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Vegetation Study in Support of the Design and Optimization of Vegetative Soil Covers, Sandia National Laboratories, Albuquerque, New Mexico

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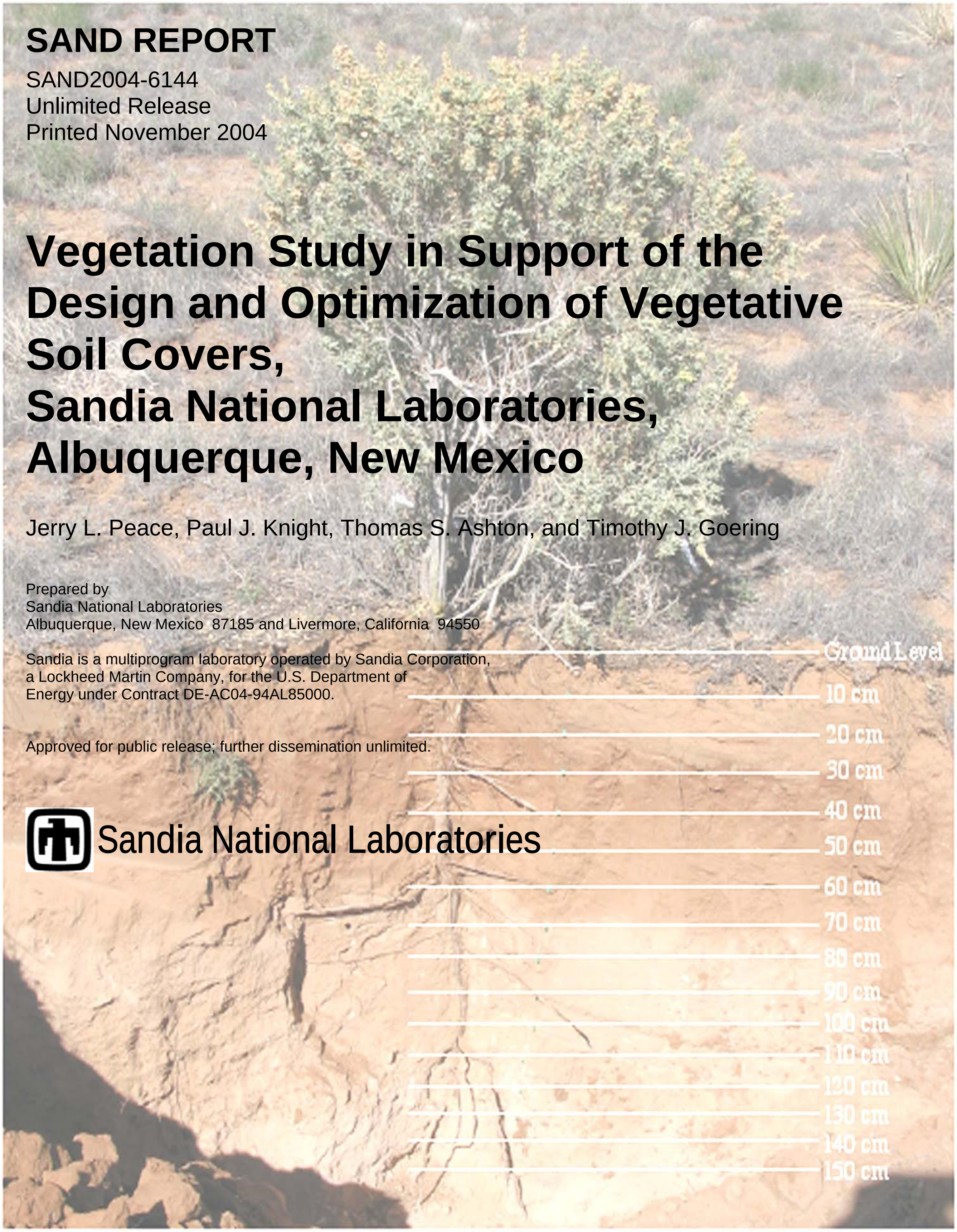

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Abstract

A vegetation study was conducted in Technical Area 3 at Sandia National Laboratories, Albuquerque, New Mexico in 2003 to assist in the design and optimization of vegetative soil covers for hazardous, radioactive, and mixed waste landfills at Sandia National Laboratories/New Mexico and Kirtland Air Force Base. The objective of the study was to obtain site-specific, vegetative input parameters for the one-dimensional code UNSAT-H and to identify suitable, diverse native plant species for use on vegetative soil covers that will persist indefinitely as a climax ecological community with little or no maintenance.

