2006-12-05

Forage Adaptability Trials for Forage and Seed Production in Bolivia; Effect of 5 Herbicides on 7 Native Utah Forbs

Joshua C. Voss
Brigham Young University - Provo

FORAGE ADAPTABILITY TRIALS FOR FORAGE AND SEED PRODUCTION IN BOLIVIA;

EFFECT OF 5 HERBICIDES ON 7 NATIVE UTAH FORBS

by

Joshua Voss

A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

Department of Plant and Animal Sciences

Brigham Young University

December 2006

BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Joshua Voss

This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

Date	Val Anderson, Chair
Date	Dwain Horrocks
Date	Bruce Roundy

BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Joshua Voss in its final form and have found that (1) its format, citations and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

Date	Val Anderson Chair, Graduate Committee

Accepted for the Department

Date	Loreen Woolstenhulme Graduate Coordinator

Accepted for the College

Date	Rodney Brown Dean, College of Biology and Agriculture

ABSTRACT

FORAGE ADAPTABILITY TRIALS FOR FORAGE AND SEED PRODUCTION IN BOLIVIA;

EFFECT OF 5 HERBICIDES ON 7 NATIVE UTAH FORBS

Joshua Voss

Department of Plant and Animal Sciences

Master of Science

The harsh environmental and poor economic conditions of the Bolivian Altiplano require intervention to assist many of those that live there to become economically self-sufficient. We attempted to find introduced dry season reserve forage grasses that could produce enough biomass to be useful as feed for livestock, and that could also produce enough seed to distribute to farmers. While some of the grasses produced reasonable amounts of biomass, none produced seed in quantities that would be even close to being economically viable. The most likely cause of this is that the timing of resources that the grasses need to flower is very different between Bolivia and the areas from which the grasses originally came. We concluded that either the conditions under which the grasses are grown would need to be changed (i.e., earlier irrigation), or pre-adapted native species should be used.

Native forbs are a critical component of any natural ecosystem, and thus should be included in wildland restoration projects. However, because the seed is currently collected by hand from the wild, it is very expensive, and this limits the ability of land managers to utilize it. A possible solution to this dilemma is for growers to commercially produce the seed and thus drive down the cost. In such a situation, it would be necessary to use herbicides to control competing weeds. We analyzed the effects of 5 herbicides on 7 species of native Utah forbs at 3 growth stages to learn which herbicides could safely be used on the test plants. We found that the plants' reaction the herbicides is largely species- and growth-stage specific.

ACKNOWLEDGMENTS

I thank the members of my graduate committee, Val Anderson, Dwain Horrocks, and Bruce Roundy for the education they gave me both in and outside of the classroom. I thank the Benson Agricultural and Food Institute and the USDA-Forest Service's Shrub Science Laboratory for their financial and administrative support of this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PART 1: FORAGE ADAPTABILITY TRIALS FOR FORAGE AND SEED PRODUCTION IN BOLIVIA

INTRODUCTION

The following quote by Armando Cardozo, a Bolivian agriculturalist, describes the plight of farmers in the Bolivian highlands:

> The rains fall approximately from the end of November until the end of March. The large part of this precipitation falls in the 90 middle days of this rainy period. The rains stimulate the growth of forage plants, [and] in a short period of time [this growth] outpaces the capacity of the animals to consume it…In contrast, the rest of the year there is a deficit of forages that is critical from the month of July until the middle of November (Cardozo 1981, my translation, pg 51).

Due to a combination of factors, most rangelands on the Altiplano have become severely overstocked and overgrazed as farmers have attempted to increase production. The Altiplano is a vast, highland plain that stretches from southern Perú through Bolivia and into northern Chile. Overgrazing and the subsequent range deterioration have naturally led to lower livestock quantity and quality. In addition, many deleterious effects on the ecology of the Altiplano have been noted, including the gradual disappearance of some forage species, the increase of other species, changes in patterns of cover, an increase in the proportion of low-growing plants, changes in groundwater flow, soil compaction and soil erosion (Garcia 1995).

It would seem plain that the simplest solution to this problem would be to reduce the number of grazing animals on the Altiplano. However, there are a number of factors at work both at the administrative and local levels that make this practically and logistically unlikely. First, there is no governmental agency in place that has the resources to determine what an appropriate number of animals in any given area would be. Second, even if this number were somehow established, there is no agency in place to enforce it. Third, even if there were an enforcement agency, the vast majority of animal owners on the Altiplano are small families that have a few animals and are scattered across large areas, so regulation in any meaningful way would be extremely difficult. Locally, economic and social factors pressure farmers to maintain larger herds. The best grazing lands (which are always in short supply) are reserved for beef cattle and draft animals and any grains that are raised as hay to supplement the diets of these animals. Grazing land left over is then used by sheep in the lower elevations and llamas or alpacas in the higher elevations. The sheep and alpacas serve several purposes, the first of which is meat, milk, and wool production for consumption or sale by the animals' owner. Because reproductive rates of these animals are quite low and because their diet is generally very poor, it takes a relatively large herd to meet these needs. Economically, larger herds provide a safer hedge against disease or natural disasters than do smaller herds. Finally, these animals provide an important service in the production of manure that is used to fertilize crops such as potatoes. The sheep or llamas are able to take the nutrients of widely scattered forage and concentrate them in a form that is readily useable by farmers (LeBaron et al. 1979).

An alternative to reducing the number of animals is to supplement their diet during the dry season. As mentioned above, this is by far the most critical time of the year for the livestock, so it would be of great benefit to them. Also, it would serve to reduce some of the grazing pressure on the rangelands during this time.

The purpose of this project was to evaluate several species of drought-tolerant forage grasses that may be successfully grown and held in fenced reserves for those times that livestock need them most. Supplementing their diet could improve the health and survival of the animals and reduce some of the grazing pressure on the existing vegetation. Additionally, to avoid the economic burden of importing the seed, research evaluations were conducted to find suitable sites for seed production.

The Bolivian Economy

Bolivia ranks lowest among all South American nations in per-capita yearly gross domestic product (GDP) (CIA 2006). At $2700, each Bolivian earns less than half that of their neighbors in Perú and less than 1/10 that of US citizens (Fig. 1). Bolivia receives tremendous amounts of foreign aid each year. In 2005, the United States alone gave approximately $85 million to Bolivia through various foreign aid programs, and the State Department estimated that nearly the same amount will be given in 2006 (USAID 2006). Klein (2003) estimated that in 1999, 30% of the Bolivian government expenditures came from foreign aid from the US, World Bank, and other sources. There is clearly a great need for appropriate development projects that will allow the country to move toward self-sufficiency.

Pre-modern Agricultural History

The present-day nation of Bolivia had a long and complex human history before the European conquest of the early 1500s. Despite the fact that the indigenous peoples kept few or no written records (Brokaw 2003; Ibarra Grasso 1985) there exists a surviving remnant of the complexity of Bolivia's past. Scholars identify approximately 77 indigenous languages currently spoken (Ibarra Grasso 1985) within a nation only slightly larger than the state of California. According to Ibarra Grasso, "each of these indicated languages and dialects points to the existence of an indigenous, pre-Columbian nation" (1985, my translation, pg 39).

There is some archaeological evidence that many of these ancient groups gradually developed agricultural systems between 8000 and 2000 B.C. (Klein 2003). The first large-scale civilization in Bolivia appeared on the southern end of Lake Titicaca around the year 100 B.C. The center of this civilization was the religious complex of Tiwanaku (spelled variously as Tihuanaco, Tiahuanaco, etc.). The ruins of large, stone temples and other structures are still visible at this site today.

In the early 1980s archaeologists discovered the remains of what has come to be known as raised field agriculture in the Lake Titicaca basin. Due to the seasonally high water table, the inhabitants of Tiwanaku dug deep canals around parcels of land to drain the excess water for crop cultivation. There is some evidence that the presence of the canals created a favorable microclimate by mitigating the steep temperature fluctuations of the Altiplano and preventing frosts to some degree. In addition, it is believed that the anaerobic conditions of the standing water in the canals produced a nutrient-rich muck that was used to fertilize the raised fields (Swartley 2002). Archaeologists claim that these fields were sufficiently productive to support a large, urban population centered at Tiwanaku. Kolata (1993) estimates that the fields could have provided sufficient nutrition for somewhere between 570,000 to just over 1 million people. For comparison, Kolata notes that according to his calculations, a sub-region of the Tiwanaku area called

Pampa Koani could have supported between 105,000 to 204,750 persons while today, there are only about 2,000 inhabitants, and most are living "at a level slightly beyond bare subsistence" (1993, pg 204).

Despite the apparent and numerous advantages to raised-fields, it appears from both historical accounts and archaeological information that this technology was not being used at the time of the Spanish conquest. Researchers disagree as to the reason for this, but many point to a gradual drying of the climate lasting some 400 years that likely reduced the productivity of the raised fields (Ortloff and Kolata 1993). The commencement of this drought coincides precisely with the sudden decline of the Tiwanaku civilization around 1200 A.D. Thereafter, smaller (but still highly organized) groups formed what came to be known as the Aymara kingdoms. Each of these kingdoms was divided into 2, mostly autonomous parts. The first was situated more toward the western side of the Altiplano and controlled colonies stretching down to the Pacific coast. The second part was on the eastern side of the Altiplano with colonies extending into semi-tropical eastern valleys (Klein 2003). A complex system of reciprocal trade developed within each kingdom so that each region supplied the others with items that were unique to that region in return for products that could only be produced in other areas. The drought mentioned above led to a reduction in the importance of crop agriculture and a corresponding increase in the herding of camelids such as llamas and alpacas (Klein 2003).

Modern Agricultural History and Land Ownership

In approximately the 1460s, the highland areas of Bolivia were conquered by Incan invaders based at present-day Cuzco, Perú. As a matter of imperial policy, the Incas generally left local cultures intact but required a substantial tribute. Such was the case in Bolivia, and the Aymara kingdoms changed little until the arrival of the Spanish *conquistadores* in South America in 1532.

The Spanish initially paid little attention to Bolivia (which was called "upper Perú" due to its elevation) because its inhabitants did not possess the mineral wealth that the Europeans so eagerly sought. However, the situation changed dramatically when the richest silver deposits of the continent were discovered at Potosí in 1545. The Spanish rapidly began to infiltrate the Bolivian highlands and create an infrastructure capable of exploiting the mines at Potosí. The city of La Paz was founded in 1548 to link the mining areas with cities such as Cuzco that were already under Spanish control (Klein 2003).

Before this time, a complex social organization existed within each Aymara community. Though the elite of a community could hold and inherit private property to some extent, most agricultural land was owned in common and worked by the local peasants. The right to work certain parcels of land on a continuing basis was generally granted to individuals. These rights were heritable, but were not considered ownership of the land; only the community could own this land (Klein 2003).

Like the Incas, the Spanish initially left local social organizations intact. However, over time the rule of large land areas (*encomiendas*) and the associated inhabitants were granted to certain Spaniards in return for their service as *conquistadores*. The Spanish rulers were known as *encomenderos* and received rights to the labor and goods of the Indians and were responsible for the religious education and enculturation of the Indians (Klein 2003). The exploitative goals of the *encomenderos* began the breakdown of the social organizations that had existed for centuries on the Altiplano (Swartley 2002).

The continued development of the mining industry centered at Potosí created an intense need for cheap labor. In the mid 1570s, the Viceroy Francisco Toledo set into motion reforms that attempted to address this problem. In order to more easily govern and tax the indigenous communities, Toledo ordered the consolidation of small, widely-dispersed villages into larger towns. He also limited the influence of the *encomenderos* and appropriated direct control of many peasants for the crown, mainly for use in the silver mines. Toledo resurrected a non-voluntary labor system used by the Incas called the *mit'a*. Whereas the Incas required all male subjects to regularly participate in large pubic works projects, Toledo required the peasants to work approximately 1 in every 6 or 7 years in the mines of Potosí. The workers were paid virtually nothing and were required to supply their own transportation to the mines and their own daily necessities such as food and clothing (Klein 2003).

The exploitation of indigenous communities by the *encomenderos* and the pressures of the Toledo reforms caused a shift in the structure of most communities. Only those individuals who had control of lands were required to pay taxes, so as the tax burden gradually increased, many simply gave up their land rights to avoid these obligations. Thus, a simultaneous surplus of both landless peasants and unused land was created. Wealthy Spaniards took advantage of the situation by acquiring vast tracts of land and then hiring peasants to farm them. The land holdings of these Spaniards became known as *haciendas*. This situation eventually stabilized and became the status quo by the year 1700 (Klein 2003).

A steep decline in mining production in the late 1600s led to a deep depression of the Bolivian economy. Consequently, Spanish interest in the region declined, and gradually an elite class of native-born whites and *mestizos* (individuals with mixed European and Native American ancestry) began to acquire wealth and political power. This situation developed to the extent that in 1780 a rebellion erupted that essentially became a war for independence. The revolt involved all ethnic and social classes with the goal of overthrowing Spanish authority. After a series of massive, bloody battles between the rebels and those still loyal to the Spanish crown, the uprising was crushed in 1782. After a long period of recovery, Bolivia joined in the independence movement that swept the continent in the early 1800s. Loyalist forces were finally defeated and Bolivia was declared free of Spanish rule in 1825 (Klein 2003).

A period of political and economic turmoil followed Bolivia's independence, and in the 1880s wealthy landowners convinced the government that the communal system of land ownership by Indians was a barrier to economic expansion. Thus, the government declared that the Indian communities had to grant land titles to individuals, and *hacienda* owners began to break up the communities through the purchase of parcels of land or by simply forcing the landholders out. The *haciendas* continued to expand, with a corresponding decline of Indian community lands until the 1930s (Klein 2003).

By the 1950s, the *haciendas* had expanded to the extent that the top 6% of landowners controlled 92% of the cultivated land in the entire country (Klein 2003). In effect, this meant that the vast majority of the Indian peasants either held very small plots of land or no land at all. Those who worked on land owned by a *hacienda* owner were required to supply all or nearly all materials for working the land, including seed, tools, and animals. In addition, many of these workers were required to regularly act without compensation as domestic servants for the *hacienda* (Klein 2003).

Throughout the nation, political turmoil continued and intensified, resulting finally in a bloody but brief civil war in 1952. Urban revolutionaries took control of the government armories and eventually defeated the army and its governmental allies. The indigenous communities, which had been relatively uninvolved in the struggle up to this point suddenly began to mobilize. After forming highly organized unions, they obtained what arms they could and began a rapid and forceful takeover of *hacienda* lands. The new Bolivian government legitimized these actions with agrarian reform legislation in 1953 (Klein 2003).

Swartley (2002) describes the manner of land redistribution in the rural community of Wankollo, a small town just south of Lake Titicaca; she claims that redistribution was handled in a similar manner in most areas. Those peasants that were living on and working the land at the time of the 1952 civil war were immediately given rights to the land they had been working. Each family was given control over the grounds immediately surrounding its house, and then some additional lands away from the house. As had been the case in the past, rather than the peasants receiving title to their lands, the community held the actual deeds to their lands. The families were simply given rights to work designated pieces of ground.

In Wankollo and many other communities, many families that had been forced off of their lands or left for other reasons returned and demanded compensation. Most of their requests were granted by the government, though these returning peasants were generally given smaller or less desirable parcels of land.

Since the reforms of the early 1950s, very little as far as land ownership has changed in rural areas. Though the population of Bolivia has increased substantially in the past 50 years, this growth has mainly occurred in urban areas. For example, the total population of the country in the census of 1950 was just over 3 million people, while in 2001, there were over 8.2 million (Klein 2003). Between 1950 and 1976, rural Bolivia experienced approximately a 70% increase in population, while urban areas grew by over 280%. Between 1976 and 1992, the population of rural areas grew by slightly more than 1%, while that of urban areas continued to balloon at 185% (Swartley 2002). This dramatic difference is due mainly to the migration of individuals from rural to urban areas. Because of this situation, there has not been a great need for change in the organization of land ownership or management in small communities. In general, the rights to work a family's lands are passed from one generation to the next, without much need for alteration of the established order (Swartley 2002).

Modern Land Use

There are basically 2 types of indigenous communities on the Altiplano (generally called *comunidades*). This split has resulted from the fact that during the era of the *hacienda*, some *comunidades* were appropriated by the Europeans and some were not; thus, those that were once part of a *hacienda* are now called *ex-hacienda comunidades*, while those that were never part of a hacienda are called *comunidades libres* ("free communities") (LeBaron et al. 1979).

