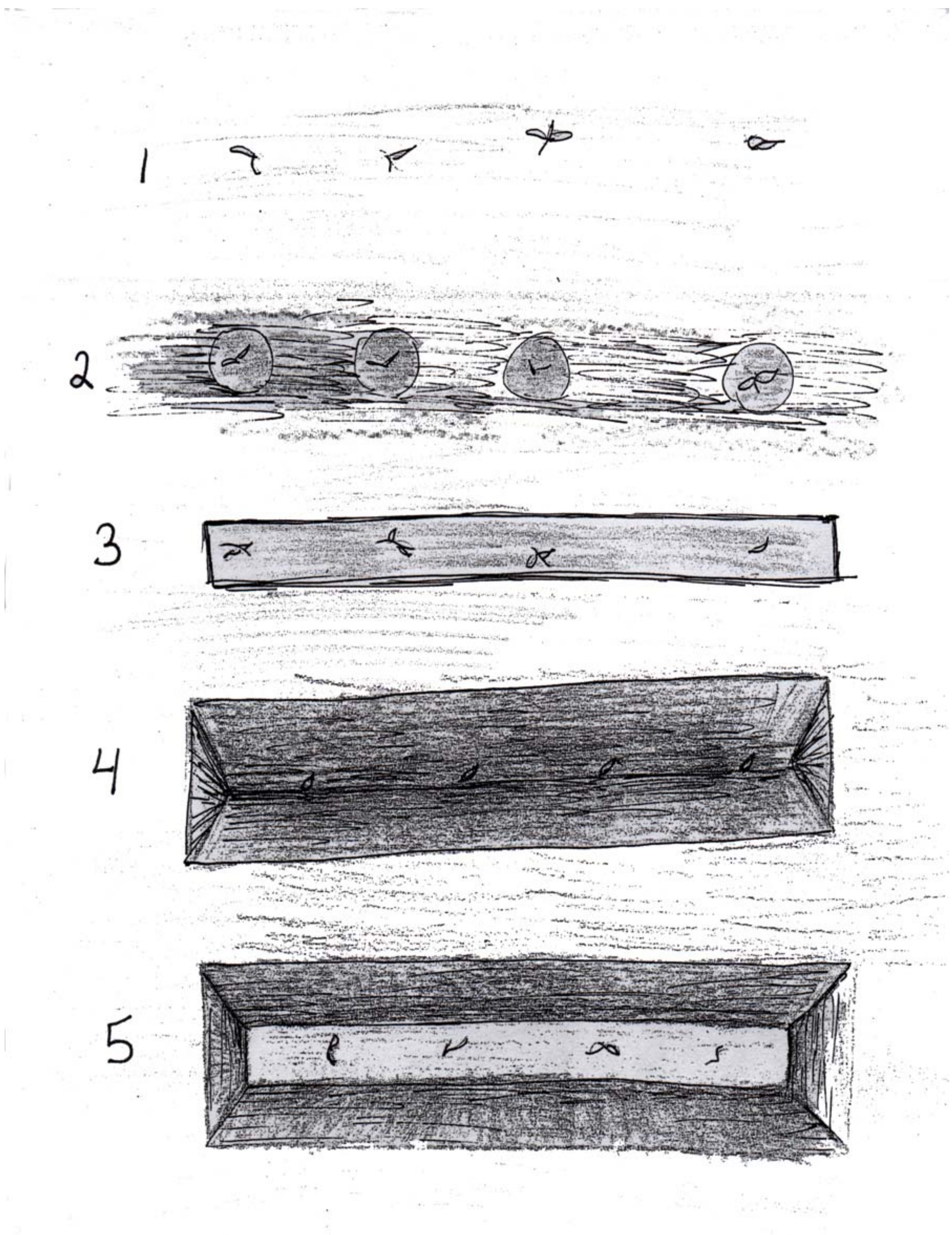


Figure 22: Treatment Design (top view) (drawing by K. Rahn)