The identification and selection of appropriate native plant species is critical to the proper design and long-term performance of vegetative soil covers. Major emphasis was placed on the acquisition of representative, site-specific vegetation data. Vegetative input parameters measured in the field during this study include root depth, root length density, and percent bare area. Site-specific leaf area index was not obtained in the area because there was no suitable platform to measure leaf area during the 2003 growing season due to severe drought that has persisted in New Mexico since 1999. Regional LAI data was obtained from two unique desert biomes in New Mexico, Sevilletta Wildlife Refuge and Jornada Research Station.

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Acronyms and Abbreviations

cm	centimeter(s)
cm^3	cubic centimeter(s)
°C	degrees Celsius
°F	degrees Fahrenheit
ft	foot/feet
KAFB	Kirtland Air Force Base
LAI	leaf area index
m	meter(s)
m^2	square meter(s)
mm	millimeter(s)
NMED	New Mexico Environment Department
NRCS	The National Resource Conservation Service
PBA	percent bare area
pls	per live seed
RLD	root length density
SNL/NM	Sandia National Laboratories/New Mexico
TA	Technical Area
UNSAT-H	Unsaturated Water and Heat Flow
USDA	U.S. Department of Agriculture

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1. Introduction

A vegetation study was conducted in Technical Area (TA)-3 at Sandia National Laboratories, Albuquerque, New Mexico (SNL/NM), in 2003 to assist in the design and optimization of vegetative soil covers at SNL/NM and Kirtland Air Force Base (KAFB) (Figure 1-1). The overall objective of the study was to

- Obtain site-specific, vegetative input parameters for the Unsaturated Water and Heat Flow (UNSAT-H) model Version 3.0 (Fayer 2000) used to optimize cover design and assess long-term cover performance; and

- Identify suitable, diverse native plant species for use on vegetative soil covers that will persist indefinitely as a climax ecological community with little or no maintenance.

Vegetative soil covers have been approved by the New Mexico Environment Department (NMED) for final closure of hazardous, radioactive, and mixed waste landfills at SNL/NM and KAFB. The primary role of a vegetative soil cover is to isolate waste from human and ecological receptors and to minimize the infiltration of water and the generation of leachate.

The proper design of a vegetative soil cover depends on a thorough understanding of soil water storage, the physics of soil water movement, evapotranspiration, vegetative cover, and climate. The design of vegetative soil covers is an imprecise science, combining traditional engineering principles with shallow vadose zone geology, ecology, hydrology, climatology, sedimentology, botany, and agronomy. Principles from these applied sciences must be applied to develop an effective, site-specific design. Vegetative soil cover design combines layers of soil, native plant species, and climatic conditions to form a sustainable, functioning ecosystem that maintains the natural water balance (ITRC 2003). This report focuses on the native plant species component of the cover designs that will be deployed at SNL/NM and KAFB.

The UNSAT-H model was developed at Pacific Northwest National Laboratory for assessing the water dynamics of arid sites and estimating recharge rates for waste disposal facilities. The UNSAT-H model accomplishes this by simulating soil water infiltration, redistribution, evaporation, plant transpiration, and deep drainage (Fayer 2000). The UNSAT-H model is used by SNL/NM design engineers and NMED regulators to optimize cover design and assess long-term cover performance.

The UNSAT-H model must be provided with relationships for water content and hydraulic conductivity as a function of suction head, vegetative data, climatic data, and initial and boundary conditions. Vegetative data includes root depth, root length density, leaf area index, growing season, and percent bare area. In order to collect these data, field investigations were conducted within a five-acre area in north-central TA-3 at SNL/NM in spring, summer, and fall of 2003. This report presents the results of these investigations.