In the *comunidades libres* there are 3 basic land divisions: the *sayaña*, the *aynoka*, and the *ahijadero*. *Sayaña* is generally translated as "house plot." It comprises the relatively small area directly around the home or homes of an extended family. The control the family has over this land most closely resembles what European culture would consider private property. The community has little or no input as to what occurs on the *sayaña*; rather, the family determines when and which crops are planted, or whether anything is planted at all (LeBaron et al. 1979).

In contrast, the *aynoka* and the *ahijadero* are both managed communally and are larger land areas. The *aynoka* is arable land that is subdivided into smaller plots that are farmed by nearby families. In general, a family maintains its right to farm the same allotments over time and even over generations. Precisely what is grown and when it is grown is decided by the community. Usually, entire *aynokas* will be either left to fallow or will be sown with a single crop (LeBaron et al. 1979). The *ahijadero* is any land that is deemed by the community to be non-arable, and thus is used for grazing rather than farming. This land is not divided into areas for certain families; rather it is used communally by those that have need of it. In addition to the *ahijadero*, a family also is allowed to graze its animals on certain *aynoka* lands that are in fallow, but these areas are not necessarily the same as those that the family would farm (LeBaron et al. 1979).

Ex-hacienda comunidades are structured similarly, except for the fact that the degree of control that a family can exercise over cultivable lands varies regionally. This includes lands that families have traditionally farmed for generations and also lands that were appropriated from the *hacendado* after the agrarian reforms of the early 1950s. In some cases, families have nearly complete control over these lands, as if they were part of the *sayaña* (LeBaron et al. 1979).

The Feasibility of Fencing

The literature available on the results of building fences in indigenous *comunidades* on the Altiplano is sparse at best. Buttolph and Coppock (2001) describe some of the results of a development project that began in 1993 and sought to improve alpaca production on the Altiplano. A part of this project consisted of the fencing of artificially created riparian areas (*bofedales*) that were often used communally for grazing, particularly during the dry season. The intention was to limit grazing of these areas during the wetter parts of the year and allow enough rest to improve the quality of forage in the dry season. Buttolph and Coppock (2001) report that, although little change was observed in plant diversity or forage abundance, a 26% reduction in young alpaca mortality was observed. They assume that the fencing allowed the young (and possibly their mothers) to obtain forage that they otherwise would not.

Along with this improvement in production, Buttolph and Coppock (2001) report the emergence of a sort of land rush in the *comunidades* that participated in the project. They state, "The appeal of fencing to households, however, came not only from improvements to alpaca recruitment, but also because it provided a new way to establish exclusive rights over productive land otherwise under common access" (Buttolph and Coppock 2001, pg 12). The fences were built by individuals that obtained credit and materials from a development agency, and so when the fences were built, the individuals in essence claimed exclusive ownership of what was often formerly communal land. Once the fencing began, it created a snowball effect with each member of the *comunidad* attempting to acquire as much land as possible to avoid the threat of losing access to all the communal land. In fact, in 1 area, "…about 50% of the formerly communal *bofedales* (riparian areas) were annexed for private use within 2 years" (Buttolph and Coppock 2001, pg 12).

Buttolph and Coppock (2001) conclude that fencing led to the partial destruction of the traditional system that regulated rights to grazing. In addition, they state, "the implications of privatization thus include increased risk and vulnerability for those without fencing, greater economic polarization within the community, and a greater likelihood that poorer households will be expelled from the system," and then, "despite some of the short-term benefits of fencing on this production system, the longer-term consequences may be more detrimental as a whole" (Buttolph and Coppock 2001, pg 13).

It is imperative that the socio-cultural context of a people be understood if a development plan is to be successful. Thus, this study of the manner of land use among indigenous *comunidades* was undertaken to provide a framework for the application of my research into the possible use of small, fenced plots of supplemental dry season forage. Without this information, it is possible that I and my colleagues would attempt to apply our findings in a manner that "may be more detrimental as a whole," despite any benefits they may provide to agriculturalists of the Altiplano.

To avoid such a situation, I present the following recommendations. First, fences may not be needed at all. Throughout the planning of my project, it has been assumed that fencing would be needed to keep stray livestock out of the plots until the appropriate time during the dry season. However, with simple observation, it can be seen that crops and forage material (i.e., barley), are grown without fencing on the Altiplano, and these are at least generally not destroyed by loose livestock. The reason behind this is a difference in the way grazing animals are handled in the US and in Bolivia. In the US, relatively large numbers of animals are turned into a fenced pasture area and allowed to roam without supervision within that area. On the Altiplano however, when animals are allowed to graze, they are under constant supervision of their owners. Thus, fields of crops do not need to be fenced because it is the responsibility of the owners of animals to make sure that they do not stray into such areas. So, perhaps the grasses used for my project could be protected in the same way, and fences would not be needed at all.

As a second option, it is possible that if fences are used the exclosure could be placed within a family's *sayaña* (house plot). Because the family has autonomous control over this land, fencing a portion of it should not cause any problems within the *comunidad*. A foreseeable problem with this solution is that there may not be sufficient space for the exclosure, or a family may have put the land to other purposes that they consider more worthwhile. If the land area is insufficient, nothing can be done about this. If the land is being used already, then only time will show whether or not this project provides sufficient benefits to persuade a family to convert an area to forage grass cultivation.

A third possibility is that the community as a whole could be consulted to determine if fencing areas of communal land would be appropriate. If it is so decided, then the community could determine rules to govern the use of the grasses, just as they now have rules for determining how open communal grazing lands may be used. In this manner, the land would remain under control of the community despite the fact that it is fenced, and hopefully this would avoid conflict.

It is likely that little or no land that has traditionally been used to cultivate food crops (*aynokas*) would be available for planting forage grasses. However, due to the fact that most of the grasses used in this study grow quite well in adverse conditions, it is certainly possible that they could be planted in part of the *ahijadero* of a *comunidad*. Thus, no farmland would have to be taken out of production. Again, because this is communal land, the entire community would have to be consulted to determine if, when, and where an exclosure would best be placed.

The Species Introduction Question

The introduction of non-native organisms has had a profound effect on all major ecosystems of the world. The most prominent examples of this are notable precisely because they had disastrous results. For example, the inadvertent introduction of the smallpox pathogen by European explorers (and the African slaves they brought with them) decimated the human population of North and South America. By 1495, only 3 years after the arrival of Columbus to the New World, somewhere between 60 and 80 percent of the natives on the island of Santo Domingo were dead (Eddins no date). Of the 71 known taxa of birds that are endemic to the Hawaiian islands, 23 are extinct and another 30 are listed as endangered or threatened. There is a long list of probable causes for this decline, but it is clear that some of the most important have been the introduction of predators such as rats and feral cats, the introduction of avian pathogens, and the introduction of competing bird species (Jacobi and Atkinson no date). Clearly, extreme caution must be exercised whenever non-native organisms are brought in to a new area.

Fortunately, not all historical examples of species introduction have resulted in ecological catastrophes. In fact, the vast majority go largely unnoticed because the organisms either fail to become established or do not have a very dramatic impact on their new environment. A good example is 1 of the grasses that we are attempting to grow in Bolivia—crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.). It was introduced to the United States as early as 1898, and has since been used by farmers and ranchers throughout the west (Rogler and Lorenz 1983). While this grass obviously occupies space and nutrients that otherwise would be utilized by native plants, its introduction has not caused any sort of disaster. Rather, by providing long-term, quality forage for livestock it reduces the grazing pressure on native grasses such as bluebunch wheatgrass (*Pseudoroegnaria spicata* Pursh) which are more susceptible to permanent damage from heavy grazing.

The goal of our project in Bolivia is to find 1 or more species of grass that provide similar benefits. We are searching for something that will grow well and provide ample forage for livestock, but will not significantly damage the natural ecosystem. Following is a list of reasons why we believe that this project will accomplish these objectives.

Previous Introductions. In the mid-1960s Utah State University (USU) began a series of agricultural development projects in Bolivia, particularly on the Altiplano. The focus of the projects was to bring improved methods, technology, plants and animals to the poor farmers in rural areas. To that end, 1 project involved the introduction of 150 varieties of forage grasses, 50 varieties of alfalfa, and 50 varieties of other legumes to 5 experimental stations on the Altiplano for adaptability trials (Anderson 1975). Included in these were all of the species used in the current experiment. Unfortunately, the vast majority of this work was never published, so I did not learn of it until my project was nearly complete.

Of these 150 grasses, very few adapted well to the environment of the Altiplano. In fact, most did so poorly that very little data was recorded on their performance. On the other hand, several documents contain information on the forage production, plant height, and seed production of the species that faired well. Allred (1971) specifically recommends orchardgrass (*Dactylis glomerata* L.), Alta tall fescue (*Festuca arundinacea* Schreb.), and Alkar tall wheatgrass (*Agropyron elongatum* [Host] Beauv.) and provides data on these species and timothy (*Phleum pratense* L.), Greenar intermediate wheatgrass (*Agropyron intermedium* [Host] Beauv.), and Nordan crested wheatgrass. In another document, McKell (1971) adds smooth bromegrass (*Bromus inermis* Leyss.) to the list of recommendations and reports that under dryland conditions, Vinall Russian wildrye (*Elymus junceus* Fisch.) and several others performed well. Unfortunately McKell (1971) provides no data to support these claims. Several other literature sources mention the introduction or the presence of species used in this experiment as well (Table 1).

Control. We have maintained strict control over when and where these grasses have been planted. They have only been grown in monitored, fenced, experimental areas. As a part of the data collection protocol, we are harvesting as much as possible of the seed that is produced by the grasses. Thus, if any seed is released, it will be a fairly small amount and the resulting plants will be easily controlled.

Reduction of Grazing Pressure on Native Grasses. The intention of this project from the beginning has been to give farmers an alternative feed source during the driest time of the year. By utilizing this alternative, animals will then be somewhat less dependent on the existing native vegetation. Thus, while it is true that we are introducing non-native plants and that this is often considered harmful for the native ecosystem, in this case the natives will likely benefit more than they would if these non-natives were not introduced.

Previous Work

In 2002, 6 species of grasses and 6 species of shrubs were planted at 3 sites on the Altiplano (Tiwanaku, Patacamaya, and Letanias). The grasses used were intermediate wheatgrass, smooth brome, Hycrest, weeping lovegrass (*Eragrostis curvula* [Schrad.] Nees), orchard grass, and timothy (Fugal 2006). Despite the fact that most species grew quite well and produced abundant biomass, none produced seed. It was assumed that the cause for this (as mentioned above) is the heavy and frequent frost that occurs on the Altiplano. Thus in the current project, 3 sites with very distinct climates and elevations were chosen in an attempt to find a more appropriate location for seed production.

METHODS AND MATERIALS

Site Selection

The locations chosen were: Tiwanaku at 3,850 m elevation, Cochabamba at 2,570 m, and Coroico at 1,525 m (Fig. 2).

Tiwanaku. Our first site is located approximately 70 km northwest of La Paz in the Lake Titicaca basin. It is only a few km from the archaeological ruins whose name we used for this site. The land itself is owned by a local farmer who has allowed us use of it for this experiment. The region receives between 500 and 700 mm of rain per year (US Army Corps of Engineers 2004), with the majority falling between December and March (Kolata 1993), and the average temperature is approximately 8° C (Bolivia Contact 2001). Due to the proximity of Bolivia to the equator, the temperature does not vary greatly seasonally. However, due to the elevation of the Altiplano, daily temperature fluctuations can be relatively large. This site is maintained on a day-to-day basis by students from the *Universidad Católica Boliviana* (Bolivian Catholic University) who are supervised by Dr Alejandro Bonifacio. A soil analysis was performed at the fertilized and non-fertilized portions of each site in May of 2004 (Table 2).

Cochabamba. The city of Cochabamba is 382 km from La Paz and is situated in a broad valley (Bolivia Web 2006). Cochabamba is a prime agricultural area for Bolivia due to its climate, good soils, and relative accessibility from the capital. Our plots are located within the experimental agricultural grounds of the *Universidad Mayor de San Simón* (Higher University of San Simón) on the outskirts of the city. In the summer time, the average temperature is about 26° C, while in the winter the average is 17° C (Bolivia Web 2005). The site receives between 500 and 700 mm of rain per year (US Army Corps of Engineers 2004). The plots are maintained by agriculture students who are supervised by Ing Juan Herbas Balderrama, a faculty member of the university. A soil analysis was performed at this site as well in May of 2004 (Table 3).

Coroico. Our third site is found in the *Yungas* region. To get there, one must climb from La Paz through the pass of *La Cumbre* at 4,725 m and then begin a precipitous drop to 1,525 m over a distance of only about 80 km. The climate changes very abruptly to humid and semi-tropical in the steep valleys. Our plots are on the grounds of a small agricultural university called the *Universidad de Coroico – Carmen Pampa* that is just outside the town. The mean annual temperature of this area is approximately 23° C, (UNODC 1950), and it receives 900 to 1000 mm of precipitation per year (US Army Corps of Engineers 2004). The site is maintained by university students supervised by faculty member Ing José Beltrán. A soil analysis was performed at this site as well in May of 2004 (Table 4).

Site Design

The layout of this experiment is a split-split-split plot design. The main plot is the site, of which there are 3: Tiwanaku, Cochabamba, and Coroico. The subplot is a fertilizer treatment, of which there are 2 levels: either a single application of an N-P-K mix as determined by soil analysis data; or no fertilizer. The sub-subplot is the species of grass that was planted (Fig. 3 and Table 5). Tweleve species were used in this experiment (Table 6).

The abbreviations used in the charts and figures are found in Table 7. All of the grasses at each site were planted within 2 weeks of each other in December of 2003. 5 rows of a single species were planted in each plot in Cochabamba, and data were collected from the inner 3 rows to avoid any edge effect. Due to space constraints at Tiwanaku and Coroico only 4 rows of each grass species were planted, and data were collected from the inner 2. In addition in Cochabamba, 2 of the species were accidentally switched—the crested wheatgrass from block 3 was switched with the tall fescue from block 4. The seeds at all sites were planted at a depth of 0.3 cm with 50 cm between rows using a manual mechanical Earthway vegetable seeder from Johnny's Selected Seeds that was set to deliver 3.5 kg of seed per acre.

Data Collection Protocols

Emergence. Seedling emergence data were collected at each site in the following manner. Beginning 1 week after the first rains of the season, the number of seedlings in three 25 cm segments was counted in each of the 3 interior rows of each plot (Fig. 4). Data were supposed to be taken at 3-day intervals until the seedling counts leveled off. However, at Tiwanaku data were taken only 3 times. If data had continued to be collected, higher levels of emergence probably would have been seen. At the other sites, data were collected 13 times (at Cochabamba) and 11 times (at Coroico).

Row Fill. Row fill was supposed to be determined 1 month after emergence leveled off and again 5 months later. In reality, this was done only in Tiwanaku in July of 2005. Gaps greater than 10 cm were recorded for each row and progressively added to provide 1 total per plot (Fig. 5).

First Year Biomass. Production (biomass) data were taken at the end of the growing season at Tiwanaku and Cochabamba. Data were not taken at Coroico because so few of the plants had survived to this point. Beginning 1 m in from each end of the plot, all plant material in the interior rows above 2.5 cm was clipped (Fig. 6). A sub sample of these clippings was taken and weighed, then dried at 40˚ C for 3 days and then weighed again. The percent dry weight was then extrapolated for the entire sample.

Phenology. The following phenological information was supposed to be collected on the timing of the following events in each experimental unit at each site: the beginning of bolt; 50% bolt; the beginning of anthesis; 50% flowering; the beginning of seed maturity; and 50% seed maturation.

Seed Harvest. Seed was collected where available from each experimental unit after 50% of the seed reached maturity. The reproductive stems were cut approximately 5 cm below the lowest branch of the inflorescence and placed in paper bags. The seeds were dried and then cleaned either by hand or machine. The seed from each experimental unit was then weighed. After all the seed for each species was harvested, it was mixed and 3 handfuls were randomly taken. These handfuls were then weighed and the seeds were counted.

Second Year Production. After the seed harvest of all species, two 1-m segments were selected randomly from the inner rows at least 0.5 m from the edges (Same as in first year biomass). All the organic material above a height of 5 cm was cut and placed in a paper bag and weighed. This material was mixed with the material of the same species from the other experimental units. A single handful was taken, placed in a paper bag, weighed, and dried in an oven at 40 ˚C for 3 days and then weighed again to obtain the percent dry matter for each species.