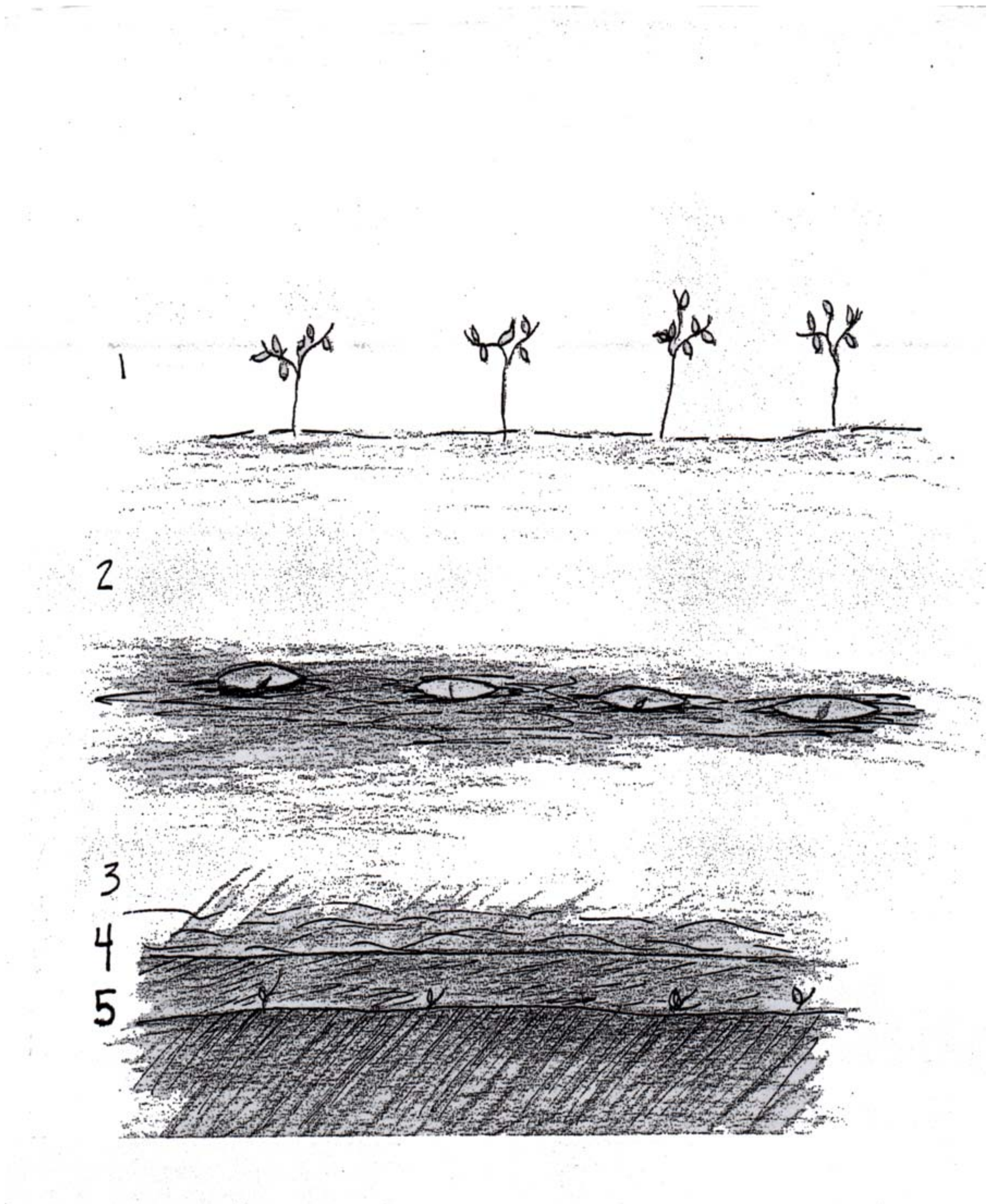


Figure 23: Treatment Design (front view) (drawing by K. Rahn)

At the time of planting, approximately 2.5 kg of sheep manure was applied to each tree in order to improve nutrient availability during transplanting. No further fertilization efforts were made throughout the remainder of the study and the trees were never irrigated. Trees were checked on a two and a half month basis for survival rates and perimeter fences were checked on a daily basis.

Soil information:

Soil infiltration information was taken in November during the driest time of the year to allow for the most accurate results. Soils within the study area are classified as having a clay to sandy clay texture with a fine subangular blocky structure (Miller and Donahue, 1990; USDA, 1981). Soil infiltration rates were recorded over an eight-hour period in which they were checked according to a set schedule. A double ring infiltrometer was used for this experiment (Bouwer, 1986, 825).

Infiltration rates over time were plotted in order to observe soil reactions (Figure 24). Since these soils are clay, infiltration rates were slow and did not exhibit a strong curve in infiltration rates during the eight-hour trial period. A normal regression analysis was performed in order to observe F-values and r^2. Residuals from the regression analysis did not exhibit a random pattern (Figure 25). The results of the regression analysis indicated an F-value of 989 and an r^2 of 0.993. A polynomial regression analysis on the data was performed. Residuals for the polynomial regression did not show a systematic pattern. The polynomial regression analysis gave an F-value of 10,649 and an r^2 of 0.999. Infiltration in millimeters at a specific time was determined to be:

$$y = t^2(0.00001445) + t\,(-.0296976) + 15.42242$$

where y is equal to infiltration in millimeters and t is equal to time in minutes.