1.1 Vegetative Input Parameters

In this study, major emphasis was placed on the acquisition of representative, site-specific vegetative data for use as input parameters for the UNSAT-H model. Vegetative input parameters measured in the field during this study include root depth, root length density (RLD), and percent bare area (PBA). Site-specific leaf area index (LAI) and growing season were not obtained in the study area because there was very little growth among the dominant perennial grasses in 2003. There was no suitable platform to measure leaf area during the 2003 growing season due to severe drought that has persisted in New Mexico since 1999 (National Climatic Data Center 2003).

Without directly measured LAI data, regional LAI data was obtained from two unique desert biomes in New Mexico, Sevilletta Wildlife Refuge and Jornada Research Station, both of which are biologically similar to the TA-3 study area. Growing season data were derived from the native plant species databases of the U.S. Department of Agriculture (USDA) and local plant specialists.

Field investigations undertaken in TA-3 to obtain vegetative input parameters included:

- Characterization of the habitat, vegetation type, and plant species community type;
- Determination of the soil structure as it relates to the vegetation in the study area;
- Determination of basal and foliar coverage and PBA within the dominant plant community;
- Determination of the composition and species structure of the plant communities;
- Determination of the root depth of dominant perennial vegetation within the study area;
- Determination of the RLD of the dominant perennial vegetation;
- Determination of the growing season of the dominant perennial vegetation; and
- Recommendations for native plant species composition for seed mixes to vegetate soil covers at SNL/NM and KAFB.

Supplementary data were collected in surrounding areas contiguous with TA-3. These data were augmented by information from prior biological studies conducted in 1992 by Sullivan and Knight (1992). Paul J. Knight and Tom S. Ashton, Marron and Associates, Inc., Albuquerque, New Mexico, provided valuable assistance and expertise in the collection of the vegetation data provided in this report.

2. Description of the Study Area

Although general data on plant species diversity and community structure were gathered throughout the north-central portion of TA-3, the principle field studies were conducted within a five-acre area west of the Mixed Waste Landfill (Figure 2-1). The study area slopes gently to the west, and ranges from 1637 to 1688 m (5370 to 5375 ft) in elevation. Although the study area is relatively flat and featureless, it contains numerous micro-variations in topography. These micro-variations include shallow depressions and low rises, and play a significant role in the distribution of native plant species within the study area.

For example, shallow depressions in the study area have collected wind-blown sand, forming deep sandy loam soils that favor species such as spike dropseed (*Sporobolus contractus*). Within these shallow depressions, spike dropseed is far more abundant than elsewhere in the study area. Sandy loam soils closely underlain by sandy clay loam soils tend to support black grama (*Bouteloua eriopoda*) and galleta grass (*Pleuraphis jamesii*). In addition to the climax communities within the study area, there are small pockets of surface disturbance along dirt roads and utility corridors that support disclimax communities. The most common vegetation in these disclimax communities includes spiny aster (*Machaeranthera canescens*) and Russian thistle (*Salsola tragus*). It is anticipated that during wetter years, a greater number of annual species are likely to occur within these disturbed areas.

2.1 TA-3 Soil Characterization

The National Resource Conservation Service (NRCS) Bernalillo County Soil Survey (USDA SCS 1977) lists the soils in TA-3 as Madurez Loamy Fine Sand. However, TA-3 is located near the boundary between the Madurez Loamy Fine Sand and the Tijeras Gravelly Fine Sandy Loam. Influences of Tijeras Gravelly Fine Sandy Loam could occur in the area. The following are descriptions of each of these soil types.

2.1.1 Madurez Series

The Madurez Series consists of generally deep, well-drained soil that formed on piedmonts within unconsolidated alluvium that has been modified by the wind. The soils most often occur between 1494 to 1798 m (4900 to 5900 ft) in elevation where they receive average annual precipitation of 17.8 to 25.4 centimeters (cm). Madurez Series soils are considered moderately permeable with available water capacity of 19.1 to 22.9 cm, and according to the NRCS Bernalillo County Soil Survey, an effective rooting depth of 152.4 cm or more. The Madurez Loamy Fine Sand is reported as having slow runoff and a severe wind erosion hazard. The typical profile provided by the NRCS for the Madurez Series consists of a fine sandy loam. The following is a general description of the Madurez Series soil profile.

2.1.2 A Horizon

1 to 10 cm: Brown fine sandy loam (in the general description of the A Horizon, the Madurez Series can also be sandy loam, gravelly fine sandy loam or loamy fine sand); weak, fine, granular structure; soft, very friable; many very fine and fine roots and interstitial pores; moderately alkaline; abrupt smooth boundaries.