Statistical Analysis

The data were analyzed with SAS version 9.1, using the MIXED procedure (SAS Institute Inc. 2006). Because of the difficulty of interpreting 3-way interactions and because the sites were significantly different, the data from each site were analyzed separately. The data were further analyzed with mean separation and the Tukey adjustment. Because the SAS MIXED procedure does not include a function that allows mean separation, it was done separately with the PDMIX800 macro (Saxton 1998). If the data did not meet the analysis of variance (ANOVA) assumptions, they were transformed with the inverse, square, square root, log, arcsin, and logit transformations and re-tested. In cases where the data still did not meet the ANOVA assumptions, they were ranked before being further analyzed (Conover and Iman 1981).

RESULTS

Emergence

Emergence data were taken at each site shortly after the seeds were planted and the grasses began to germinate.

Tiwanaku. Timothy had by far the highest density at Tiwanaku (Figs. 7a and 7b), eventually reaching approximately 960 seedlings per m. The next highest-emerging species were tall fescue and orchardgrass, which both reached approximately 210 seedlings per m. The remaining species fell in the range below this level, and inland saltgrass did not germinate at all at this site.

Cochabamba. At Cochabamba most species approximately reached their maximum emergence after only 9 days (Fig. 8). Tall fescue emerged at the highest rate (approximately 98 seedlings per m). Again, inland saltgrass did not emerge at all, and the remaining species fell in the range between these extremes.

Coroico. Like at Tiwanaku, Timothy showed by far the greatest emergence at Coroico, reaching a peak of approximately 626 seedlings per m (Figs. 9a and 9b). The peaks of the remaining species fell in a range between 140 and 4 seedlings per m. Surprisingly, inland saltgrass did emerge slightly at this site.

In contrast with the other sites, most of the grasses in Coroico showed good emergence, but the number of seedlings reached a peak approximately 13-16 days after being planted and then declined dramatically. In fact, this trend continued for nearly all the species until all the seedlings had died. It was supposed that the excessive moisture at this site was the cause, and the grasses were reseeded several months later at the tail end of the wet season. Unfortunately, the results were the same.

The only species that almost entirely failed to germinate at all 3 sites was inland saltgrass. The likely explanation for this is that the germination requirements for this grass are very specific and were probably not met. Cluff et al. (1983) showed that in general the highest germination rates were achieved with an alternating temperature regime of 16 h at 10º C and then 8 h at 40º C with the osmotic potential of -1 bar. Deviations from this scheme resulted in dramatically lowered germination. The researchers concluded that "…saltgrass seed germination is an episodic event in nature, occurring only when moisture events coincide with optimum seedbed temperatures and can leach sufficient salts to raise moisture potentials above -15 bars" (Cluff et al. 1983, pg 419). Apparently, these conditions were not sufficiently met at any of the sites to produce significant emergence.

Rowfill

Tiwanaku. Rowfill data were taken in July of 2005. Great Basin wildrye and inland saltgrass did not survive at this site, so they had mean rowfill scores of 0 before ranking (Fig. 10). These were not different from Russian wildrye, and these 3 species were significantly lower than the remaining species. Tall fescue, Timothy, and Hycrest were not different from each other and had the greatest rowfill.

Cochabamba. No data.

Coroico. No data.

Year 1 Biomass Production

Tiwanaku. Inland saltgrass, Russian wildrye, and Great Basin wildrye produced no biomass (Fig. 11). The mean separation showed few clear differences between treatments, though those that produced the highest rowfill (such as the fertilized tall wheatgrass and orchardgrass) were clearly different from the species listed above that produced no biomass.

Cochabamba. The fertilized blocks produced significantly more biomass than the unfertilized blocks at this site (Fig. 12a). Again, there were few clear differences between the species (Fig. 12b). Inland saltgrass produced no biomass, so was significantly lower than the other species, and above this there was a gradation of increasing biomass up to tall wheatgrass.

Coroico. No data.

Year 1 Seed Production

Tiwanaku. Unfortunately, the only seed data that were obtained from Tiwanaku was the weight of uncleaned seed. Thus, the numbers presented can give only a very general idea of the production of the grasses at this site, and they were not analyzed statistically. The greatest amount produced was only 7.7 kg/ha by fertilized pubescent wheatgrass. When fertilized, Russian wildrye, Great Basin wildrye, and orchardgrass also produced some seed (Fig. 13).

Cochabamba. The seed from Cochabamba was cleaned before the weight data were taken. The fertilizer made no significant difference for seed production. Most species produced virtually no seed (Fig. 14). Seed production of Russian wildrye, tall fescue, and smooth brome was significantly greater than that of the species that failed to produce seed. However the highest seed production by any species (tall fescue in this case) was 18.4 kg/ha.

Coroico. No data.

Phenology

Tiwanaku. Due to the remoteness of the Tiwanaku site, phenology information was not collected as often as would be ideal. However, the information that is available will be presented.

50% Bolt. Tall wheatgrass, Siberian wheatgrass, pubescent wheatgrass, Hycrest, orchardgrass, NewHy, and tall fescue reached 50% bolt by 12 January 2006. Smooth brome and timothy reached the same stage by 5 February 2006 (Table 8).

50% Flowering. Some species reached 50% flowering as early as 28 January 2006, while others took until 12 March 2006 to reach the same stage. Russian wildrye, Great Basin wildrye, and 1 plot of pubescent wheatgrass did not flower in 2006 (Table 9).

Anthesis. Russian wildrye and Great Basin wildrye (and, of course inland saltgrass) did not reach anthesis in 2006. All of the other species did so between 25 February 2006 and 15 March 2006 (Table 10).

Seed Harvest. Russian wildrye, Great Basin wildrye, and inland saltgrass did not produce any seed in 2006. All of the other species did so between 29 March 2006 and 10 May 2006 (Table 11).

Cochabamba.

Initial Bolt. Siberian wheatgrass, Hycrest, inland saltgrass, and timothy did not bolt at all during late 2005 and early 2006. The species smooth brome and NewHy had only 1 plot each that reached bolt. All species that began bolt did so between 23 November 2006 and 13 April 2006 (Table 12).

50% Bolt. Tall wheatgrass, Siberian wheatgrass, pubescent wheatgrass, Hycrest, smooth brome, inland saltgrass, NewHy, and timothy did not reach 50% bolt. The remaining species did so between 30 November 2005 and 3 April 2006 (Table 13).

Initial Anthesis. Siberian wheatgrass, Hycrest, inland saltgrass, NewHy, and timothy did not reach anthesis. Smooth brome reached anthesis in only 1 block on 20

December 2005. All other species did so in 3 or more blocks between 30 November 2005 and 12 April 2006 (Table 14).

50% Anthesis. Tall wheatgrass, Siberian wheatgrass, pubescent wheatgrass, Hycrest, smooth brome, inland saltgrass, NewHy, Great Basin wildrye, and timothy did not make it to 50% anthesis. The remaining species did so between 8 December 2005 and 12 April 2006 (Table 15).

Initial Seed Maturity. Only 4 species had seed that reached maturity: orchardgrass, Russian wildrye, tall fescue, and Great Basin wildrye. They did so between 20 December 2005 and 23 March 2006. Orchardgrass and Great Basin wildrye reached this point only in 1 block each (Table 16).

50% Seed Maturity. Only 2 species reached the point of 50% seed maturity: Russian wildrye and tall fescue. The seed matured between 29 November 2005 and 20 March 2006 (Table 17).

Coroico. No data.

Year 2 Rowfill

Tiwanaku. There were few clear significant difference between the treatments (Fig. 15). The exceptions to this were inland saltgrass, Russian wildrye, and Great Basin wildrye, which had no rowfill, and Timothy, which was not different from these. Fertilized Hycrest produced the highest rowfill (approximately 93%), but this was not different from many of the other treatments.

Cochabamba. The only species that produced no rowfill was inland saltgrass, which was significantly lower than all other species (Fig. 16). Timothy, smooth brome, NewHy, and tall fescue had the highest rowfill and were not different from one another. The remaining species were lower.

Coroico. No data.

Year 2 Seed Production

Tiwanaku. Data were obtained for only 2 species (Hycrest and Siberian wheatgrass), and unfortunately the seed was not cleaned. So again, statistical analyses were not performed (Fig. 17).

Cochabamba. Seed was produced by only 3 species—Hycrest, Russian wildrye, and tall fescue (Fig. 18). Hycrest was not statistically different from 0. Russian wildrye and tall fescue were different from 0, but were not different from each other. The most seed produced by any species (tall fescue in this case) was 0.07 kg/ha.

Coroico. No data.

Year 2 Biomass

Tiwanaku. No data.

Cochabamba. Data were only taken from plots that actually produced seed (only 2 species). This included all Russian wildrye plots, but only 2 of the 4 unfertilized tall fescue plots and only 1 of the 2 fertilized tall fescue plots (Fig. 19). Because so little data were collected (and so little seed was collected) these data were not analyzed statistically.

Coroico. No data.

DISCUSSION

As stated in the introduction, the focus of this study was to find a site suitable for seed production, and as far as this objective goes, we were unsuccessful. The greatest observed seed production was Siberian wheatgrass in Tiwanaku in 2006, which produced 58.8 kg/ha of uncleaned seed. As a rough estimation, if it is assumed that the cleaned seed would have weighed about half of this amount, it would equal about 29 kg/ha. To put this figure in perspective, this species is reported to produce an average of 168-224 kg/ha here in the US under dryland conditions (USDA NRCS 2003). Even at their best, the grasses in this trial produced only a tiny fraction of the quantity of seed that they regularly produce in other locations. The most likely explanation for this is that the timing of resource availability differs in Bolivia compared to sites in the Northern hemisphere where these grasses are typically grown.

Resource Availability

In the Western US spring rains generally fall and many plants grow rapidly just after the March equinox as the days are getting longer and temperatures are rising (Fig. 20). Long-day plants (which includes all of the grasses used in this experiment) generally flower during this period when the daylight increases to a certain critical length. Because the seasons are reversed in Bolivia, the analogous season of the year would occur from approximately September to November as again the days are getting longer and temperatures are rising. However, the seasonal rains generally do not begin to fall regularly until December (Wikipedia 2006, Cardozo 1981). It is possible that the deficit of water when the day length flowering cue arrives prevents the plants from producing more acceptable seed yields. If this is the case, the problem could conceivably be circumvented by irrigating the plants at the appropriate time--beginning probably in September and continuing until the rains arrive. Indeed, during 2006 this was attempted in Cochabamba but produced no obvious increase in seed yield. We learned later that irrigation water had been quite scarce at that time, and it had not been possible to water the plants consistently.

Another potential problem at Tiwanaku is the constant threat of freezing temperatures at any time of the year (Allred 1972). Even if all other problems (such as water, described above) could be solved, farmers would always face the risk of a frost while the grasses are flowering that could prevent them from producing viable seed.

Communication

Quite apart from the physiological problems encountered with the grasses, it turned out that communication was a serious obstacle to this project. Obviously, there was a language barrier to overcome. This did not turn out to be too great a problem because there were several bilingual people involved, and because the Benson Institute provided excellent translators. However, it was difficult to maintain contact with some of the participants in Bolivia, particularly at the Tiwanaku site. Because it is an extremely rural area, there is no internet access and many of the students do not have reliable phone service. This resulted in several instances in which instructions or reports were not transmitted, and this explains some of the gaps in the data.

Later in the project, we found it to be extremely helpful to have a single person with the Benson Institute in Bolivia that was in charge of day-to-day concerns. This greatly facilitated communication and our ability to obtain more consistent data between the sites.

Earlier Work

As mentioned above, Utah State University (USU) realized a large number of adaptability trials on the Altiplano in the late 1960s. Included in the list of species they used were all of the grass species from the current project. After several years of work, 1 of the principal USU researchers concluded,

> …that it would be uneconomical and impractical to get involved in commercial seed production of the introduced forage grasses and legumes on the Altiplano. The growing season is short, nights are cool, and night frosts occur at any time of the year...This means that forage seed must be produced in the lower valleys and semi-tropical regions, or it must be imported (Allred 1972, pg 4).

Chase Allred, a Brigham Young University (BYU) researcher who worked in Bolivia on contract with USU stated that, “despite the wide diversification of genera and species represented by the introduced legumes and grasses, none of them are capable of seed production in economic quantities” (Allred 1973, pg 12).

These scientists came to this conclusion more than 30 years ago. Unfortunately the vast majority of this work (including the statements above) was never published; instead, it was placed in boxes in the archives of the USU library. It was found only after an extensive search well after our project had begun. Not surprisingly, we have come to the same conclusion--that this group of introduced grasses does not produce seed in sufficient quantities to be of practical use to local farmers.

All of the seed production trials mentioned in the USU papers were performed on the Altiplano. As mentioned above, Allred (1972) believed that although they had no success on the Altiplano, perhaps it would be possible to get these grasses to produce more abundant seed at lower elevations. Our experiment shows that under the conditions described above (without regular irrigation), this was equally unproductive.

Management Implications

The difficulties we have encountered lead us to believe that there are perhaps 2 practical solutions to the dilemma faced by farmers on the Altiplano. First, it is possible that the issue of resource timing mentioned above could be circumvented by providing consistent irrigation to the developing grasses from September to November when the days are lengthening. This could provide the grasses with the resources they need to flower and develop seed at the same time they receive the photoperiod cue to do so. In addition, if the plants flower much sooner, they would be much less likely to face any issues with frost damage.

The second possible solution would be to search for palatable, nutritious grasses that are native to the Altiplano. We may logically assume that the intense grazing pressure in most areas will have made most such grasses locally extinct; yet it is conceivable that they may still exist in very remote areas or those to which livestock would have little access (i.e., cliff faces, etc.). If suitable grasses could be found and cultivated, they could be used as dry season reserve forage, and because they are native, would be much better adapted to local conditions.

CONCLUSION

The harsh environmental and poor economic conditions of the Bolivian Altiplano require intervention to assist many of those that live there to become economically self-sufficient. We sought a dry season reserve forage grass that could produce enough biomass to be useful as feed for livestock, and that could also produce enough seed to distribute to farmers. While some of the grasses produced reasonable amounts of biomass, none produced seed in quantities that would be even close to being economically viable. The likely cause for this is that the grasses used are adapted to the timing of resources in the Northern hemisphere, not that of Bolivia. If this timing could be artificially altered, perhaps the grasses could be induced to produce more seed.

LITERATURE CITED

Allred, C. 1973. End of tour report. Utah State University Series 30/73 [unpublished manuscript]. Logan, UT: Utah State University. 16p.

Allred, K. R. 1971. Forage research and testing results from the high plains of Bolivia. Utah State University Contract L.A. 319 [unpublished manuscript]. Logan, UT: Utah State University. 41p.

Allred, K. R. 1972. End of tour report. Utah State University Series 15/72. [unpublished manuscript]. Logan, UT: Utah State University. 6p.

Anderson, B. H. 1975. Bolivia and Utah State University: A decade of contracts: Summary report 1965-1975. *Utah State University Bulletin* 75:1-200.

Bolivia Contact. 2001. *Tourism in Tiawanacu - La Paz. Available at:* http://www.boliviacontact.com/en/conozca/tiwanaku.php. *Accessed 26 October 2006.*

Bolivia Web. 2006. *Cochabamba. Available at:* http://www.boliviaweb.com/cities/cbba.htm. *Accessed 26 October 2006.*

Brokaw, G. 2003. The poetics of khipu historiography: Felipe Guaman Poma de Ayala's Nueva corónica and the relación de los quipucamayos. *Latin American Research Review* 38:111-147.

Buttolph, L. P. and D. L. Coppock. 2001. Project alpaca: Intensified alpaca production leads to privatization of key grazing resources in Bolivia. *Rangelands* 23:10-13.

Cardozo, A. 1981. Proyecciónes de la gandería de ovinos y camélidos en el departamento de Oruro. La Paz, Bolivia: Empresa Editora Urquizo S.A. 120p.

CIA. 2006. *The World Factbook. Available at:* http://www.cia.gov/cia/publications/factbook/. *Accessed 10 July 2006.*

Cluff, G. J., R. A. Evans, and J. A. Young. 1983. Desert saltgrass seed germination and seedbed ecology. *Journal of Range Management* 36:419-422.

Davies, H. L. 2005. Digestibility, nitrogen balance, and blood metabolites in llama (Lama *glama*) and alpaca (*Lama pacos*) fed barley and barley alfalfa diets [unpublished master's thesis]. Provo, UT: Brigham Young University. 122p.