Figure 24: Water Level Height vs. Time

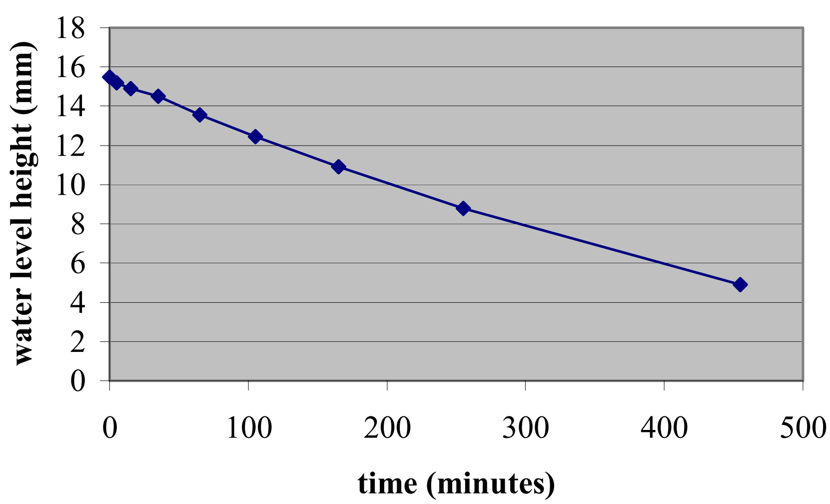
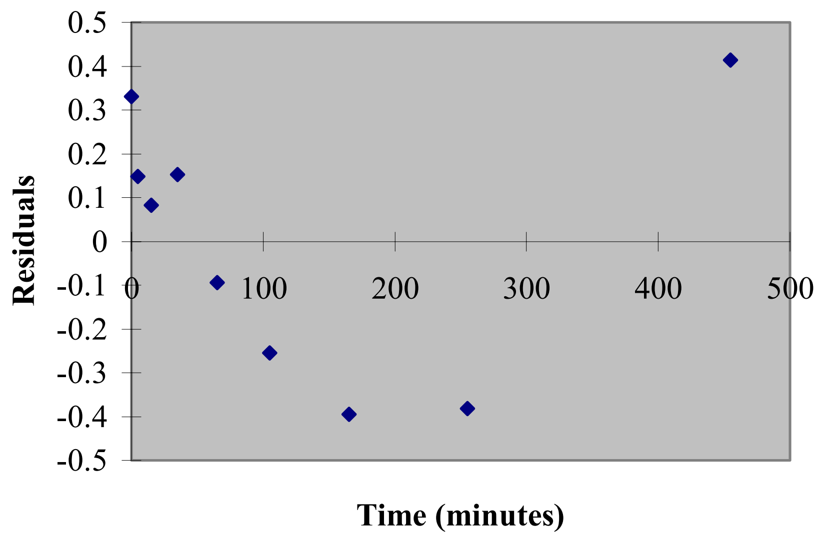


Figure 25: Residual Plot for Time Regression



Because of the high presence of clay in these soils, water uptake by plants in undisturbed soils of this type may be more difficult than in other soils. Clay particles, upon wetting, tend to swell and thus reduce the size of pores in the soil (Dunne and Leopold, 1978, 166). These pores are used by plants to draw water up into the root systems and hence the reduction of these pores reduces the total amount of free water available to plants. Plants must therefore increase their uptake efforts which serves to heighten plant stress levels. In the case of this study, soil infiltration rates for the soil immediately surrounding the trees may have been higher than in surrounding areas. Disturbance of the soil during planting can cause the soil to become more porous and less compact. As a result of this change in the physical status of the soil, infiltration rates would be higher and water intake and storage by the soil that is available to the trees would increase (Singer and Munns, 1991, 123).

Species Used in the Study:

For the purposes of this study, I decided to select two species of trees commonly used or found in this area. In order to facilitate comparisons in survival rates, I selected one native and one non-native species. The native species I selected was *Polylepsis tarapacana* Hieron. while the non-native species I selected was *Cupressus macrocarpa* Hart.. What follows is a general description of both species as well as their current uses and values within the Bolivian high plains society.

Polylepsis tarapacana

P. tarapacana grows at the highest altitude in the world for any tree. Forests in which these trees are the dominant species are considered to be some of the most endangered forest ecosystems in South America (Hjarsen, 1998). *P. tarapacana* is commonly known as Kehuiña, Kewiña, Queñua, Keuña or Q'iwiña and is typically found in Bolivia along the central and southern high plains regions at altitudes ranging from 4100-5200 meters (13,500-17,000 feet) above sea level (Argollo *et al*., 2001; Loayza *et al*., 2001; Rada *et al*., 2001). The species is described by Fjeldså (1992) as appearing in either a bush or tree form with a twisted trunk, evergreen foliage, dense nanophyllus leaves and often associated with a large amount of dead twigs and other organic material at its base (Figures 26 and 27). The bark is generally easy to remove but is quite thick and heavily laminated. Although generally small in height, some individuals have been observed to reach up to twenty meters (65 feet). Cárdenas (2001) estimated that at higher altitudes *P. tarapacana* has a height growth rate of only fourteen millimeters (0.55 inches) per year with the majority of that growth occurring in the summer months from

January to March. Using increment core counts, Argollo *et al.* (2001) discovered that *P. tarapacana* can reach ages of more than 230 years.

Figure 26: Polylepsis Tree

Figure 27: Polylepsis Bark and Leaves Up-Close

Polylepsis sp. are presumed to have first appeared in the Plio-Pleistocene era within the Andean region of Venezuela and Columbia and subsequently evolved within the variable geographic and climatological zones which currently constitute the Andean mountain regions (Baied, 2001). The nine species currently found within the borders of Bolivia are relicts, isolated by human activity over the past millennia. Ellenberg (1958) and Ruthsatz (1977) estimated that much of the present day high plains region was at one time pristine *P. tarapacana* habitat. Today approximately ten percent of the *P. tarapacana* forests survive in largely protected sites such as rock faces, rocky slopes or along streams (Kessler, 2001). Along the eastern region of the Bolivian Andes, only one to two percent of the original forest cover remains with most patches isolated in one to two hectare plots (Kessler, 1995 as cited in Kessler, 2001).

Within forests where *P. tarapacana* are present, these species are generally the dominant or only tree species found within the region although shrub vegetation may be present (*Baccharis sp., Berberis sp., Chuquiragua sp., Durantha sp.*) (Fjeldså, 1992). *P. tarapacana* are typically found in open forest habitats (Figure 28) and in climates where they are subjected to environmental stresses. Approximately 40 species of birds are found within *P. tarapacana* forests, with seven species being exclusively dependent on them (Yensen and Tarifa, 2001). Local indigenous groups have discovered more than 100 medicinal uses for *P. tarapacana* treating a variety of ailments such as arthritis, coughs, rheumatism, and urinary diseases (Loayza *et al*., 2001).