2.1.2.1 B Horizon

10 to 33 cm: Brown sandy clay loam (in the general description of the B Horizon, the Madurez Series can also be heavy sandy loam, light clay loam, heavy fine sandy loam, or light sandy clay loam); weak, coarse, sub-angular blocky structure; hard, friable, sticky and plastic; many very fine and fine roots and interstitial pores; moderately alkaline; clear, smooth boundaries.

33 to 53 cm: Light brown heavy fine sandy loam (in the general description of the B Horizon, the Madurez Series can also be heavy sandy loam, light clay loam, heavy fine sandy loam, or light sandy clay loam); weak, coarse, sub-angular blocky structure; hard, friable, sticky and plastic; common very fine and fine roots and interstitial pores; moderately calcareous; moderately alkaline; clear, smooth boundary.

2.1.2.2 C Horizon

53 to 89 cm: Pink heavy sandy loam (in the general description of the C Horizon, the Madurez Series can also be sandy clay loam, light clay loam, heavy fine sandy loam or light sandy clay loam); massive; hard, friable, sticky and plastic; few very fine roots and interstitial pores; moderately calcareous; moderately alkaline; clear smooth boundary.

89 to 130 cm: Pinkish gray sandy loam (in the general description of the C Horizon, the Madurez Series can also be sandy clay loam, light clay loam, heavy fine sandy loam or light sandy clay loam); massive; hard, friable, slightly sticky and slightly plastic; strongly calcareous; moderately alkaline; gradual smooth boundaries.

130 to 152 cm: Light brown sandy loam (in the general description of the C Horizon, the Madurez Series can also be sandy clay loam, light clay loam, heavy fine sandy loam or light sandy clay loam); slightly hard, friable; moderately calcareous; moderately alkaline.

2.1.3 Tijeras Series

The Tijeras Series consists of deep, well-drained soils that formed on alluvial fans. The soils most often occur between 1524 to 1981 m (5000 to 6500 ft) in elevation, where they receive average, annual precipitation of 17.8 to 25.4 cm. Tijeras Series soils are considered moderately permeable with available water capacity of 7.6 to 16.5 cm, and according to the NRCS Bernalillo County Soil Survey, an effective rooting depth of 152.4 cm or more. The Tijeras Gravelly Fine Sand is reported as having moderate runoff and a moderate water erosion hazard. The typical profile provided by the NRCS for the Tijeras Series consists of a fine sandy loam. The following is a general description of the Tijeras Series soil profile.

2.1.3.1 A Horizon

0 to 10 cm: Brown gravelly fine sandy loam; weak, thin, plate to like, platy structure in upper 1.3 to 2.5 cm and weak, fine, granular structure in the lower part; soft, very friable; many fine and very fine roots and interstitial pores; about 20% very fine granitic gravel; moderately alkaline; abrupt, smooth boundary.

2.1.3.2 B Horizon

10 to 23 cm: Brown sandy clay loam (in the general description of the B Horizon, the Tijeras Series can also be heavy sandy loam or heavy loam); moderate, medium, sub-angular blocky structure; slightly hard, very friable, sticky and plastic; many fine and very fine roots and tubular pores; many moderately thick clay films on peds and in tubular pores; about 5% very fine granitic gravel; moderately alkaline; clear, wavy boundary.

23 to 36 cm: Brown sandy clay loam (in the general description of the B Horizon, the Tijeras Series can also be heavy sandy loam or heavy loam); moderate, medium, sub-angular blocky structure; hard, friable, sticky and plastic; many fine and very fine roots and tubular pores; commonly moderately thick clay films on peds and many moderately thick clay films in tubular pores; about 5% very fine granitic gravel; moderately alkaline; clear, wavy boundary.

36 to 48 cm: Brown sandy clay loam (in the general description of the B Horizon, the Tijeras Series can also be heavy sandy loam or heavy loam); moderate, medium, sub-angular blocky structure; hard, friable, sticky and plastic; many fine and very fine roots and tubular pores; few moderately thick clay films on peds and moderately thick clay films in tubular pores; about 12% very fine granitic gravel; slightly calcareous; lime is segregated as thin lime mycelium on peds and in pores; moderately alkaline; abrupt smooth boundary.