Eddins, O. No date. *Plains Indian smallpox genocide. Available at:* http://www.thefurtrapper.com/indian_smallpox.htm. *Accessed 10 July 2006.*

Fugal, R. and V. J. Anderson. 2006. Llama preference for forage species on the Bolivian Altiplano [unpublished masters' thesis] Provo, UT: Brigham Young University.

García, E. 1995. El pastoreo y los recursos forrajeros de Bolivia. La Paz, Bolivia: Ofavin. 19p.

Harris, A. and N. Small. 2000. *Viruses, phytoplasmas and spiroplasmas of clonal grasses and their diagnosis - consultancy report. Available at:* http://www.daff.gov.au/corporate_docs/publications/word/market_access/biosecurity/plant/clonal_grasses.doc. *Accessed 10 July 2006.*

Ibarra Grasso, D. E. 1985. Pueblos indígenas de Bolivia. La Paz, Bolivia: Urquizo S.A. 506p.

Jacobi, J. D. and C. T. Atkinson. No date. *Hawaii's Endemic Birds. Available at:* http://biology.usgs.gov/s+t/noframe/t018.htm#27220. *Accessed 10 July 2006.*

Klein, H. S. 2003. A concise history of Bolivia. New York, NY: Cambridge University Press. 320p.

Kolata, A. 1993. The Tiwanaku: Portrait of an Andean civilization. Cambridge, MA: Blackwell Publishers. 317p.

LeBaron, A., L. K. Bond, P. Aitken S., and L. Michaelson. 1979. An explanation of the Bolivian highlands grazing – erosion syndrome. *Journal of Range Management* 32:201-208.

McKell, C. 1971. Observations and recommendations for technical support in range management to Bolivia. USU Series 71-9 [unpublished manuscript]. Logan, UT: Utah State University. 25p.

Ortloff, C. R. and A. L. Kolata. 1993. Climate and collapse: Agro-ecological perspectives on the decline of the Tiwanaku state. *Journal of Archaeological Science* 20:195-221.

Rogler, G. A. and R. J. Lorenz. 1983. Crested wheatgrass - early history in the United States. *Journal of Range Management* 36: 91-93.

Ruiz Canales, C and M. E. Tapia Núñez. 1987. Producción y manejo de forrajes en los Andes del Perú. Ayacucho, Perú: Universidad Nacional San Cristóbal de Huamanga. 304p.

SAS Institute Inc. 2006. SAS OnlineDoc 9.1.3. SAS Institute Inc. *Available online:* http://support.sas.com/onlinedoc/913/docMainpage.jsp. *Accessed 9 October 2006.*

Saxton, A. M. 1998. A macro for converting mean separation output to letter groupings in Proc Mixed. *In:* Proceedings of the 23rd SAS Users Group International, SAS Institute, Cary, NC. p.1243-1246.

Swartley, L. 2002. Inventing indigenous knowledge: Archaeology, rural development, and the raised field rehabilitation project in Bolivia. New York, NY: Routledge. 210p.

UNODC. 1950. *Coca Chewing, Geography and Nutrition. Available at:* http://www.unodc.org/unodc/bulletin/bulletin_1950-01-01_4_page002.html. *Accessed 26 October 2006.*

USAID. 2006. *Bolivia: USAID Program Profile. Available at:* http://www.usaid.gov/locations/latin_america_caribbean/country/program_profiles/boliviaprofile.html. *Accessed 10 July 2006.*

US Army Corps of Engineers. 2004. *Water resources assesment of Bolivia. Available at:* http://www.sam.usace.army.mil/en/wra/Bolivia/FINAL%20BOLIVIA%20WRA%20COMBINED%2013%20DEC%202004.pdf. *Accessed 7 October 2006.*

USDA, ARS, National Genetic Resources Program. 2006. *Germplasm Resources Information Network - (GRIN) [Online Database]. Available at:* http://www.ars-grin.gov2/cgi-bin/npgs/html/taxon.pl?14415. *Accessed 10 July 2006.*

USDA NRCS. 2003. *Plant Guide: Siberian wheatgrass. Available at:* http://plant-materials.nrcs.usda.gov/pubs/idpmspg04844.pdf. *Accessed 26 October 2006.*

Valencia, J. P. and J. S. de Quieroz. 2001. Range improvements at Santiago de Machaca. *In:* Coppock, D. L. and C. Valdivia (EDS.). Sustaining agropastoralism on the Bolivian Altiplano: The case of San José Llanga. Logan, UT: Department of Rangeland Resources, Utah State University. 292p.

Wikipedia. 2006. *Solstice. Available:* http://en.wikipedia.org/wiki/Solstice. *Accessed 10 July 2006.*

FIGURES

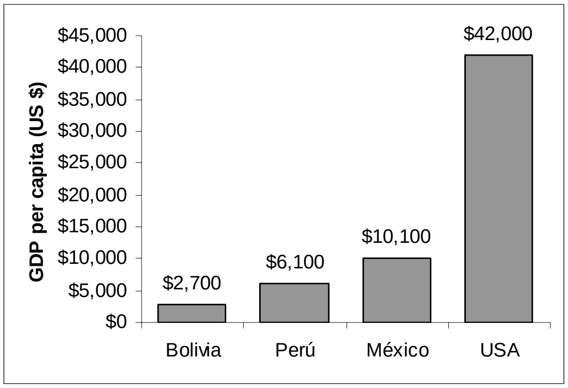


Figure 1. 2004 per capita gross domestic product (GDP) for selected countries. Per capita GDP is a measure of the wealth of individuals in a given country.

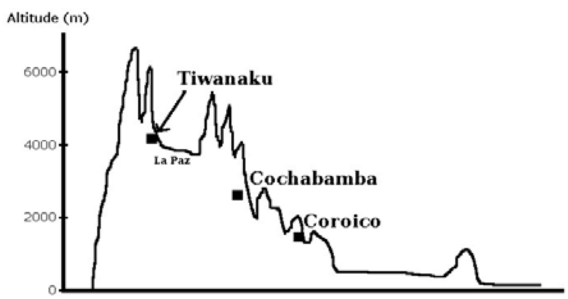


Figure 2. Elevation diagram of Bolivia showing the relative positions of the study sites.

Block 1	H	F	L	I	A	G	J	K	D	C	B	E	
Block 2	E	K	F	I	H	J	B	G	C	D	L	A	Fertilized
Block 3	E	A	B	K	L	I	J	G	D	H	F	C	
Block 4	A	E	K	J	H	D	I	L	C	G	F	B	
Block 5	I	C	E	J	K	D	F	H	L	B	G	A	Non-fertilized
Block 6	D	E	G	C	J	B	I	K	F	H	A	L	

Figure 3. Site diagram. The 12 grass species are represented by letters (A – L) across each row. There are 6 rows all together, with half in a subplot that received a fertilizer treatment and half that did not.

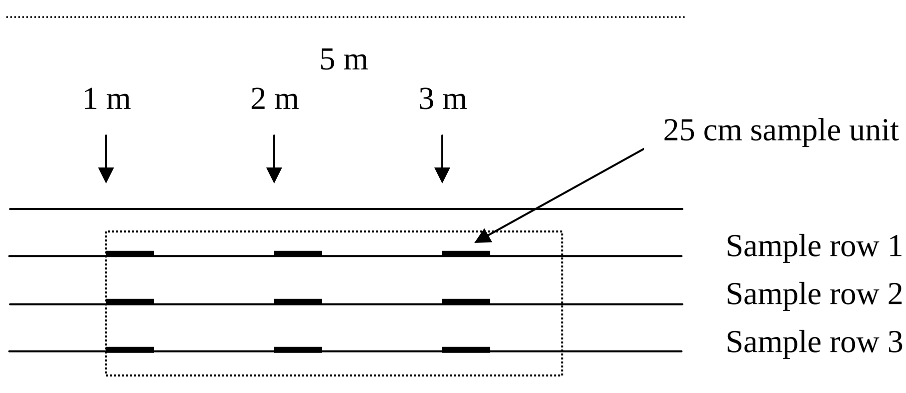


Figure 4. Seedling emergence data collection protocol diagram for all sites.

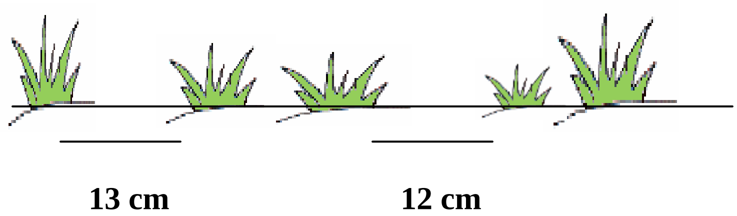


Figure 5. Rowfill data collection protocol diagram for all sites.

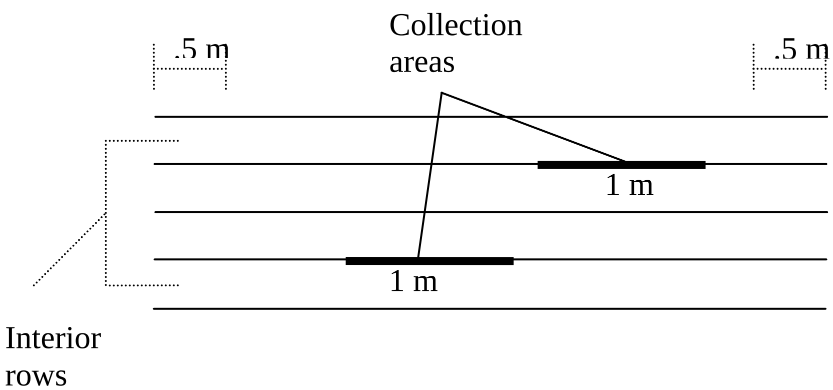
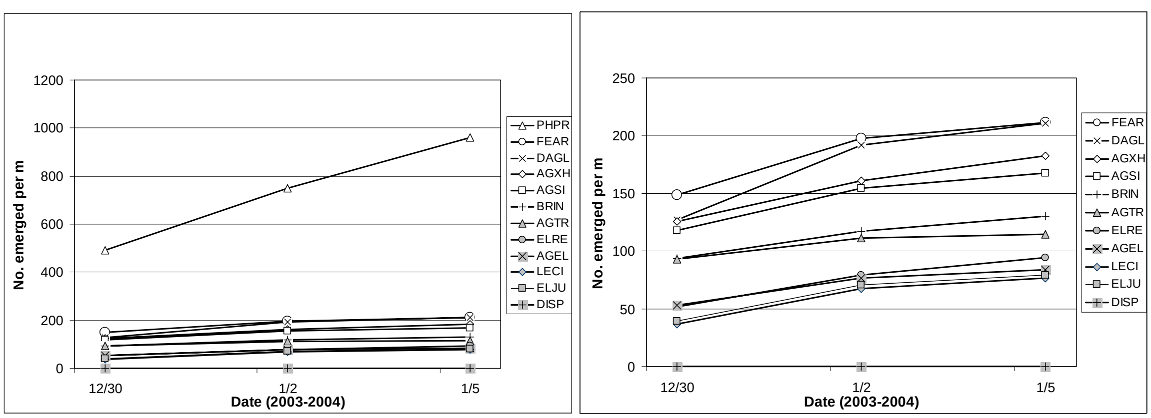


Figure 6. Biomass data collection protocol diagram for all sites.



Figures 7a and 7b. Emergence at Tiwanaku for all species (Fig. 7a) and for all but timothy (PHPR—Fig. 7b). An explanation of the species abbreviations used is in Table 7.

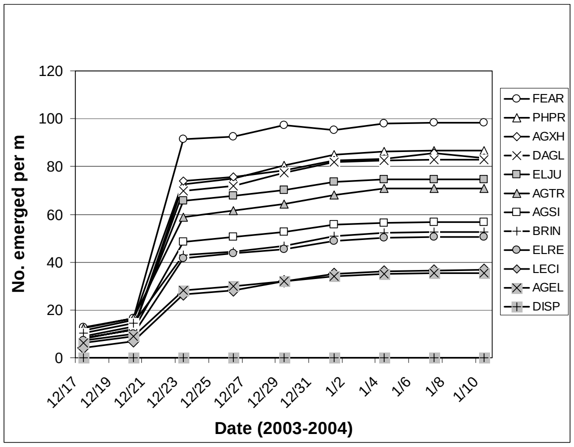
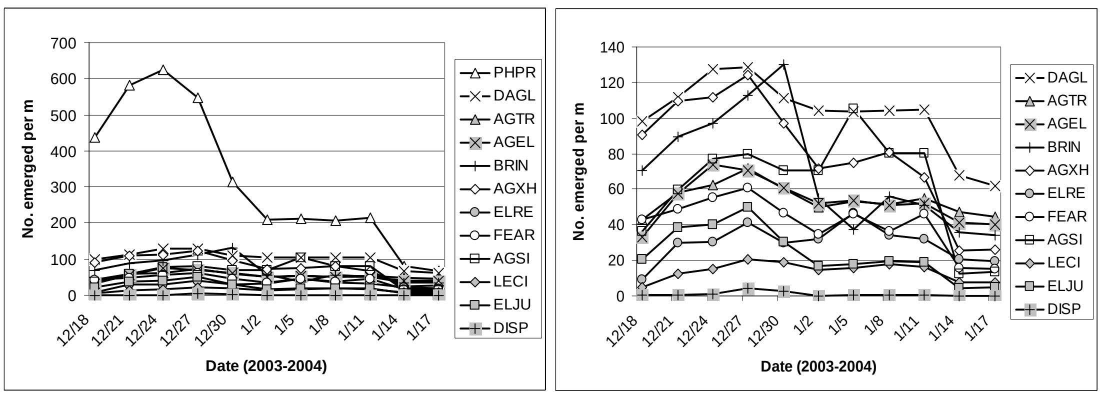


Figure 8. Emergence at Cochabamba for all species. An explanation of the species abbreviations used is in Table 7.



Figures 9a and 9b. Emergence at Coroico for all species (Fig. 9a) and for all but timothy (PHPR—Fig. 9b). An explanation of the species abbreviations used is in Table 7.

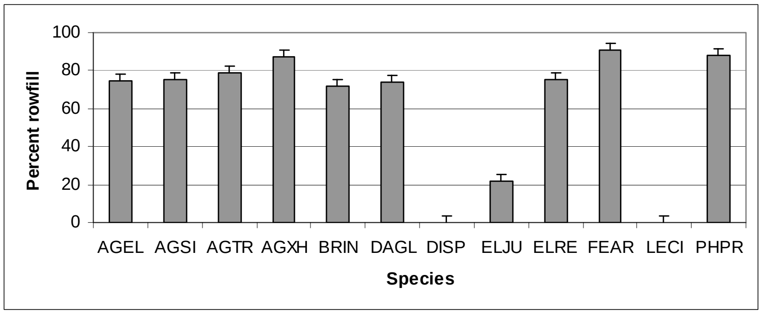


Figure 10. Tiwanaku 2005 rowfill. The fertilization effect was not significant (P = 0.56), while the species effect was highly significant ($P < 0.01$). An explanation of the species abbreviations used is in Table 7.

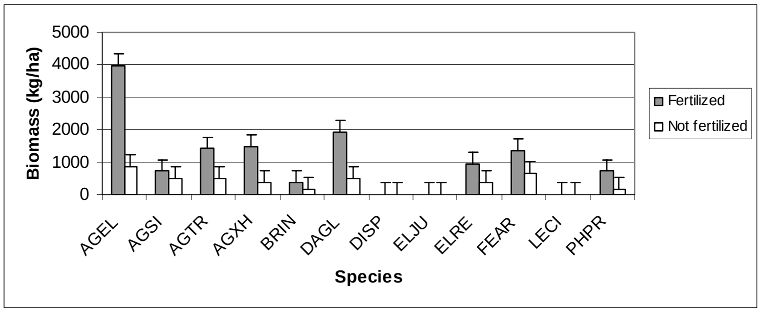
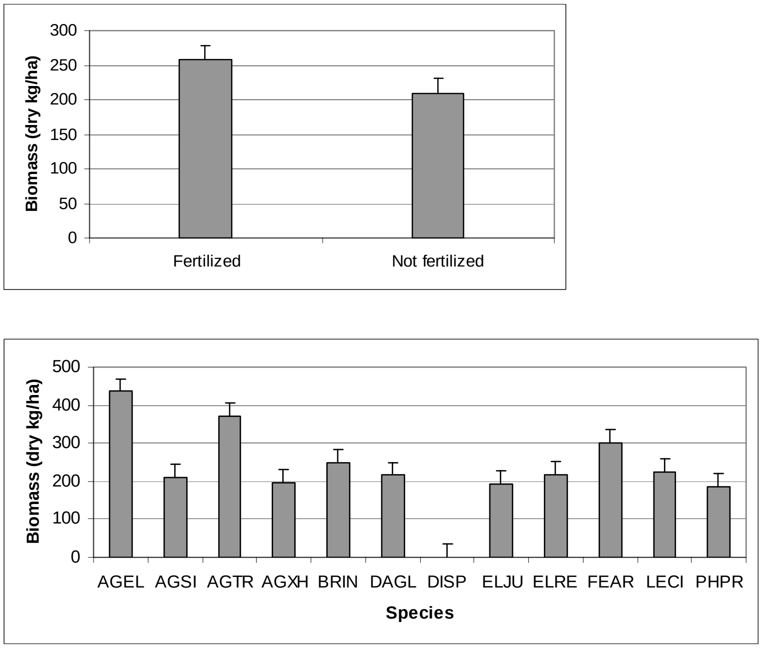


Figure 11. Tiwanaku 2005 biomass. The interaction of the species and fertilization effects was highly significant ($P < 0.01$). An explanation of the species abbreviations used is in Table 7.