Researchers have found that *P. tarapacana* can withstand sharp temperature variations and extremely high altitudes. Rada *et al*. (2001) observed that injury temperatures for *P. tarapacana* ranged from -18°C to -23°C (0°F to -9°F). Among altitudinal distributions, Gonazales *et al*. (2001) discovered populations at or above 5,000 meters above sea level exhibited a higher leaf area, leaf dry weight, chlorophyll, caroteniods, glucose, fructose, and sucrose levels as well as higher palisade cell numbers. Garcia-Nuñez *et al*. (2001, 37) found there were differences in water potential and stomatal conductance at various altitudes as well. CO_2 levels remained unchanged and *P. tarapacana* showed "a rapid recovery after night freezing permits a favorable carbon balance at leaf level all year round".

Figure 28: Polylepsis Forest

Due to its relic status, *P. tarapacana*, is not widely used by farmers. While the wood from its trunk and branches serve as good firewood, its twisted trunk and slow growth rate tend to make it undesirable for commercial uses. In certain areas where some trees exist however, dead branches are used to make corrals and other animal enclosures on small farm parcels. As a native species for forestry plantation production, this would not be a viable option because of its slow growth rate and undesirable commercial characteristics. From an ecological standpoint however, this species would be an excellent choice for long-term rehabilitation of previously disturbed or degraded habitat.

Cupressus macrocarpa

C. macrocarpa, otherwise known as Monterey Cypress, originates from Monterey Bay in the northern coast of California. Currently, there are only two native groves of *C. macrocarpa* in the entire world with both occurring in the Monterrey region (Montara, 2002). *C. macrocarpa* ranges in height from 21-27 meters (70-90 feet) although when transplanted from its native area it has been known to reach heights of more than 30 meters (100 feet) (Floridata, 2002; Gilman and Watson, 1993). Gilman and Watson (1993) describes the species as having a columnar, pyramidal shape, straight trunk, moderate density, and simple, scale-like opposite/subopposite leaf arrangement (Figures 29 and 30).

C. macrocarpa grows in full sun on a variety of soils including clay, loam, and sand and has a high aerosol salt tolerance. Miller and Knowles (1990) state that *C. macrocarpa* is capable of surviving in a wide variety of climates and can withstand up to -10°C (14°F) of ground frost. They further note that *C. macrocarpa* is generally better than average on cold, dry sites, or any area where nitrogen availability is low and that individuals of these species respond well to shelter but can withstand wind and endure salt blasting.

Figure 29: Large Cypress Tree in Oruro

(conical shaped tree in center)

Figure 30: Cypress Tree in Treatment Two

Hybrids and adaptations of this tree have been widely used throughout Bolivia with varying results. Johnson (1974) lists some of the potential uses of this tree as timber production, habitat or food for wildlife, shelterbelt, and environmental forestry. Within Bolivia, this species is primarily used for construction, windbreak protection, and ornamental purposes. In previous studies done by my counterpart Jesús Cárdenas and myself at CEAC, *C. macrocarpa* has shown poor adaptability to the high plains conditions. In one trial in which 150 individuals were planted above ground with adobe protective walls, less than two percent were surviving at the end of two years. Those individuals who have had some degree of success in growing *C. macrocarpa* have grown them in areas such as their front patios. In one instance, a local farmer Epifanio Aroja R., had a cypress in his patio reach a height of nearly three meters (10 feet) in fifteen years. Because of their long straight trunks and evergreen appearance most farmers prefer these trees over more suitably adapted native species.

Data:

In this section I will first list the random experiment design layout (Table 5) and then follow that with data on total survival (Table 6) as well as within species survival. Data on mortality rates according to time of the year are given and will be discussed in further detail in the results section.

Data for this study was collected at four times throughout the calendar year at approximately two and one half month intervals. The dates for data collection are April 14, June 25, August 27, and November 12 of the year 2001. Trees were judged to be surviving if they contained green leaves, and flexible, green trunks (underneath bark). Trees considered to be on the edge of dying were still considered alive until at least the next data collection period if they exhibited these characteristics.

Table 5: Experiment Design

Treatment Order		Treatment Order	
Block 1	**Tree Order**	**Block 2**	**Tree Order**
4	QCQCQC	3	CCQQCQ
2	QQCQCC	4	CCCQQQ
5	QCCQCQ	2	QCCQQC
3	QCQQCC	1	QQCCQC
1	CQQCQC	5	CQCQCQ
Block 3	**Tree Order**	**Block 4**	**Tree Order**
5	CQQCCQ	2	CCCQQQ
3	QCQQCC	5	CCQCQQ
4	QCCQQC	1	QCCQCQ
1	CQCQQC	3	QCQQCC
2	QCQQCC	4	CQCQCQ
Block 5	**Tree Order**	**Block 6**	**Tree Order**
4	CQQQCC	2	CQCQCQ
1	QQCCQC	1	QQCQCC
3	CQQQCC	4	QCCQQC
2	QCQCCQ	3	CCQQCQ
5	QCCQCQ	5	QQCCQC
Block 7	**Tree Order**	**Block 8**	**Unit Order**
4	CQQCQC	4	QQQCCC
3	CQCQCQ	5	QCQCQC
2	QCQCQC	2	QQCCCQ
5	CQQCQC	3	CQCQQC
1	QCCQQC	1	CCCQQQ
Block 9	**Tree Order**	**Block 10**	**Tree Order**
1	QCQCQC	2	CCQQQC
3	QCQCQC	4	QQCCCQ
5	QQQCCC	3	QQCQCC
2	QCCQCQ	1	CCQQCQ
4	QQCCCQ	5	CQCQQC