2.1.3.3 C Horizon

36 to 152 cm: Pale brown strata of gravelly sandy loam and very gravelly loamy sand; single grained; loose; few and very fine roots; many fine and very fine interstitial pores; moderately calcareous; lime is segregated as few fine soft masses; moderately alkaline.

2.2 Study Area Soil Characterization

Soil data were collected at 16 locations within the study area. Soil data were collected during the excavation of four deep trenches using a backhoe, 10 shallow trenches using shovels, and two RLD pits using a trowel. At many of these locations, soils data were recorded to a depth of 100 cm. Although the structure of the upper soil profile (less than 60 to 70 cm below the surface) was similar among the various trenches examined, the occurrence of a caliche layer varied both in structure and depth within the study area.

The following is a description of the soil encountered within the study area in 10 cm intervals to 100 cm in depth. A photograph of the typical soil profile is shown in Figure 2-2.

0 to 10 cm: The soil is brown, loose, very friable, soft, and consisted of loamy sand or fine sandy loam. Most of the soil passes through a 1.0 millimeter (mm) and 0.5 mm mesh screen with ease. There is little, if any, gravel present. There are numerous, coarse fibrous roots present throughout this interval, ranging from 0.3 to 0.8 mm in diameter. However, there are also smaller roots ranging from 0.1 to 0.3 mm in diameter (measured when dry).

10 to 20 cm: The soil is brown, slightly firmer than the 0 to 10 cm interval, but still very friable and soft. The soil appears to be a sandy loam. Most of the soil passes through a 1.0 and 0.5 mm mesh screen with ease. There are a few small gravel pebbles present, but these are insignificant in relation to the total soil volume. Like the 0 to 10 cm interval, this interval has numerous, coarse fibrous roots ranging from 0.3 to 0.8 mm in diameter. Unlike the 0 to 10 cm interval, approximately 50% of the roots range from 0.1 to 0.3 (measured when dry). In addition, the overall root density in this interval is perhaps half that noted in the 0 to 10 cm interval.

20 to 30 cm: The soil is brown, firm, and somewhat blocky. There are a few small pebbles present and occasionally a piece of gravel. There is an abrupt change in the soil texture noted at about 25 cm below the surface. When wet, the soil at this level becomes slightly sticky but still has a coarse structure when rubbed between ones' fingers. Although the soil was only slightly damp during the study, it tended to aggregate into small balls when agitated on the 1.0 mm mesh screen. The soil appears to be a sandy loam or a sandy clay loam. Although there were still a large number of coarse fibrous roots ranging from 0.3 to 0.8 mm in diameter, these coarse roots comprised perhaps only 25% of the visible root mass. A greater percentage of fine fibrous roots were present.

30 to 40 cm: The soil is brown, hard, and very blocky. A rock hammer or small chisel is required to break up the dried soil, which often dislodges into large blocks. When wet, the soil becomes slightly sticky but still has a coarse structure when rubbed between ones' fingers. It requires considerable soaking in water to dissolve the blocks of soil. The soil appears to be a sandy clay loam. There are occasional pieces of gravel present in this interval, but overall, gravel is absent. The visible root configuration changes substantially at this interval. The coarse roots so common in the upper intervals become scarcer within this interval. They branch out profusely into finer roots that form a dense reticulate network throughout the soil profile.

40 to 50 cm: The soil is brown, hard, and blocky and for the most part, has very little gravel present. The gravel present is often coated with calcium carbonate. When wet, the soil becomes slightly sticky but still has a coarse texture when rubbed between ones' fingers. As with the previous interval, the soil appears to be a sandy clay loam. There are very few coarse roots present, but there is a proliferation of fine roots in the 0.1 to 0.2 mm range which branch throughout the soil profile in a reticulate manner.

50 to 60 cm: The soil is light brown, hard, blocky with occasional scattered pieces of gravel coated with calcium carbonate. Flecks of calcareous concretions are also scattered through this interval. The soil is somewhat sticky when wet, but sand grains can still be felt when the soil was rubbed between ones' fingers. The soil appears to be a sandy clay loam. Diffuse fine roots branch throughout the soil profile. No coarse roots are present.