Figures 12a and 12b. Cochabamba 2005 biomass by fertilization (Fig. 12a) and by species (Fig. 12b). The data showed a significant difference (*P* = 0.02) between fertilized and non-fertilized groups and a highly significant difference among the grass species (*P* < 0.01). An explanation of the species abbreviations used is in Table 7.

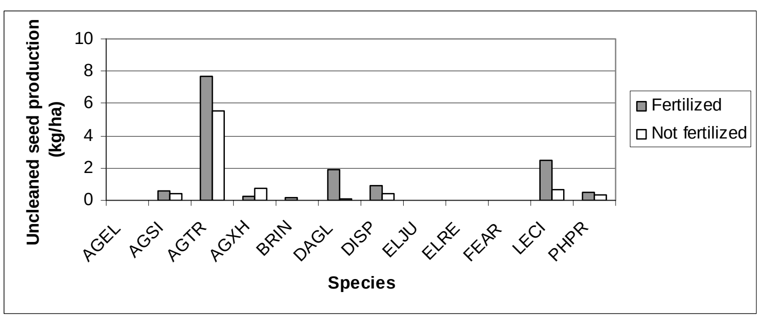


Figure 13. Tiwanaku 2005 uncleaned, unanalyzed seed production. An explanation of the species abbreviations used is in Table 7.

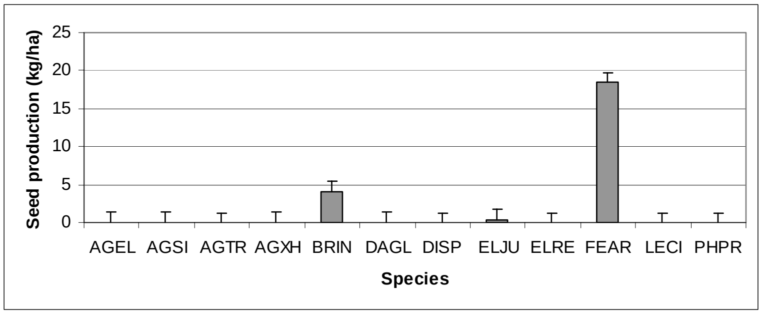


Figure 14. Cochabamba 2005 seed production. The fertilization effect was not significant ($P = 0.31$), but the species effect was ($P < 0.01$). An explanation of the species abbreviations used is in Table 7.

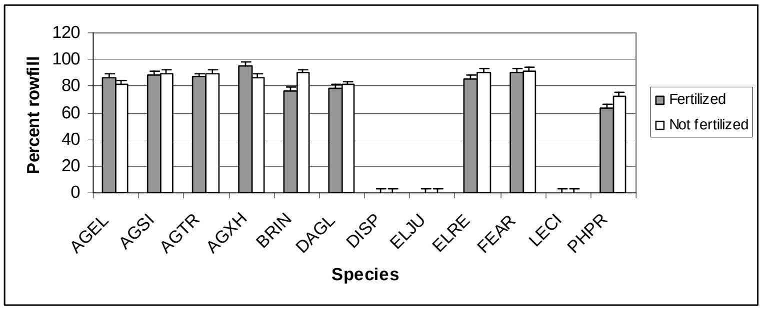


Figure 15. Tiwanaku 2006 rowfill. The interaction of the main effects (species and fertilization) was highly significant ($P < 0.01$). An explanation of the species abbreviations used is in Table 7.

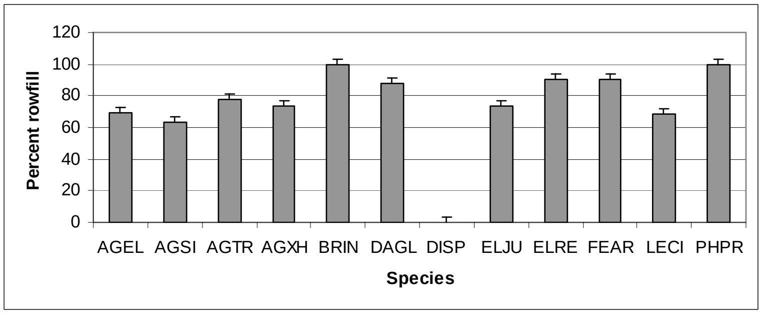


Figure 16. Cochabamba 2006 rowfill. There was no significant difference between the fertilized and non-fertilized plots ($P = 0.18$), but there was a difference between the species ($P < 0.01$). An explanation of the species abbreviations used is in Table 7.

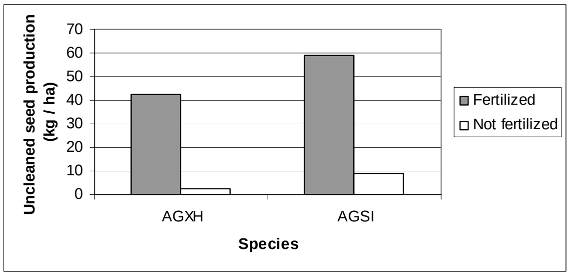


Figure 17. Tiwanaku 2006 unanalyzed seed production. An explanation of the species abbreviations used is in Table 7.

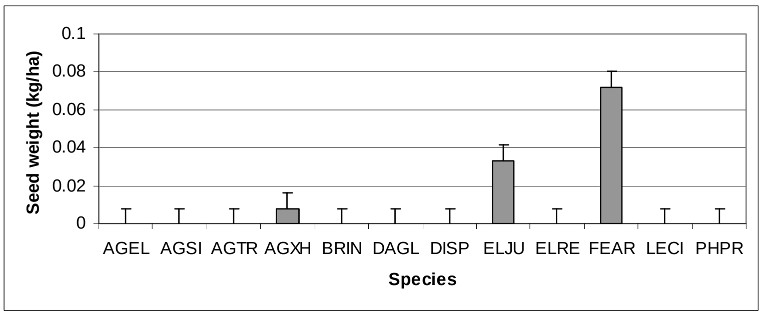


Figure 18. Cochabamba 2006 seed production. The fertilization effect was not significant ($P = 0.99$), but the species effect was significant ($P < 0.01$). An explanation of the species abbreviations used is in Table 7.

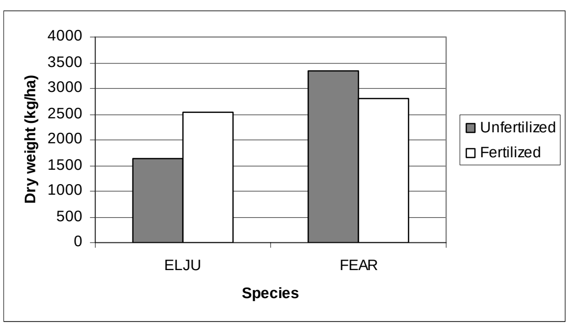


Figure 19. Cochabamba 2006 unanalyzed biomass. An explanation of the species abbreviations used is in Table 7.

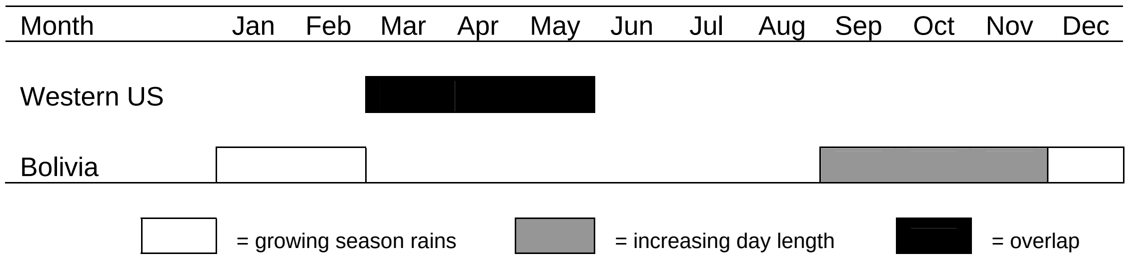


Figure 20. Comparison of resource availability in the Western US and Bolivia.

TABLES

Table 1. Previous forage grass introductions to Bolivia.

Species	References
Hycrest (*Agropyron xhybrid* auct.)	Ruiz and Tapia 1987; Davies 2005
Tall wheatgrass	Ruiz and Tapia 1987; Valencia and de Quieroz 2001
Siberian wheatgrass (*Agropyron sibiricum* [Willd.] Beauv.)	Davies 2005
Smooth brome	Ruiz and Tapia 1987
Orchard grass	Ruiz and Tapia 1987
Inland saltgrass (*Distichlis spicata* L. Greene)	Ruiz and Tapia 1987; Harris and Small 2000; USDA, ARS, National Genetic Resources Program no date
Tall fescue	Ruiz and Tapia 1987
Timothy	Ruiz and Tapia 1987

Table 2. Soil analysis results – Tiwanaku.

Property	Fertilized	Non-fertilized
Depth (cm)	0-20	0-20
% Sand	58	54
% Silt	25	27
% Clay	17	19
Texture	Sandy loam	Sandy loam
Apparent Density (g/cm3)	1.39	1.35
pH (1:2.5 soil-water)	7.5	7.7
E.C. (Milliohms/cm 1:2.5 soil-water)	0.101	0.119
Potassium (me/100g)	0.36	0.44
Organic material (%)	1.35	0.81
Total Nitrogen (%)	0.077	0.045
Avaliable Phosphorous (ppm)	5.7	4.2
C:N ratio	8	8.2

Table 3. Soil analysis results – Cochabamba.

Property	Result
Depth (cm)	20
% Sand	41.5
% Silt	32
% Clay	26.5
Texture	Loam
Apparent Density (g/cm3)	1.32
pH (1:2.5 soil-water)	8
E.C. (Milliohms/cm 1:2.5 soil-water)	0.306
Potassium (me/100g)	0.73
Organic material (%)	2.33
Total Nitrogen (%)	0.123
Avaliable Phosphorous (ppm)	13.3

Table 4. Soil analysis results – Coroico.

Property	Fertilized	Non-fertilized
Depth (cm)	0-20	0-20
% Sand	24	20
% Silt	35	40
% Clay	41	40
Texture	Loam	Loam/silt-loam
Apparent Density (g/cm3)	0.86	0.92
pH (1:2.5 soil-water)	4.8	4.8
E.C. (Milliohms/cm 1:2.5 soil-water)	0.154	0.083
Potassium (me/100g)	0.51	0.36
Organic material (%)	2.49	1.8
Total Nitrogen (%)	0.131	0.1
Avaliable Phosphorous (ppm)	3.6 (1)	2.8 (1)

Table 5. ANOVA source table for all Bolivian sites.

Source	df	Source (continued)	df
Total	215		
Main plot		Sub-subplot	
Site	2	Species	11
Block	2	Site x Species	22
Error a	4	Species x Fertilizer	11
Block x Site (4)		Site x Species x Fertilizer	22
		Error c	132
Sub plot		Block x Species (22)	
Fertilizer	1	Block x Site x Species (44)	
Site x Fertilizer	2	Block x Species x Fertilizer (22)	
Error b	6	Block x Site x Species x Fertilizer (44)	
Block x Fertilizer (2)			
Block x Site x Fertilizer (4)			

Table 6. Species list.

Common name	Scientific name
Alkar tall wheatgrass	*Agropyron elongatum* (Host) Beauv.
Bozoyski Russian wildrye	*Elymus junceus* (Fisch.) Nevski
Crown Royal orchard grass	*Dactylis glomerata* L.
Fawn tall fescue	*Festuca arundinacea* Schreb.
Hycrest CDII crested wheatgrass	*Agropyron xhybrid* (Auct.)
Inland saltgrass	*Distichlis spicata* (L.) Green
Luna pubescent wheatgrass	*Agropyron trichophorum* (Link) Richter
Manchar smooth brome	*Bromus inermis* Leyss.
NewHy	*Elytrigia repens* (L.) *nevski* x *Pseudoroegneria spicata* (PURSH) A. Löve
Outlaw timothy	*Phleum pratense* L.
Trailhead Great Basin wildrye	*Leymus cinereus* (Scribn. & Merr.) A. Löve
Vavilov Siberian wheatgrass	*Agropyron sibiricum* (Willd.) Beauv.

Table 7. Species abbreviations.

Species	Abbreviation
Great Basin wildrye	LECI
Hycrest	AGXH
Inland saltgrass	DISP
NewHy	ELRE
Orchard grass	DAGL
Pubescent wheatgrass	AGTR
Russian wildrye	ELJU
Siberian wheatgrass	AGSI
Smooth brome	BRIN
Tall fescue	FEAR
Tall wheatgrass	AGEL
Timothy	PHPR

Table 8. Date of 50% bolt - Tiwanaku 2006. An explanation of the species abbreviations used is in Table 7.

	Block					
Species	1	2	3	4	5	6
AGEL	1/12	1/12	1/12	1/12	1/12	1/12
AGSI	1/12		1/12	1/12	1/12	1/12
AGTR		1/12	1/12		1/12	
AGXH	1/12	1/12		1/12	1/12	
BRIN	2/5	2/5	2/5	2/5	2/5	2/5
DAGL	1/12		1/12	1/12	1/12	1/12
DISP						
ELJU						
ELRE	1/12		1/12	1/12	1/12	
FEAR		1/12	1/12		1/12	1/12
LECI						
PHPR	2/5	2/5	2/5	2/5	2/5	2/5

Table 9. Date 50% flowering - Tiwanaku 2006. An explanation of the species abbreviations used is in Table 7.

	Block					
Species	1	2	3	4	5	6
AGEL	1/28	1/28	2/12	1/28	1/28	1/28
AGSI	1/28	2/12	2/12	1/28	2/12	2/12
AGTR		1/28	2/12	1/28	1/28	1/28
AGXH	2/12	2/12	2/12	1/28	2/12	1/28
BRIN	2/27	3/12	2/27	2/27	2/27	3/12
DAGL	2/12	2/12	1/28	1/28	1/28	2/12
DISP						
ELJU						
ELRE	2/12	2/12	2/12	2/12	2/12	1/28
FEAR	1/28	1/28	1/28	2/12	1/28	1/28
LECI						
PHPR	3/12	3/12	3/12	2/27	3/12	2/27

Table 10. Date of anthesis - Tiwanaku 2006. An explanation of the species abbreviations used is in Table 7.

Species	All blocks
AGEL	3/15
AGSI	2/25
AGTR	2/25
AGXH	2/25
BRIN	3/15
DAGL	2/25
DISP	
ELJU	
ELRE	2/25
FEAR	2/25
LECI	
PHPR	3/15

Table 11. Date of seed harvest - Tiwanaku 2006. An explanation of the species abbreviations used is in Table 7.

	Block					
Species	1	2	3	4	5	6
AGEL	5/8	5/8	5/8	5/10	5/10	5/10
AGSI	4/19			4/20		4/20
AGTR	5/8	5/8		5/9	4/20	5/9
AGXH	4/19				4/20	4/20
BRIN	4/19	5/8		5/8		3/29
DAGL	4/19	3/29			4/20	
DISP						
ELJU						
ELRE	4/19	3/29	3/29	5/8	5/9	5/9
FEAR	3/29	3/29	3/29	3/29	3/29	
LECI						
PHPR	4/19		5/8	5/8	5/9	5/9

Table 12. Date of initial bolt - Cochabamba. An explanation of the species abbreviations used is in Table 7.