Legend: Q= *Polylepsis tarapacana*, C= *Cupressus macrocarpa*
Treatments are listed according to numbers as described in the methods chapter
1=control, 2= pit planting, 3= basic trench system, 4= widened trench system,
5= slanted trench system

Table 7: Treatment Survival Data by Species

	Polylepsis tarapacana	*Cupressus macrocarpa*	**Total**	**% Survival**
Treatment 1	26	1	27	45
Treatment 2	28	20	48	80
Treatment 3	25	5	30	50
Treatment 4	29	2	31	51
Treatment 5	27	3	30	50
Total	135	31	166	55

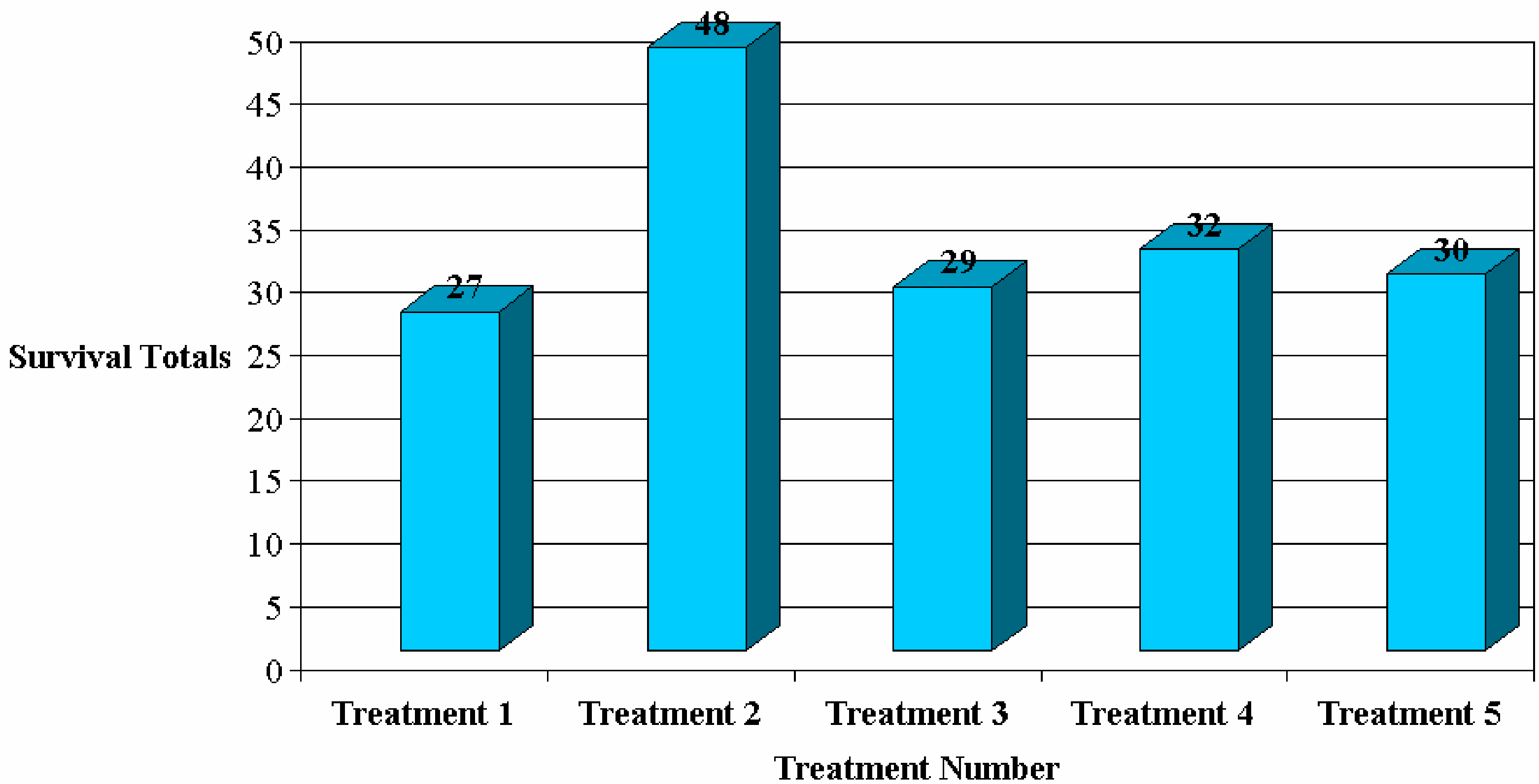
In table 7 we observe that *Polylepsis tarapacana* has high rates of survival across all treatments while *Cupressus macrocarpa* exhibit low survival rates in all treatments except treatment number two. Overall tree survival for *Polylepsis tarapacana* was 90% while overall survival for *Cupressus macrocarpa* was 21%.