60 to 70 cm: The soil is very light brown, hard, and blocky. The soil is somewhat sticky when wet, but fine sand grains can still be felt when the soil is rubbed between ones' fingers. Gravel is scarce, scattered, and occasional. The soil appears to be a sandy clay loam. The soil is noticeably lighter in color than the previous interval, and the small white calcareous concretions observed become larger and more prevalent. The boundary between the lighter and darker soil is abrupt and wavy. The fine roots present decrease in abundance and appear mainly in small reticulate pockets. No coarse roots are present.

70 to 80 cm: The soil is light brown (almost pink), hard, blocky, and grows perceptively lighter in color, appearing to be calcareous. There are often large mottles of white calcareous material. When placed in water, the soil is sticky and somewhat milky. The soil appears to be a sandy clay loam. Gravel is scarce, although occasionally present. Roots are very scarce, occurring mainly in pockets or stringers along pores in the soil structure. Roots are typically less than 0.1 mm in diameter.

80 to 90 cm: The soil varies from light brown to pink, and turns milky when stirred into water. In some areas, this interval contains chunks of caliche; in other areas it is represented by merely a clay loam soil flecked with calcareous concretions. The soil is very hard, not very friable, and somewhat sticky when wet. Gravel is slightly more prevalent than in the previous intervals, but is still far less than 1% by volume. Roots are very scarce, but when present occur mainly in stringers following pores or cracks in the soil structure. All observed roots are very fine, often less than 0.1 mm in diameter.

90 to 100 cm: Depending upon the location, the soil in this interval varies from a calcareous sandy clay loam to caliche. In most areas this soil is very light colored, varying from a very light brown, light pink, to almost white. Caliche is present either as small concretions or as pronounced layers. The soil is very hard, calcareous, milky when stirred into water, and sticky when wet. Gravel is intermittent but never abundant. Roots are extremely scarce, but when present, were usually 0.1 mm in diameter or less.

2.3 Summary of Study Area Soils Characterization

Soils within the study area fit the general description of the Madurez Series. Although typical Madurez soils are sandy loams below 30 cm, those in the study area are increasingly sandy clay loams below 30 cm. However, the soils did not fit the description for the Tijeras Series, which generally have an abundance of gravel, in some cases reaching 20% by volume. Gravel is scarce and intermittent throughout the entire soil profile.

The most significant properties of the soil profile within the study area are the increasing content of clay with depth and the occurrence of a predominant caliche layer. The sandy clay loam soils begin between 20 and 30 cm below the surface. These soils appear to have a greater capacity to hold water than the overlying loamy sands and sandy loams. The overlying sandy loam soils are more permeable, allowing for rapid infiltration of water from precipitation. The caliche layer occurs between 100 cm and 1.5 meter (m) below the surface. The caliche layer is a common feature at this depth throughout TA-3.

Soils throughout the study area showed variable thickness and disposition. In some areas, the loamy sand usually found in the top 10 cm of the soil profile extended downwards to 50 cm below the surface. In other areas, the sandy clay loam soils typically encountered between 20 and 30 cm below the surface were found within 10 cm of the surface. This variability contributed to micro-variations in species composition of dominant plants within the study area.

3. Vegetation

The dominant vegetation type within the study area and throughout north-central TA-3 is classified as Desert Grassland (Dick-Peddie 1993). Specifically, the species composition in the area best fits the Desert Grassland Shrub series to Black Grama Series. Desert Grassland is considered a transitional zone by most authors, but Brown (1982) recognized that this arid grassland, even as an ecotone community, is a distinct and separate biome. Since this vegetation type is ecotonal, it intergrades with other biomes both above and below in elevation. For example in the Albuquerque area, Desert Grassland often blends into Plains Mesa Sand Scrub community type at lower elevations just above the Rio Grande Valley. At higher elevations near the Sandia and Manzano mountains, Desert Grassland blends into Juniper Savanna.