	Block					
Species	1	2	3	4	5	6
AGEL	1/6/06	4/13/06	1/21/06	12/30/05	1/31/06	1/2/06
AGSI						
AGTR	2/23/06	3/16/06	2/3/06	2/12/06	3/1/06	3/10/06
AGXH			*			
BRIN						12/7/05
DAGL	1/5/06	1/10/06	12/8/05	12/30/05	1/20/06	1/5/06
DISP						
ELJU	11/25/05	11/30/05	11/25/05	11/25/05	11/28/05	11/24/05
ELRE		1/30/06				
FEAR	11/29/05	12/8/05	11/23/05	**	1/2/06	11/23/05
LECI	1/10/06	12/28/05	1/4/06	12/30/05	1/5/06	12/20/05
PHPR						

* Extra FEAR from block 3 - 11/23/05

** Extra AGDE from block 4

Table 13. Date of 50% bolt - Cochabamba. An explanation of the species abbreviations used is in Table 7.

	Block					
Species	1	2	3	4	5	6
AGEL						
AGSI						
AGTR						
AGXH			*			
BRIN						
DAGL	3/9/06		1/24/06		2/19/06	2/10/06
DISP						
ELJU	12/9/05	12/6/05	12/8/05	11/30/05	12/5/05	12/2/05
ELRE						
FEAR	4/3/06	12/23/05	12/2/05	**	1/26/06	11/30/05
LECI	1/24/06	1/21/06	3/28/06	1/21/06		1/30/06
PHPR						

* Extra FEAR from block 3 - 12/4/05

** Extra AGDE from block 4

Table 14. Date of initial anthesis - Cochabamba. An explanation of the species abbreviations used is in Table 7.

	Block					
Species	1	2	3	4	5	6
AGEL			4/12/06		4/12/06	1/21/06
AGSI						
AGTR	4/3/06	4/10/06	3/18/06	3/7/06	4/15/06	
AGXH			*			
BRIN						12/20/06
DAGL	2/19/06	2/9/06	1/2/06	1/21/06	3/6/06	2/3/06
DISP						
ELJU	12/15/05	12/9/05	12/16/05	12/2/05	12/3/05	12/3/05
ELRE						
FEAR	12/7/05	1/2/06	12/8/05	**	2/3/06	11/30/05
LECI	1/26/06	2/3/06	1/21/06	1/3/06		1/5/06
PHPR						

* Extra FEAR from block 3 - 12/9/05

** Extra AGDE from block 4

Table 15. Date of 50% anthesis - Cochabamba. An explanation of the species abbreviations used is in Table 7.

	Block					
Species	1	2	3	4	5	6
AGEL						
AGSI						
AGTR						
AGXH			*			
BRIN						
DAGL	3/17/06		3/1/06		4/12/06	3/1/06
DISP						
ELJU	12/21/05	12/15/05	12/13/05	12/8/05	12/9/05	12/9/05
ELRE						
FEAR	3/9/06	2/11/06	12/24/05	**	2/17/06	12/3/05
LECI						
PHPR						

* Extra FEAR from block 3 - 12/24/05

** Extra AGDE from block 4

Table 16. Date of initial seed maturity - Cochabamba. An explanation of the species abbreviations used is in Table 7.

	Block					
Species	1	2	3	4	5	6
AGEL						
AGSI						
AGTR						
AGXH			*			
BRIN						
DAGL			3/23/06			
DISP						
ELJU	1/6/06	12/20/05	12/29/05	1/5/06	1/2/06	1/6/06
ELRE						
FEAR	12/28/06	2/19/06	12/23/05	**	3/1/06	12/20/05
LECI				3/23/06		
PHPR						

* Extra FEAR from block 3 - 12/23/05

** Extra AGDE from block 4

Table 17. Date of 50% seed maturity - Cochabamba. An explanation of the species abbreviations used is in Table 7.

	Block					
Species	1	2	3	4	5	6
AGEL						
AGSI						
AGTR						
AGXH			*			
BRIN						
DAGL						
DISP						
ELJU	2/3/06	1/28/06	2/3/06	3/20/06	1/29/06	3/20/06
ELRE						
FEAR	3/20/06		1/30/06	**	3/20/06	11/29/05
LECI						
PHPR						

* Extra FEAR from block 3 - 1/13/06

** Extra AGDE from block 4

PART 2: EFFECT OF 5 HERBICIDES ON 7 NATIVE UTAH FORBS

INTRODUCTION

Wildfires and other severe disturbances are common occurrences in the dry conditions that prevail in western North America. These disturbances frequently lead to high levels of soil erosion or weed invasion (Certini 2005). To prevent this, land managers often broadcast seed of desirable species across the disturbed area. In the past, introduced species were generally used because of their success and availability. More recently, more native species have been used as the understanding of their importance in the local ecosystem has been realized (Fig. 21). However, there has been little or no overall increase in the use of native forbs due to the high cost of and difficulty of obtaining seed, since it is generally collected by hand from the wild. These forbs are a vital component of any ecosystem because according to Walker and Shaw (2005 p 57):

1. They increase community diversity, health, and resilience.
2. Pioneer forbs provide ground cover and soil stabilization on disturbed and unstable sites.
3. Leguminous forbs improve nitrogen availability.
4. Forbs reduce the ability of exotic species to enter the community.
5. Vegetative plant parts as well as fruits and seeds of individual forb species are often valuable seasonal food sources for specific organisms.
6. The fire resistance of seedings may be improved by the addition of forbs that remain green well into the summer.
7. Forbs improve the aesthetics of seeded disturbances and low maintenance landscaping projects.

To increase their use in restoration projects, the supply of forb seed must be increased. The only practical approach of increasing seed supply is to grow the plants in a large-scale agricultural setting and harvest the seed mechanically. As in any agricultural situation, the plants must be kept weed-free (either mechanically or chemically) in order to assure a high-quality and certifiable seed crop. However, there is virtually no information available on how these plants will react to the application of available herbicides. Thus the purpose of this study is to determine the short-term effects of the application of 5 herbicides at various rates to 7 forb species that have been identified as desirable for possible use in wildland restoration projects.

MATERIALS AND METHODS

The plants used in this experiment, their common names, and abbreviations used for each are found in the Table 18 (USDA NRCS 2006). According to Scott Jensen, a botanist with the Forest Service, these species

> …are a subset of native and introduced species identified by federal and state agency resources staffs and public and private university personnel as having potential for restoration purposes…They were chosen based on perceived market demand, distribution, and wildland seed availability (S. Jensen, personal communication, July 2006).

The treatments were applied to the plants at each of 3 growth stages: pre-germination, seedling (at the 2nd true leaf stage), and established (post 1st growing season). The herbicides used, their active ingredients, and the recommended application rates are found in Table 19. The herbicides were applied at 3 rates. For each the medium rate was that recommended by the manufacturer, high was twice that rate, and low was half the medium rate.

For the pre-germination trials, the seeds were place in a 10 cm pot and covered with approximately 0.6 cm of soil. The number of seeds placed in each pot varied by species. Previously determined germination rates were used to calculate the number of seeds necessary to produce 20 seedlings per pot. The soil surface was then sprayed with the appropriate herbicide at the appropriate concentration. Each treatment combination was replicated 5 times. Pale agoseris, tapertip hawksbeard, and cushion buckwheat require a 4-week cold treatment to increase germination, so the soil was sprayed and the pots were placed in a cooler at approximately 3°C for 4 weeks. Three species require an acid scarification treatment to improve germination, so this was done before the seeds were planted. The time in the acid was 8 minutes for Utah milkvetch, 26 minutes for the scarlet globemallow, and 4 minutes for the gooseberryleaf globemallow. For the seedling and established plant trials, the plants were grown in a greenhouse in 10 cm pots until they were the appropriate size. The herbicides at the appropriate concentration were then applied to the foliage of the plants. Again, each treatment combination had 5 replicates. The control group for each herbicide was either 5 pots of seedlings (pre-germination stage) or 5 plants (seedling and established stages) that received no herbicide application.

The plants were observed for 4 weeks, and data was taken once per week. The information collected was either the number of live seedlings (for the pre-germination study) or the vigor of the plants (for the seedling and established trials). A vigor score between 0 and 10 was given according to the visible health of the plant. A score of 10 meant that the plants appeared perfectly healthy, while stunting, deformation, discoloration, and necrosis lowered the score according to their degree. A slight change in the plants in any of these areas would drop the vigor score to a 9 or 8, while more severe changes would drop the score further. A plant was given a vigor score of 0 only when it appeared to be completely dead.

It was decided that the most important pieces of data were the final states of the plants after the 28 day period because at that point, it was generally clear whether or not the herbicides were having any effect. For this reason and to keep the analysis and results more straightforward, the analysis of variance (ANOVA) was performed only on the data from the final data collection period, rather than on the repeated measures made throughout the experiment. When these data were taken, they were analyzed to see whether they met the assumptions of the analysis of variance (ANOVA). This was done in SAS using the UNIVARIATE procedure for the Shapiro-Wilk test of normality and the GLM procedure with the Levene test of homogeneity of variance (SAS Institute Inc. 2006). If the data did not meet the ANOVA assumptions, they were transformed with the inverse, square, square root, log, arcsin, and logit transformations and re-tested. In cases where the data still did not meet the ANOVA assumptions, they were ranked before being further analyzed (Conover and Iman 1981). The ANOVA was performed for each species at each growth stage using the MIXED procedure and mean separation with the Tukey adjustment. Because the SAS MIXED procedure does not include a function that performs mean separation, it was done separately with the PDMIX800 macro (Saxton 1998).

RESULTS

Pre-germination

Pale Agoseris. Axiom killed all plants to which it was applied. This group was removed from the analysis because it would clearly not work for the purpose described above and because it caused the data to violate the ANOVA assumptions. After the Axiom data were removed, Levene's test was not significant ($P = 0.08$) so the group variances were homogenous, and the Shapiro-Wilk test was not significant ($P = 0.11$), so the data were normal. Only Raptor at the high and low rates was lower than the control (Fig. 22).

Utah Milkvetch. The Axiom data remained in the analysis because many of the plants remained alive. The data did not meet the ANOVA assumptions even after being transformed, so they were ranked before they were analyzed. Only the high rate of Axiom was lower than the control group (Fig. 23).

Tapertip Hawksbeard. All the plants to which Axiom was applied died during the data collection period, so these data were left out of the analysis. When the data were squared, they met the ANOVA assumptions (Levene's test $P = 0.06$, Shapiro-Wilk $P = 0.47$). All rates of Pendulum were not different from the control, but all other herbicides at all rates were lower than the control (Fig. 24).

Cushion Buckwheat. All of the Axiom plants at all rates died, so were removed from the analysis. When the data were transformed with the logit transformation, they met the ANOVA assumptions: neither the Levene test ($P = 0.37$) nor the Shapiro-Wilk test ($P = 0.25$) were significant. In the ANOVA, there was a significant difference between the herbicides ($P = 0.05$), but not between the rates ($P = 0.82$), nor the interaction (P = 0.71). Poast was greater than Pursuit, but was not different from Pendulum or Raptor. Pursuit was not different from Pendulum or Raptor either.

Longleaf Phlox. When the inverse transformation was used, these data met the ANOVA assumptions: Levene's test P = 0.66 and the Shapiro-Wilk test P = 0.05. All of the high and medium rate Axiom plants died, but a few of the low rate plants survived. As with other species, it was clear that Axiom would not be suitable for keeping weeds down around this species. Thus the data for this herbicide were excluded from the analysis. At all rates, Pendulum was lower than the control. All rates of the remaining herbicides were not significantly different from the control (Fig. 25).

Scarlet Globemallow. Only a few Axiom plants survived, so once again these data were removed. The remaining data were squared and met the ANOVA assumptions: both Levene's test (P = 0.11) and the Shapiro-Wilk test (P = 0.19) were not significant. There was no difference between the herbicides (P = 0.47), nor in the interaction of herbicides and rates (P = 0.40). The rates were different (P < 0.01). The high, medium, and low rates were lower than the control but not different from one another.

Gooseberryleaf Globemallow. Survival at any level was seen in only 1 of the replicates to which Axiom was applied, so all were removed. The resulting data set met the ANOVA assumptions without any transformation (Levene's test P = 0.14; Shapiro-Wilk P = 0.06). The low rate of Raptor was the only treatment that was lower than the control. The remaining treatments were not different from the control (Fig. 26).

Seedling

Pale Agoseris. All the plants to which Axiom was applied died within the data collection period, so these data were excluded from the analysis. The data failed to meet the ANOVA assumptions (even when transformed), so were ranked. Raptor at all rates was lower than the control. The remaining treatments were also greater than Raptor and not different from the control (Fig. 27).

Utah Milkvetch. Axiom did not kill all of the plants of this species, so all the data were kept. Without transformation, the set met the ANOVA assumptions (Levene's $P = 0.18$ and Shapiro-Wilk $P = 0.26$). The herbicides were different ($P = 0.05$) as were the rates ($P < 0.01$), but the interaction was not significant ($P = 0.85$). Pendulum was greater than Axiom but was not different from the other herbicides. The control was greater than any of the application rates, and these were not different from one another.

Tapertip Hawksbeard. Some of the Axiom plants did not die, so all the data were kept. With the logit transformation, the data met the ANOVA assumption of the homogeneity of variance (Levene's test $P = 0.18$). The Shapiro-Wilk test ($P = 0.03$) showed that the data were sufficiently normal for the ANOVA. Only Axiom at all rates was lower than the control and the remaining treatments (Fig. 28).

Cushion Buckwheat. Only 1 plant that was sprayed with Axiom survived, so the data from all of the Axiom plants was left out of the analysis. The remaining data nearly met the ANOVA assumptions (Levene's test $P = 0.02$ and Shapiro-Wilk test $P = 0.04$). Pendulum at the high rate and Pursuit and Raptor at all rates were lower than the control. The remaining treatments were not different from the control (Fig. 29).

Longleaf Phlox. The data did not meet the ANOVA assumptions even with transformations, so were ranked prior to the analysis. Axiom at the high rate was the only treatment lower than the control. The others were not different from the control (Fig. 30).

Scarlet Globemallow. Both with and without transformations, these data did not meet the ANOVA assumptions. They were ranked, and then the analysis was performed. It showed that the high and medium rates of Axiom were lower than the control with the remaining treatments were not different from the control (Fig. 31).

Gooseberryleaf Globemallow. With 1 exception, Axiom killed all the plants to which it was applied, so these data were removed. When the remaining data were transformed with the logit transformation, the data approximately met the ANOVA assumptions. The homogeneity of variance assumption was met (Levene's test $P = 0.15$), and the normality assumption was approximately met (Shapiro-Wilk test $P = 0.03$). There were significant differences between the herbicides ($P = 0.01$) and between rates ($P < 0.01$), but not in the interaction ($P = 0.31$). Poast and Pursuit were greater than Pendulum but not different from Raptor. Pendulum was also not different from Raptor. The medium and low rates were actually greater than the control, and the high rate was not different from the control.

Established

Pale Agoseris. With or without transformation, these data did not meet the ANOVA assumptions so were ranked. The only difference shown by the mean separation was that the high rate of Raptor was greater than the high rate of Axiom (Fig. 32). All other comparisons were not different.

Utah Milkvetch. As with the pale agoseris, these data did not meet the ANOVA assumptions whether they were transformed or not. Thus they were ranked before the analysis. None of the treatments were different from the control plants (Fig. 33). The low rate of Axiom was greater than the high rates of Pursuit and Axiom. Also, the low and high rates of Poast were greater than the high rate of Axiom.

Tapertip Hawksbeard. No data.

Cushion Buckwheat. These data didn't meet the ANOVA assumptions whether transformed or not, so they were ranked before they were analyzed. There were significant differences between the herbicides ($P < 0.01$), between the rates ($P = 0.03$), but not between the interaction of these effects ($P = 0.59$). Pendulum, Pursuit, and Raptor were significantly greater than Axiom. Poast was not different from Axiom nor from the other herbicides. The control was greater than the low and medium application rates. The high rate was not different from either the control or the low and medium rates.

Longleaf Phlox. With and without transformations, these data failed to meet the assumptions of the ANOVA, so were ranked. There were no significant differences between the herbicides ($P = 0.82$) though there were differences between the rates ($P = 0.03$). The control was greater than the medium and low rates. The high rate was not different from any of the other rates.