Table 8: Mortality Data According to Month

Mortality #/ Period of Death	*Polylepsis tarapacana*	*Cupressus macrocarpa*
1/12/01-4/14/01	8	3
4/15/01-6/25/01	1	14
6/26/01-8/27/01	3	17
8/28/01-11/12/01	3	85
Total	15	119

According to the data in Table 8, most mortality for *P. tarapacana* occurred in the first three months following planting. Mortality rates for *C. macrocarpa* were highest in the last three months of the study from August until November. Total survival numbers according to treatment are given in figure 31.

Figure 31: Survival Totals According to Treatment



Chapter 6: Results and Discussion

Of the five different treatments within this experiment, treatment number two had a much higher survival rate. An analysis of variance was performed following Steele and Torrie (1960, 135) in which the sums of squares for the blocks, treatments, and error was determined according to the formulas given in chapter five (Table 9). The data results including the mean squares for each source of variation were also determined. The F-statistic value for the data set is 13.24. As this number is much higher than the F-value at an $\propto$ of .005 with 4 and 32 degrees of freedom (6.35) the differences among the treatment survival totals were determined to be significant.

In order to further analyze this data, a Tukey test (Steele and Torrie, 1960, 109) was performed on the mean treatment values in order to determine if the remaining treatments were significantly different from each other. The only significant comparison was that treatment two was significantly higher than the other four treatments (Figure 32).

Table 9: Analysis of Variance

Source	df	SS	MS
Blocks	9	14.08	1.564444
Treatments	4	26.68	6.67
Error	32	16.12	0.50375
Total	45	56.88	

Figure 32: Tukey Test Results

Treatment means:	**4.8**	**3.2**	**3.0**	**2.9**	**2.7**
Treatment #:	**2**	**4**	**5**	**3**	**1**

In order to ensure accurate analysis results, an additional analysis of variance test was performed among treatment means for treatment two against the averages of treatments one, three, four, and five. The results indicated an F-treatment value of 43.19. As this value is much larger than the F-value number for an $\propto$ of .005 with 1 and 32 degrees of freedom (9.18) it was determined that the difference between treatment two and treatments one, three, four, and five were significant (Reese 1984,122).

Further statistical modeling was performed in order to observe whether differences in the survival rates of species within the same treatments were significant. An analysis of variance model was run for both species and an F-treatment value was determined. The results are as indicated in Tables 10 and 11. In the case of *Polylepsis tarapacana*, differences were determined not to be significant between any of the treatments based on an F-value of 1.14 with a critical F-value of 4.62 at an $\propto$ of .005 with 4 and 32 degrees of freedom. *Cupressus macrocarpa* treatments were determined to be significant apparently resulting from a larger survival value at treatment two with an F-value of 28.53 at the same critical F-value as for the *Polylepsis tarapacana* analysis.

Table 10: Analysis of Variance for Polylepsis tarapacana

Source	Df	SS	MS
Blocks	9	3.3	0.366667
Treatments	4	1.4	0.35
Error	32	9.8	0.30625
Total	45	14.5	

Table 11: Analysis of Variance for Cupressus macrocarpa

Source	df	SS	MS
Blocks	9	6.18	0.686667
Treatments	4	24.68	6.17
Error	32	6.92	0.21625
Total	45	37.78	

These results indicate strongly that the design of treatment two had a large effect on the survival rates of *Cupressus macrocarpa.* The three other modified treatments fared equally with the control treatment. There does not seem to be any correlation in the case of *Polylepsis tarapacana* as each treatment had approximately similar survival numbers. The increased rainfall this past year did not seem to have any effect on increasing establishment rates in the control plots.

In regards to the effectiveness of microcatchment systems, comparable experiments performed in other parts of the world point to similar conclusions. In the most closely related study to this one, Sheikh *et al.* (1984) planted eight species within five treatments with four replications in the Thal Desert region of Pakistan. They found that the best design for a microcatchment system was one in which sloping catchments with or without a trench were used. The overall survival percentage on their study ranged from a high of 76% in sloping catchments without trenches to a low of 64.1% in normal surface planting. The pit treatments used in their study (comparable to treatment number two in this study) did not vary statistically from surface planting.

I believe the main determining factor as to the difference of outcomes in their study and my own can be attributed to the varying climatological conditions found in the Bolivian high plains. In the Thal Desert region, average low temperatures were much higher (17.7°C, 63.9°F) than in Oruro (0°C, 32°F) and as a result, less overall stress was placed on the trees in their establishment phase. It is my belief that frost and high winds played a large role in the mortality of open trench treatments as they acted as a desiccating factor on the unprotected trees. Most notably, the highest mortality rates of trees in my experiment occurred during the months of September, October, and November when nighttime temperatures can reach freezing and higher humidity levels (43%) during this period resulting from early rains can create frost conditions.

In a study done by Whisenant *et al.* (1995), 32 trapezoidal shaped microcatchment basins were constructed with varying catchment areas of 1:1 to 1:30 in Reagan County, Texas. Survival of the species *Leucaena retusa* ranged from 100% within microcatchment basins to only 50% in unmodified plantings in the first year of the study. In the second year of the study survival was 98% and 45% respectively.

Ojasvi *et al.* (1999) conducted a study using *Zisyphus mauritiana* in western Rajastan, Indian. The experiment was a complete randomized block design with five treatments and three blocks with three trees per block surrounded by conical microcatchments of one-meter radius. Treated plants within this experiment suffered only one mortality while those in the fields suffered 48 mortalities. Ojasvi *et al.* (1999) found that lining treatments with waste materials achieved better soil moisture status and that trees with stone and marble linings within the catchments achieved an increase in plant height by 40-48% more than in unlined catchments.