The dominant grass and indicator of Desert Grassland is black grama (*Bouteloua eriopoda*). Much of the habitat in north-central TA-3 is dominated by black grama. Within the study area, black grama forms almost monospecific stands where it accounts for nearly 62% of the foliar coverage in the entire vegetative community. Since Desert Grassland is an ecotone community, it has the potential for a wide variety of associated and subdominant species. This diversity can increase in areas where Desert Grassland interfaces with other community types. In combination, a total of 109 species of vascular plants were identified in TA-3 as a result of this and previous studies (Sullivan and Knight 1992). These species are presented alphabetically in Appendix A.

The state of New Mexico has experienced severe drought since 1999 (National Climatic Data Center 2003). Consequently, there was very little growth within the native plant communities in the study area during the 2003 growing season, and species diversity was very low. Thirty-five of the 109 vascular plant species documented in 1992 in TA-3 were found within the five-acre study area during the 2003 growing season. In addition to black grama, four subdominant perennial species found within the area include threadleaf snakeweed (*Gutierrezia microcephala*), galleta grass (*Pleuraphis jamesii*), spike dropseed (*Sporobolus contractus*), and sand sage (*Artemisia filifolia*). In aggregate, these species, combined with black grama, account for over 84% of the total foliar cover in the study area. Deertongue (*Cryptantha crassisepala*) and Russian thistle (*Salsola tragus*) are the dominant annual species; combined they account for over 12% of the foliar coverage. Basically, seven species (black grama, galleta grass, spike dropseed, sand sage, threadleaf snakeweed, deertongue, and Russian thistle) account for nearly 96% of the foliar cover (annual and perennial) in the study area. Although conspicuous by their size and unique appearance, species such as prickly pear cactus (*Opuntia phaeacantha*) and small soapweed yucca (*Yucca glauca*) were insignificant in the total coverage and composition of the community.

3.1 Vegetative Input Parameters

Field investigations were conducted in areas undisturbed by previous field work in TA-3. These areas were checked using aerial photography dating back 40 years for fire, herbivore, and field tests related to the cold war. Field investigations evaluated root depth, RLD, and PBA.

3.1.1 Root Depth

Root depth and distribution data were obtained for the dominant and subdominant species within the study area. These data were obtained by direct excavation and profiling of each species' root system. Observations of root systems were collected at fourteen different locations (Figure 3-1). The data from 10 of these observations were obtained from pits excavated with a shovel to depths varying from 50 to 100 cm. Each of these pits was excavated adjacent to the species under study. Once the primary pit was excavated, the sidewalls of the pits were carefully worked backward toward the root system of the species utilizing a trowel, paintbrushes, and canned air. Eventually, a two-dimensional view of the root system was exposed. Once the root system was profiled, a series of pins were placed in the sidewall of the pit at decimeter increments along the vertical axis of the root system. The illustrated root system was then photographed utilizing a digital camera.

In addition to the 10 hand-dug pits, four deep pits were excavated adjacent to large shrubs utilizing a backhoe. These pits extended to 2 m in depth. Utilizing the same techniques described above, the root systems of these large shrubs were profiled and photographed.

Root depth was measured for black grama, threadleaf snakeweed, galleta grass, spike dropseed, and sand sage. Root depth and distribution was also measured for ring muhly (*Muhlenbergia torreyi*) and fourwing saltbush (*Atriplex canescens*). Neither of these species were dominants or subdominants, but ring muhly is being considered as a possible candidate for planting on vegetative soil covers. Fourwing saltbush appears only occasionally in the study area, but it was noted growing on the Mixed Waste Landfill and interest developed as to how deeply the roots of this species might penetrate into the existing landfill cover.

The following is a discussion of the root depth and distribution of each species, examined in order of its dominance within the vegetative community at the site. Figure 3-2 graphically shows the general structure and root depth as observed and projected for each species within the study area.

3.1.1.1 Black Grama

Black grama has a well-developed and finely divided root system, with the greatest concentration of roots found within the uppermost 30 cm of the soil profile (Figure 3-3). These roots are arranged in a dense reticulate pattern and penetrate the entire soil profile. Below 25 cm, smaller roots continue to penetrate the soil profile to 80 cm but steadily decrease in abundance. Below 80 cm, roots are very scarce and minute, penetrating to a depth of approximately 1.3 m below the ground surface. Lateral spreading of primary roots from the root crown was limited to the dripline at the time of the survey. Lateral spreading of fine, secondary and tertiary roots may extend beyond the dripline.