Scarlet Globemallow. These data met the ANOVA assumptions without transformation, both for homogeneity of variance (Levene's test P = 0.43) and for normality (Shapiro-Wilk test P = 0.12). Only the high rate of Axiom was lower than the control. All the other treatments were the same (Fig. 34).

Gooseberryleaf Globemallow. When the square transformation was applied to these data, they met the ANOVA assumptions (Levene's test $P = 0.07$, Shapiro-Wilk test $P = 0.08$). There was a significant difference between the herbicides ($P < 0.01$). Poast was greater than Axiom, Pendulum, and Pursuit, but was not different from Raptor. Axiom was less than Poast, Raptor, and Pursuit, but was not different from Pendulum. There was also a difference between the rates ($P < 0.01$). The control was greater than any of the other rates. There was no difference in the interaction ($P = 0.19$).

DISCUSSION

Wildfires are a natural part of the ecosystem of western North America. Hot, dry summers combined with frequent lightning storms provide an ideal situation for regular, natural burns. The flora of this area (including the forbs) has evolved in response to such conditions to the point that many species require periodic fires in order to disperse seeds or maintain optimum health (Despain 2001). However, a severe fire results in a situation that can lead in 2 principal ways to site degradation. First the fire can lead to dramatic soil erosion, and second it can open a window of opportunity for the invasion of weeds.

Certini (2005) concluded that a variety of fire effects on temperate forest soils lead to greater erosion: increased hydrophobicity and the clogging of soil pores by ash decrease infiltration rates, which leads to greater surface runoff and greater erosion; decreased soil aggregation allows smaller soil particles to be carried away more easily; and the removal of the protective, organic litter layer exposes soil to the full force of raindrop impacts and wind. Bailey and Copeland (1961, quoted in Beyers 2004) reported that when 90% or more of ground cover is removed, surface runoff could increase over 70% and erosion by 3 orders of magnitude. Vermeire et al. (2005) found that wind erosion increased from 2 to 48 times on burned patches compared with similar unburned patches in Oklahoma.

Apart from the effects fire can have directly on the soil of a site, the destruction of its flora leaves a large, open ecological niche into which invading weeds can rapidly become entrenched. This problem is particularly acute in the western US with cheatgrass (*Bromus tectorum* L.), which is not only an invasive problem after a fire, but can actually alter a site's fire regime to favor its own growth strategy (West and Hassan 1985, Evangelista et al. 2004, Evans et al. 2001). Even in a paper in which they question the effectiveness and utility of post-burn seeding, West and Hassan (1985) recommend seeding cheatgrass-dominated sites after a fire in an attempt to combat this weed.

In 2001, Humphrey and Schupp studied the composition of the seed bank of plant communities dominated by cheatgrass. They found that in unburned plots, introduced annuals (mainly cheatgrass) made up over 99% of the seed bank. These sites contained a paltry 2-3 seeds of native perennial species per m^2 compared to 4800-12,800 seeds per m^2 of cheatgrass. After a fire however, the number of cheatgrass seeds dropped to only 3% of the original level and took approximately 2 years to recover. Humphrey and Schupp conclude that 1 of the factors that inhibits the recovery of native perennial plants in such communities is the relative absence of viable seeds after a fire when cheatgrass seed numbers are low. Keeley et al. (2003) studied blue oak savanna, chaparral, and coniferous forest sites in the Sierra Nevada mountains and also found a dramatic reduction in weedy species directly following fire. Within 3 years however, the invasive plants had dramatically increased in the number of species present, in density, and in cover, particularly after a severe fire. Thus a window exists in which seeding can be used in such situations to promote the establishment of desirable native species and regain some ground against invasive weeds.

It was recognized long ago that the recovery of a burned area could be artificially hastened by seeding to avoid site degradation (as described above). In the 1920s, foresters in California began seeding burned chaparral sites; interestingly, they initially used seed from native shrub species but eventually switched to using exotic mustards and grasses because the natives didn't appear to speed the site's recovery. The exotics, on the other hand, germinated and grew quickly, effectively protecting the soil (Beyers 2004).

In the 1960s, public and scientific understanding of the importance of natural ecosystems led to the creation of legislation such as the Multiple Use Sustained Yield Act of 1960, the Classification and Multiple Use Act of 1964, the Wilderness Act of 1964, and the National Environmental Policy Act of 1969. These acts marked a shift in policy away from management for consumption only to consideration of various land uses, including wildlife habitat. This trend continued in the 1970s with important acts such as the Endangered Species Act of 1973, the Forest and Rangeland Renewable Resources Planning Act of 1974, the National Forest Management Act of 1976, and the Federal Land Policy and Management Act also of 1976. In 1977, President Jimmy Carter issued an Executive Order mandating that the Bureau of Land Management (BLM) restrict the use of introduced species and use native species when possible for restoration projects. The BLM responded by incorporating this directive into its national rules of 1985 and 1992 which require extra evaluation procedures for the use of non-native species, thus making it simpler for the agency to use natives (Richards et al. 1998).

The trend of increasing emphasis on the importance of native vegetation has continued to the present as the complex ecological interactions of many organisms have been intensely studied. This has resulted in the recognition that many parts of the native ecosystem depend on the presence of native vegetation for their survival (Beschta et al. 2004). An example of this relationship is the recent decline of the sage grouse (*Centrocercus urophasianus*) in the western US. While admitting that it is a complex problem, Crawford et al. (2004) state that 1 of the most important factors involved in the birds' decline is the recent changes in the plant communities in which the birds reside. Specifically, they mention "alterations in fire regime; excessive livestock grazing; proliferation of non-native plant species; conversion of rangeland to seeded pastures [e.g. crested wheatgrass (*Agropyron cristatum* L.)], cropland and roads; and other land alterations" (p 3). It is assumed that the restoration of a plant community that more closely resembles that which was present before European settlement will allow the sage grouse and many other native species to maintain stable populations.

Thus in recent years land managers have included ever-increasing amounts of native species in restoration projects (Fig. 21). Only 20% of the total amount of seed used between 1985 and 1991 was native species, though virtually no native forbs were used. The proportion of native species rose to 45% in the period from 1998-2002 (Shaw et al. 2005) and then to 55% in 2005, though the proportion of forbs was still negligible (S. L. Lambert, personal communication, March 2005).

The question naturally arises: why are forbs not being used? They are clearly an important ecological component of any natural ecosystem. Walker and Shaw (2005 p 56) list the problems preventing the increased use of native forbs in restoration projects. They include: "the large number of forb species present in the Great Basin, our limited knowledge of seed production and seeding requirements for most species, the difficulty of harvesting forb seed from wildland stands, the highly unpredictable quality and quantity of wildland seed collections, and the frequently high cost of available seed." Other authors mention similar concerns (Wallace et al. 1986).

In 2006, crested wheatgrass (an introduced species) cost approximately $6.60 per kg. Native grasses such as Great Basin wildrye (*Leymus cinereus* [Scribn. & Merr.] A. Löve), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh.] A. Löve), and Indian ricegrass (*Oryzopsis hymenoides* [Roemer & J.S. Shultes] Ricker ex Piper) cost between $13.20 and $26.50 per kg (R. Timoney, personal communication, October 2006). Native forbs, however cost substantially more: gooseberryleaf globemallow costs $176.40 per kg, and scarlet globemallow costs $220.50 per kg. Indian paintbrush (*Castilleja* spp.) seed can cost more than $3 300 per kg (Sunmark Seeds 2006). Clearly, a land manager with a limited budget would be forced to use few or no forb species in a large restoration project because it simply would not be economical to do so. The most logical solution to this problem would be to increase the supply of these expensive seeds to drive the price down. The more the price is lowered, the more feasible it will be for these species to be included in seed mixes.

Currently, most forb seed is collected by hand from stands of wild plants. Because this is a laborious, time-consuming process, the resulting product is very expensive. To circumvent this problem, native plants could be grown in a controlled, large-scale setting and the seed collected mechanically. However, so little is known about the ecology and physiology of many of these plants that at present this is extremely difficult to do. Research is needed to understand how these plants will react in such a setting and which practices will maximize seed production.

The purpose of this project was to test the effects of several different herbicides on 7 species of plants that are native to Utah. The end goal was to find those herbicides that have little effect on these desirable species so that competing weeds that would lower seed production and contaminate harvests can be effectively controlled. When such herbicides are found, labor costs related to manual weeding could be dramatically reduced.

Extensive herbicide work has been done on some forbs, but chiefly on those that are used agriculturally or horticulturally, or are pests, or affect human activities in some other manner. For example, picloram and metasulfuron were applied to wooly loco (*Astragalus mollissimus* Torr.) and their rates of uptake and translocation were observed (Sterling and Jochem 1995). Wooly loco can poison livestock if ingested, and herbicides are used in attempts to eradicate it. Because it can be a useful forage crop, work has also been done on cicer milkvetch (*Astragalus cicer* L.) to attempt to increase its resistance to 2,4-D (Townsend 1994). Several different herbicides were applied at varying rates to creeping phlox (*Phlox subulata* L.) to observe the effects (Briggs and Whitwell 2003). Creeping phlox is cultivated as an ornamental flowering plant. Despite these and many other findings on plants closely related to those in the current study, I found no mention in the literature of the study of the effects of any herbicide on the species in this study. However they are occasionally mentioned in other contexts. For example pale agoseris (*Agoseris glauca* [Pursh] Raf.) was listed as part of a plant community that had colonized an abandoned mine in Canada (Russell and La Roi 1986), and it was shown in 2003 that prescribed fire reduced the frequency and relative abundance of longleaf phlox (*Phlox longifolia* Nutt.) in Oregon (Wrobleski 2003). Two varieties of cushion buckwheat

(*Eriogonum ovalifolium* Nutt.) that are found in California and Nevada (*vineum* [Small] Jepson and *williamsiae* Reveal respectively) are currently on the US endangered species list (US Fish and Wildlife Service 2006a and US Fish and Wildlife Service 2006b), so consequently are mentioned more often in the literature (Neel 2003, Neel 2001, Archibald et al. 2001). Scarlet globemallow (*Sphaeralcea coccinea* [Nutt.] Rydb.) has been studied for its possible use in reclamation (Uresk and Yamamoto 1994), as a commercially grown ornamental (Dougher 2003), and as a forage for sheep (Rafique et al. 1993) and cattle (Shoop et al. 1985). Gooseberryleaf globemallow (*Sphaeralcea grossulariifolia* [Hook. & Arn.] Rydb.) was found in 1998 to be affected by a leaf and stem rust (Briere and Franc 1998).

In the present study, it became clear that the reaction of these forbs to these herbicides is largely species-specific, rate-specific, and growth stage-specific. For example, tapertip hawksbeard was resistant only to Pendulum in the pre-germination stage. Yet in the seedling stage, it was susceptible to Axiom only at the high and medium rates. Longleaf phlox was susceptible to Axiom and Pendulum at all rates in the pre-germination stage. As a seedling, it was susceptible only to Axiom at the high rate, and as an established plant it was resistant to all treatments.

Management Implications

The herbicides and rates that did least damage to the plants to which they were applied are those that we recommend for use (Tables 20-22).

Future Work

The next step for this research is to perform field trials and a study of the long-term effects of these herbicides, particularly on seed production over several years. This study only attempted to show the short-term and establishment-phase plant response to the herbicides. It is possible that although a species showed no response during the study, some effect could become apparent later. Conversely, plants that showed a response during the study could rebound later and become perfectly healthy.

CONCLUSION

Native forbs are a critical component of any natural ecosystem, and thus must be included in wildland restoration projects. However, the scarcity and high cost of forb seed make this extremely difficult for land managers with limited resources to do. Continued research can alleviate this problem by providing the information that will allow growers to commercially produce the seed at a more reasonable cost. We found that the reaction of the forbs used in this experiment to the herbicides were largely species- and growth-stage specific.

LITERATURE CITED

Archibald, J. K., P. G. Wolf, V. J. Tepedino, and J. Bair. Genetic relationships and population structure of the endangered Steamboat buckwheat, *Eriogonum ovalifolium* var. *williamsiae* (Polygonaceae). *American Journal of Botany* 88:608-615.

Bailey, R. W. and O. L. Copeland. 1961. Vegetation and engineering structures in flood and erosion control. *In*: Proceedings, 13th Congress, September 1961, Vienna, Austria. International Union of Forest Research Organizations Paper 11-1.

Beschta, R. L., J. J. Rhodes, J. B. Kauffman, R. E. Gresswell, G. W. Minshall, J. R. Karr, D. A. Perry, F. R. Hauer, C. A. Frissell. 2004. Postfire management on forested public lands of the western United States. *Conservation Biology* 18:957-967.

Beyers, J. L. 2004. Postfire seeding for erosion control: effectiveness and impacts on native plant communities. *Conservation Biology* 18:947-956.

Briere, S. C. and G. D. Franc. 1998. First report of leaf and stem rust caused by *Puccinia sherardiana* on *Sphaeralcea grossulariaefolia* in North America and *S. munroana* in Wyoming. *Plant Disease* 82:831.

Briggs, J. and T. Whitwell. 2003. Preemergent bittercress control in creeping phlox (*Phlox subulata*). *Journal of Environmental Horticulture* 21:24-29.

Certini, G. 2005. Effects of fire on properties of forest soils: a review. *Oecologia* 143:1–10.

Conover, W. J. and R. L. Iman. 1981. Rank transformations as a bridge between parametric and nonparametric statistics. *The American Statistician* 35:124-129.

Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. *Journal of Range Management* 57:2-19.

Despain, D. G. 2001. Dispersal ecology of lodgepole pine (*Pinus contorta* Dougl.) in its native environment as related to Swedish forestry. *Forest Ecology and Management* 141:59-68.

Dougher, T. 2003. Commercializing production of native intermountain species. *Hortscience* 38:752-753.

Evangelista, P., T. J. Stohlgren, D. Guenther, S. Stewart. 2004. Vegetation response to fire and postburn seeding treatments in juniper woodlands of the Grand Staircase-Escalante National Monument, Utah. *Western North American Naturalist* 64:293-305.

Evans, R. D., R. Riber, L. Sperry, and J. Belnap. 2001. Exotic plant invasion alters nitrogen dynamics in an arid grassland. 2001. *Ecological Applications* 11:1301-1310.

Humphrey, L. and E. W. Schupp. 2001. Seed banks of *Bromus tectorum*-domiated communities in the Great Basin. *Western North American Naturalist* 61:85-92.

Jensen, S. 2006. Personal communication.

Keeley, J. E., D. Lubin, C. J. Fotheringham. 2003. Fire and grazing impactos on plant diversity and alien plant invasions in the southern Sierra Nevada. *Ecological Applications* 13:1355-1374.

Lambert, S. M. 2005. Personal communication.

Neel, M. C. 2001. Implications of mating patterns for conservation of the endangered plant *Eriogonum ovalifolium* var. *Vineum* (Polygonaceae). *American Journal of Botany* 88:1214-1222.

Neel, M. C. 2003. Conservation of genetic diversity in the endangered plant *Eriogonum ovalifolium* var. *vineum* (Polygonaceae). *Conservation Genetics* 4:337-352.

Rafique, S., J. D. Wallace, M. L. Galyean, J. L. Holechek. 1993. Influence of forbs and shrubs on ruminal fermentation and digesta kinetics in sheep fed a grass hay/straw diet. *Agrogorestry Systems* 24:145-156.

Richards, R. T., J. C. Chambers, C. Ross. 1998. Use of native plants on federal lands: Policy and practice. *Journal of Range Management* 51:625-632.

Russell, W. B. and G. H. La Roi. 1986. Natural vegetation and ecology of abandoned coal-mined land Rocky Mountain foothills Alberta Canada. *Canadian Journal of Botany* 64:1286-1298.

SAS Institute Inc. 2006. SAS OnlineDoc 9.1.3. SAS Institute Inc. *Available online:* http://support.sas.com/onlinedoc/913/docMainpage.jsp. *Accessed 9 October 2006.*

Saxton, A. M. 1998. A macro for converting mean separation output to letter groupings in Proc Mixed. *In:* Proceedings of the 23rd SAS Users Group International, SAS Institute, Cary, NC. p.1243-1246.

Shaw, N. L., S. M. Lambert, A. M. DeBolt, M. Pellant. 2005. Increasing native forb seed supplies for the Great Basin. USDA Forest Service Proceedings RMRS-P-35. *Available online:* http://www.fs.fed.us/rm/pubs/rmrs_p035/rmrs_p035_094_102.pdf. *Accessed 2 August 2006*.