Rao (1989) conducted an experiment in Mchakos, Kenya using *Leucaena leucocephla* L. where he compared two microcatchment systems in which some trees were planted in sunken pits dug to 45 cm and others were planted normally. Ten months later, stand mortality in sunken pit planting was only half (52%) the normal level planting mortality rates.

These results, as well as previously discussed agricultural data on microcatchments, strongly indicate that in most cases, micro catchments can significantly increase tree establishment and long term survival in arid areas. This study found that as a result of ecological constraints imposed on trees by the variable climate, those trees sheltered from the wind and cold by way of some structure had an advantage in terms of long term survivability. Treatment two provided a degree of such protection. In the Bolivian high plains construction of windbreaks around each treatment may provide additional protection to the more open trench microcatchment treatments.

The two species obtained different results with respect to establishment and survival rates across the microcatchment treatments. Native *P. tarapacana* establishment rates were independent of treatment effects as their survival rate was statistically equal across all treatment levels. *C. macrocarpa* establishment and survival rates varied, and survival in treatment two was much greater. Possible explanations for this discrepancy lie in the evolutionary origins of each species. *P. tarapaca* is a species native to the high plains region of Bolivia and as such has evolved to adapt to the challenging environmental conditions which exist within the study area. It would seem that increases in water had no effect on *P. tarapaca* survival through the first year. Growth rates may have been greater but as this measurement was beyond the scope of this experiment, this is only conjecture.

C. macrocarpa evolved along the coastal regions of northern California and does not adapt well to the high plains. The high winds and sharp temperature variations acted as a desiccating factor upon the trees and burned them. Observations of *C. macrocarpa* leaves and stems showed discoloration and extreme dryness. Although more study would be needed, it can be postulated based on prior field observations that many other of the commonly used introduced tree species would exhibit similar establishment outcomes. In other tree planting projects conducted at CEAC, introduced tree species planted without protective structures exhibited similar characteristics of leaf burning and high mortality regardless of their species. In some cases where frost and low temperatures were present, newly planted native species had poor establishment rates as well.

The use of protective structures by farmers for aiding tree establishment is widely practiced by foresters working in the high plains region. Currently, two methods are adopted in order to protect a tree from the elements and animal intrusion. One method involves building an adobe wall structure around the seedling. Construction of a circular wall allows for protection from animal intrusions as well as from the environment. The disadvantage of this method is that adobe structures are time consuming to build and the adobe is difficult to transport. Because of these characteristics, adobe structures are not economically feasible in cases where many trees must be planted. Another popular method is to assemble a wall of grass around the plant in order to protect it from wind and frost. While cheap and easy to build, these structures tend to last only one or two seasons and are vulnerable to animal damage.

Attempts to protect tree seedlings from the surrounding environmental hazards have been widely studied. In a trial conducted to increase tree establishment rates on previously degraded mining land, Farley *et al.* (1995) found that tree shelters act as mini-greenhouses which reduce water loss, increase humidity levels, and control temperature variations. The inclusion of tree shelters in their study augmented the survival rates of red oak seedlings (*Quercus rubra* L.) from 50 to 80% in the first year. Ponder (1995) found that using tree shelters increased survival rates from nearly 50% to 82% in the first year and from 62% to 92% after three years. In a study designed to increase desert shrub establishment rates in California, Bainbridge and MacAller (1995) reported that in addition to increased survival rates, the tree protection devices also served to improve irrigation delivery, provide protection from wind, and moderate temperature changes. When used in conjunction with microcatchment systems, protection devices have great potential to increase non-native tree establishment rates on the high plains of Bolivia.

Chapter 7: Conclusions

The challenges imposed on Andean high plains farmers are daunting. Living under harsh climatological conditions with little water and short growing seasons, these robust souls have been able to successfully eek out an existence for millennia. The accomplishments in the way of cultural adaptations to a changing society and triumph over incredible odds have earned these individuals the admiration and respect of many people who have come to this edge of the world.

Today, the Andean farmer faces numerous new challenges. Increased population pressures coupled with degrading land quality and poor farming practices have led to a crisis situation. Within the last twenty years, migration from the rural areas has increased as a way of life that was once prosperous has become perilous. What is needed today in the high plains of Bolivia are new solutions and low cost technologies to problems. This study provides insight to potential solutions.

Two major ideas emerged from this study regarding the establishment rates of trees in the high plains of Bolivia. The selection of appropriate species proved to be an important aspect of this trial in that the species selected greatly affected the success rates of tree establishments. Equally important, this study also showed that the introduction of microcatchment systems to this region could help to greatly improve tree establishment rates.

In an examination of species adaptability, there appeared to be a large difference between the success rates of native versus non-native species. Evolutionary strategies of different plants and their relative adaptability to the high plains climate are important topics that need to be addressed more when determining which species to introduce to this region. Historically, the species selection does not seem to be very good. Two introduced species commonly used in this region are Monterrey Pine (*Pinus radiata*) and Monterrey Cypress (*Cupressus macrocarpa*). Because both of these species originate in the humid coastal areas of northern California, their low field establishment rates in the high plains should not be surprising. However, despite their poor growth and survival characteristics in this region, they are continually used in reforestation programs. Trees are too often selected for their seed availability and production characteristics rather than their adaptability.