Shoop, M. C., R. C. Clark, W. A. Laycock, R. M. Hansen. 1985. Cattle diets on shortgrass ranges with different amounts of fourwing saltbush. *Journal of Range Management* 38:443-449.

Sterling, T. M. and H. S. Jochem. 1995. Uptake, translocation, and metabolism of picloram and metasulfuron methyl by 2 locoweed species. *Weed Science* 43:13-17.

Sunmark Seeds. 2006. *Wildflower seeds. Available at:* http://www.sunmarkseeds.com/apps/productcat.phtml?id=485&action=Go&single=1. Accessed 24 October 06.

Timoney, R. 2006. Personal communication.

Townsend, C. E. 1994. Recurrent selection for 2,4-D tolerance in cicer milkvetch. *Crop Science* 34:1484-1487.

US Fish and Wildlife Service. 2006a. *Species profile for cushenbury buckwheat. Available at:* http://ecos.fws.gov/species_profile/servlet/gov.doi.species_profile.servlets.SpeciesProfile?spcode=Q1W8. Accessed 1 June 06.

US Fish and Wildlife Service. 2006b. *Species profile for steamboat buckwheat. Available at:* http://ecos.fws.gov/species_profile/servlet/gov.doi.species_profile.servlets.SpeciesProfile?spcode=Q2OR. Accessed 1 June 06.

USDA NRCS. 2006. *Plants database. Available online:* http://plants.usda.gov. Accessed 10 July 2006.

Uresk, D. W. and T. Yamamoto. 1994. Field study of plant survival as affected by amendments to bentonite spoil. *Great Basin Naturalist* 54:156-161.

Vermeire, L. T., D. B. Wester, R. B. Mitchell, S. D. Fuhlendorf. 2005. Fire and grazing effects on wind erosion, soil water content, and soil temperature. *Journal of Environmental Quality* 34:1559-1565.

Walker, S. C. and N. L. Shaw. 2005. Current and potential use of broadleaf herbs for reestablishing native communities. *In*: N. L. Shaw, M. Pellant, S. B. Monsen (COMPS.), Sage-grouse habitat restoration symposium proc.; 4–7 June 2005, Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 56-61.

Wallace, V. K., S. Pequignot, and W. Yoder. 1986. The role of state forest nurseries in prairie plant propagation. *In:* G. K. Clambey and R. H. Pemble (EDS.), The prairie: past, present, and future: proceedings of the Ninth North American Prairie Conference. 29 July to 1 August 1984; Moorehead, MN. p. 201-203. *Available at:* http://digicoll.library.wisc.edu/cgi-bin/EcoNatRes/EcoNatRes-idx?type=div&did=ECONATRES.0003.0205.0051&isize=text. *Accessed 25 July 2006*.

West, N. F. and M. A. Hassan. 1985. Recovery of a sagebrush-grass vegetation following wildfire. *Journal of Range Management*. 38:131-134.

Wrobleski, D. W. 2003. Initial effects of prescribed fire on morphology, abundance, and phenology of forbs in big sagebrush communities in Southeastern Oregon. *Restoration Ecology*. 11:82-90.

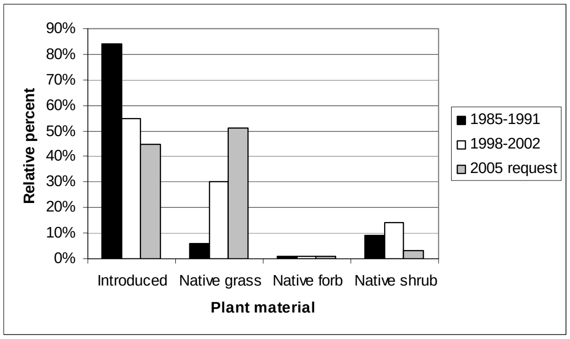


Figure 21. Relative BLM revegetation seed purchase trends for selected periods between 1985 and 2005. The black bars show the relative proportions of introduced species, native grass, native forb, and native shrub seed purchased between 1985 and 1991. The white bars show the same data for 1988 to 2002, and the gray bars show the most recent data available from 2005 (Shaw et al. 2005, S. L. Lambert, personal communication, March 2005).

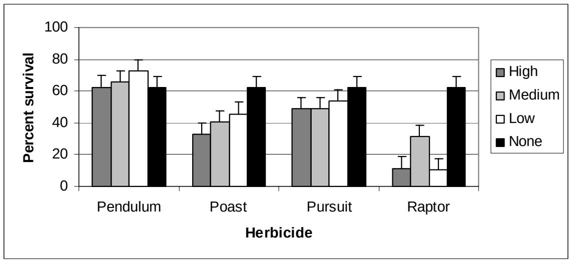


Figure 22. Pale agoseris pre-germination plant survival raw data by herbicide and rate. There was a significant difference in the interaction between these 2 variables ($P < 0.01$).

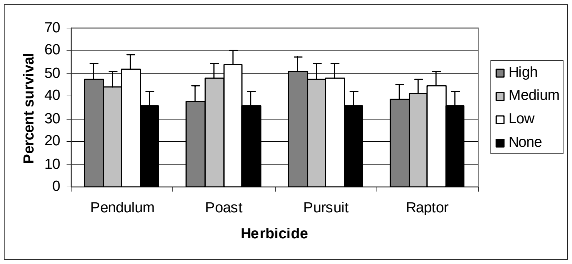


Figure 23. Utah milkvetch pre-germination plant survival by herbicide and rate. The interaction between the herbicide and rate effects was significant at the $P = 0.08$ level.

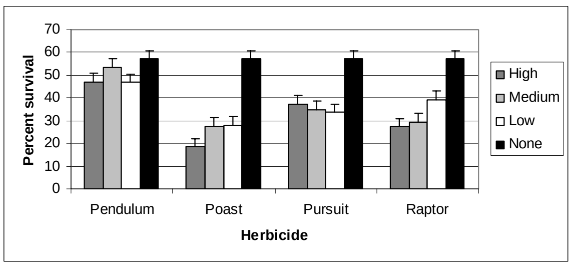


Figure 24. Tapertip hawksbeard pre-germination plant survival by herbicide and rate. The interaction between the herbicides and rates was significant ($P < 0.01$).

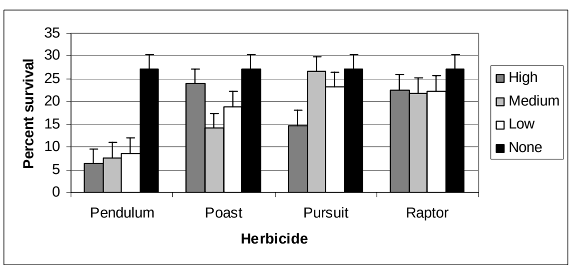


Figure 25. Longleaf phlox pre-germination plant survival by herbicide and rate. The interaction between herbicides and rates was significant ($P = 0.01$).

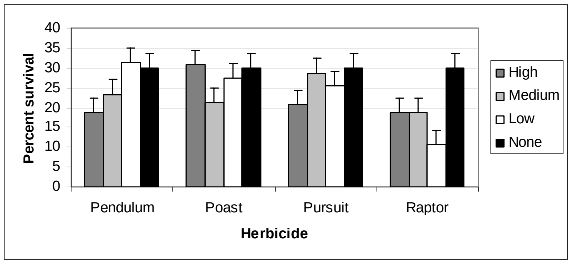


Figure 26. Gooseberryleaf globemallow pre-germination plant survival by herbicide and rate. The interaction between the herbicide and rate effects was significant at the P = 0.09 level.

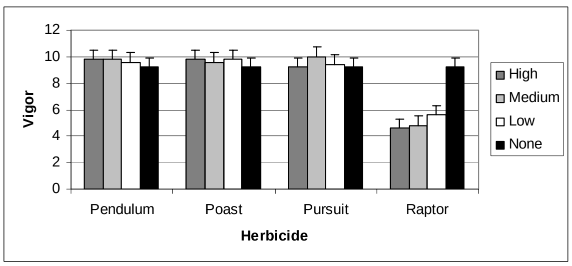


Figure 27. Pale agoseris seedling vigor by herbicide and rate. The interaction between herbicides and rates was significant ($P < 0.01$).

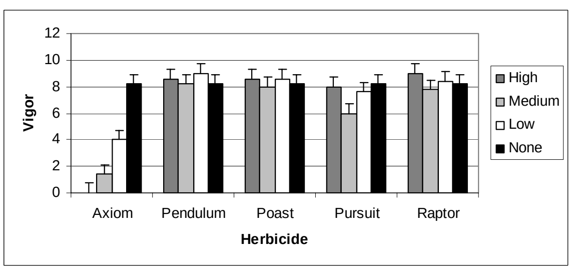


Figure 28. Tapertip hawksbeard seedling vigor by herbicide and rate. The interaction between herbicides and rates was significant (P = 0.03).

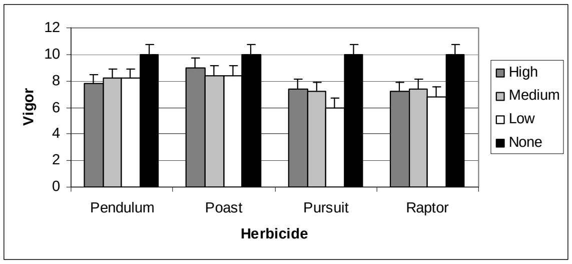


Figure 29. Cushion buckwheat seedling vigor by herbicide and rate. The interaction between herbicides and rates was significant ($P = 0.01$).

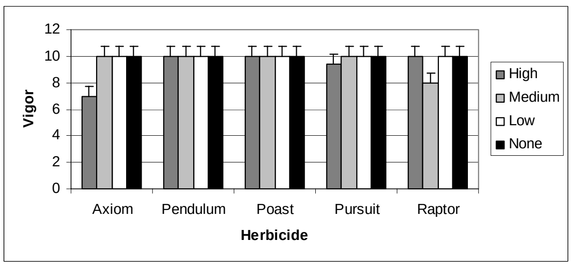


Figure 30. Longleaf phlox seedling vigor by herbicide and rate. The interaction between herbicides and rates was significant ($P < 0.01$).

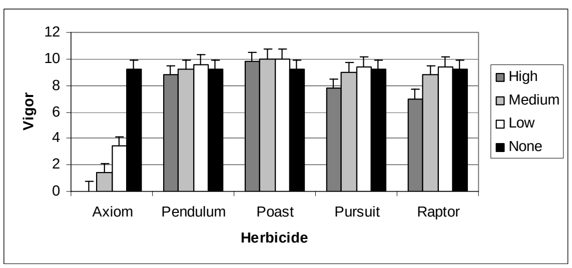


Figure 31. Scarlet globemallow seedling vigor by herbicide and rate. The interaction between herbicides and rates was significant ($P = 0.03$).

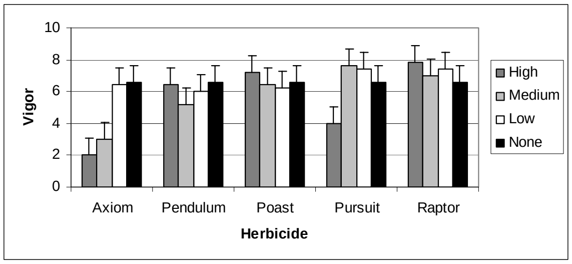


Figure 32. Pale agoseris established plant vigor by herbicide and by rate. The interaction between the herbicides and rates was significant at the *P* = 0.10 level.

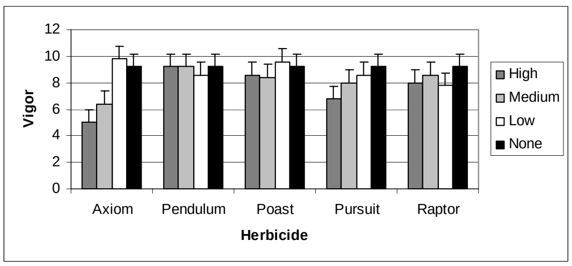


Figure 33. Utah milkvetch established plant vigor by herbicide and rate. The interaction between herbicides and rates was significant (*P* = 0.04).

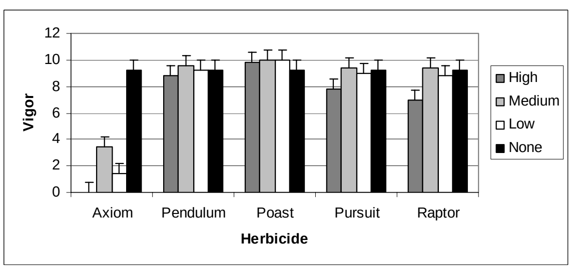


Figure 34. Scarlet globemallow established plant vigor by herbicide and rate. The interaction between the rates and herbicides was significant at the *P* = 0.09 level.

TABLES

Table 18. List of scientific names, common names, and abbreviations used for each plant species used in the experiment.

Scientific name	Common name(s)	Abbreviation
Astragalus utahensis (Torr.) Torr. & Gray	Utah milkvetch	ASUT
	ladyslipper	
Agoseris glauca (Pursh) Raf.	pale agoseris	AGGL
	false dandelion	
	mountain dandelion	
Crepis acuminata Nutt.	tapertip hawksbeard	CRAC
	mountain hawksbeard	
Eriogonum ovalifolium Nutt.	cushion buckwheat	EROV
	oval-leaved eriogonum	
Phlox longifolia Nutt.	longleaf phlox	PHLO
Sphaeralcea coccinea (Nutt.) Rydb.	scarlet globemallow	SPCO
	copper mallow	
	red falsemallow	
	common globemallow	
Sphaeralcea grossulariifolia (Hook. & Arn.) Rydb.	gooseberry-leaf globemallow	SPGR

Table 19. List of herbicides used in the experiment.

Herbicide	Active ingredient(s)	Recommended rate
Axiom®	flufenacet, metribuzin	1.09 kg/ha
Pendulum 3.8®	pendimethalin	5.50 L/ha
Poast®	sethoxydim	1.75 L/ha
Pursiut®	ammonium salt of imazethapyr	328.8 mL/ha
Raptor®	ammonium salt of imazamox	365.4 mL/ha

Table 20. Recommended herbicides and rates at the pre-germination stage for all species. An explanation of the abbreviations used is in Table 18.

		Species						
Herbicide	Rate	AGGL	ASUT	CRAC	EROV	PHLO	SPCO	SPGR
Axiom	High							
	Med		X					
	Low		X					
Pendulum	High	X	X	X	X		X	X
	Med	X	X	X	X		X	X
	Low	X	X	X	X		X	X
Poast	High	X	X		X	X	X	X
	Med	X	X		X	X	X	X
	Low	X	X		X	X	X	X
Pursuit	High	X	X		X	X	X	X
	Med	X	X			X	X	X
	Low	X	X			X	X	X
Raptor	High		X		X	X	X	
	Med		X		X	X	X	
	Low		X		X	X	X	

Table 21. Recommended herbicides and rates at the seedling stage for all species. An explanation of the abbreviations used is in Table 18.

		Species						
Herbicide	Rate	AGGL	ASUT	CRAC	EROV	PHLO	SPCO	SPGR
Axiom	High							
	Med					X		
	Low					X	X	
Pendulum	High	X	X	X		X	X	X
	Med	X	X	X	X	X	X	X
	Low	X	X	X	X	X	X	X
Poast	High	X	X	X	X	X	X	X
	Med	X	X	X	X	X	X	X
	Low	X	X	X	X	X	X	X
Pursuit	High	X	X	X		X	X	X
	Med	X	X	X		X	X	X
	Low	X	X	X		X	X	X
Raptor	High		X	X		X	X	
	Med		X	X		X	X	
	Low		X	X		X	X	

Table 22. Recommended herbicides and rates at the established stage for all species. An explanation of the abbreviations used is in Table 18.

Herbicide	Rate	Species					
		AGGL	ASUT	EROV	PHLO	SPCO	SPGR
Axiom	High				X		
	Med	X	X		X	X	
	Low	X	X		X	X	
Pendulum	High	X	X	X	X	X	X
	Med	X	X	X	X	X	X
	Low	X	X	X	X	X	X
Poast	High	X	X		X	X	X
	Med	X	X		X	X	X
	Low	X	X		X	X	X
Pursuit	High	X		X	X	X	X
	Med	X	X	X	X	X	X
	Low	X	X	X	X	X	X
Raptor	High	X	X	X	X	X	X
	Med	X	X	X	X	X	X
	Low	X	X	X	X	X	X