If introduced species are to be used over native species, more emphasis on adaptability of these introduced species is needed. Ideas such as these are slowly beginning to take root. In a study done to determine the adaptability of forage crops to the Bolivian Andes, Wheeler *et al.* (1999) used simulations to compare how various agricultural species from around the world would match the climate found in the study regions. Their findings indicate that in addition to the native species currently used, two cover crops from Nepal could successfully be integrated into Bolivian farm systems located at altitudes of around 3,000 meters (10,100 feet) above sea level.

Throughout the world, a number of climate zones exist which could compare well with the Bolivian high plains. Examining tree species from areas such as the Himalayan mountain ranges or the Sierra Nevada Mountains could yield species more adaptable to the conditions that exist in the high plains. Trees could still be selected based on desired characteristics but such selection should be restricted to certain geographical zones. The introduction of these more suitable species, tied with the utilization of microcatchment systems could greatly increase tree establishment rates.

While the use of microcatchment systems around the world is not new, its introduction to this area of the world is only just beginning to take root. Increasing the establishment rates of plant species through their early years and beyond has the potential to become an important resource to many farmers as they struggle to improve their lands and their production. The results of this experiment clearly indicate that while challenging, reforestation efforts in this region are not impossible. Using microcatchment systems is a viable option for farmers with modest resources as they cost little to construct and provide a number of benefits in way of increased production.

Weather changes and problems associated with the high altitude still remain difficult obstacles which must be dealt with in order to achieve significant progress. However, the use of these microcatchment systems or some adaptation of them may provide one answer. Casual observation of plants growth rates in all microcatchment systems indicated that not only survival was increased, but also tree growth and vigor. Treatment number two in this study, the pit planting method, shows great promise in increasing tree establishment rates. This method can greatly aid trees through helping to harvest rainwater and protecting them from the elements. Although farmers will still need to protect their trees from animals, this system could provide partial answers to their problems of chronic water shortages and climate fluctuations.

Adaptations to these treatments may serve to further increase the establishment rates of trees. The other treatment methods used in this study need further research in order to test their adaptability to this region. I believe that all of these systems, when used in combination with a windbreak or other protective structure, may greatly help to harvest rainwater and thus increase tree establishment rates. Small trenches may be easier and more cost effective to build as they can be made using draft animals and a plow. Modifications to the pit planting treatment are also possible and show potential. Such additions as earthen bunds and larger catchment areas may serve to increase plant viability and stimulate more growth and higher establishment percentages. In order to maximize catchment quality, annual cleaning of all microcatchment structures is needed.

A combination of better species selection with the use of microcatchment systems has the capacity to greatly increase forestry production in the Bolivian high plains. The increase in water availability as well as the search for more productive species could lead to greater tree establishment and growth rates over time. Since the financial investment required to attain such goals would be relatively small, their adoption should be encouraged.

Microcatchment systems and the goals of this trial should not stay limited to forestry related activities. The adaptation of these systems to agricultural uses is already being implemented on a small scale at CEAC and within the surrounding communities comprising San Antonio de Condoriri. As part of my Peace Corps work with Jesús Cárdenas and local farmers, we constructed a variety of trenching systems adapted from Kenya called Fanya Juu. These trenches are designed so that water infiltrates into two separate catchment zones to increase hillside soil moisture, thereby increasing crop production. Promotion of this work from our experimental plots has already led to the trial adoption of this method in at least one community and shows promise as an inexpensive way to harvest rainwater for use in crop systems. Recently, acting as advisor to an undergraduate thesis project, I helped design a trial testing the introduction of eight-meter wide half moon microcatchment systems on CEAC lands for agricultural purposes.

While the initial results still await analysis, these systems also show promise in the area of microcatchment systems for agricultural systems.

Cultural sensitivity must be taken in to account before any project of this type can be successfully undertaken. In the case of the Aymara Indians, a subtle reminder that these technologies were once widely utilized by their ancestors greatly served to motivate the adoption of this technology. In this manner, outside influences served to only help them recover their lost heritage rather than supplant it.

Much remains to be done. In order for the Andean farmer to maintain their way of life in this ever-changing world, production must rise to meet demand and sustainability and restoration of previously degraded lands must be promoted. The task is daunting. However, I believe that with the proper assistance the Aymara people can and will rise up to these challenges.

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APPENDIX 1: ANIMAL INFORMATION DATA FROM CONDORIRI

Name	# Sheep	# Cattle	# Llama
1.) Sr. Lucio Torres	80	11	5
2.) Sr. Edwin Torres	80	11	5
3.) Sr. Andrés Choque	100	12	20
4.) Sr. Rogelio Flores	100	4	6
5.) Sr. Carlos Canaviri	50	0	0
6.) Sra. Erminia Choque	100	5	12
7.) Sr. Pablo Choque	100	12	20
8.) Sr. Leandro Álvarez	100	10	10
9.) Sra. Dorotea Ceacari	50	5	2
10.) Sr. Freddy Álvarez	100	10	10
11.) Sr. Epifanio Aroja	150	10	0
12.) Sr. Felix Alvarez	60	5	14
13.) Sr. Juan Canaviri	30	2	0
14.) Sra. Severina Álvarez	50	2	4
15.) Sra. Reyna Mejia	60	2	0
16.) Sra. Martha Quispe	20	6	0
17.) Sr. Andrés Pascual	50	4	12
Average animals per farmer	68	5	6