The existing literature reports that black grama has a well-developed and finely divided root system with the greatest concentration of roots found within the uppermost 25 cm of the soil (Campbell et al. 1934, Dwyer and DeGarmo 1970). In sand, these roots may extend downward as far as 1.2 m (Paulson et al. 1962). The water-regulating physiology and root morphology of this dominant species places it in the ‘intensive exploiter’ classification (Burgess 1995). Intensive exploiters are plants that derive the majority of their moisture through dense rooting networks situated within shallow soil horizons. They exploit the moisture from ephemeral storm events with rapid root growth and water absorption. Intensive exploiters are also good competitors for limited, shallow soil moisture and recover rapidly from stress or damage with readily available soil moisture. Hence, intensive exploiter species such as black grama are ideal candidate species for vegetative soil covers.

3.1.1.2 Threadleaf Snakeweed

Threadleaf snakeweed has a well-developed taproot and lateral root system, with the greatest concentration of roots found within the upper 60 cm of the soil profile (Figure 3-4). The shortest taproot penetrated to approximately 40 cm where smaller, lateral roots extended another 20 cm. The longest taproot penetrated to approximately 60 cm, where smaller, lateral roots extended another 20 to 30 cm. Based on field observations, the taproot and the smaller, lateral roots may extend to a depth of 100 cm below the surface. Lateral spreading of some of the secondary, lateral roots from the central taproot extended 30 cm beyond the drip line. Fletcher (2003) reports that threadleaf snakeweed can have roots that extend 1.8 to 2.4 m below the surface in extremely sandy soil.

3.1.1.3 Galleta Grass

Galleta grass has a rhizomatous root system, with the greatest concentration of roots found within the uppermost 30 cm of the soil profile (Figure 3-5). Below 30 cm, smaller roots continue to permeate the soil profile to 60 cm, decreasing in abundance. Below 60 cm, roots are very scarce and minute. Based on field observations, these minute roots may extend to a depth of 75 cm below the surface.

The primary, rhizomatous roots spread outward from the root crown to approximately 10 cm beyond the dripline. Fine secondary and tertiary roots likely extend beyond this point. West et al. (1972) and Hassell (1982) reported that the roots of this species are commonly found within the upper soil profile, with few roots extending further than 50 cm below the surface. Galleta usually grows in bunches, but under favorable conditions these clumps can merge forming a sod (West et al. 1972).

3.1.1.4 Spike Dropseed

Spike dropseed has a well-developed and finely divided root system, with the greatest concentration of roots found within the uppermost 30 cm of the soil profile (Figure 3-6). These roots are arranged in a dense reticulate pattern and penetrate the entire soil profile. Below 30 cm, smaller roots continue to penetrate the soil profile to 70 cm, but steadily decrease in abundance. Below 70 cm, roots are very scarce and minute, and may extend to a depth of 100 cm below the surface. Little information was found in the literature relating to rooting depth of spike dropseed, but closely related sand dropseed roots have been reported to a depth of 78 cm (Coupland et al. 1965). Lateral spreading of primary roots from the root crown was limited to the dripline at the time of the survey.

3.1.1.5 Sand Sage

Sand sage has a well-developed pronounced taproot and lateral root system, with the greatest concentration of roots found within the uppermost 80 cm of the soil profile (Figure 3-7). Taproots penetrated to approximately 80 cm to 1.5 m, with numerous, lateral roots extending another 20 to 50 cm. Based on field observations, the taproot and the smaller, lateral roots may extend to a depth of 2 m below the surface. Although the tap root dominated the structure of the root system, some large secondary roots extended laterally to as much as 50 cm beyond the dripline.

3.1.1.6 Ring Muhly

Ring Muhly has a fibrous root system, with the greatest concentration of roots found within the uppermost 40 cm of the soil profile (Figure 3-8). Below 40 cm, smaller roots continued to penetrate the soil profile to 70 cm, but steadily decrease in abundance. No roots were observed below 70 cm. Ring muhly appears to have the same root configuration as black grama but does not appear to root as deeply. Based on field observations, these minute roots may extend to a depth of 100 cm below the surface. Ring muhly may have been more common in the study area prior to the drought but this species fairs poorly in drought conditions (Fletcher 2003). Lateral spreading of the primary roots from the root crown extended upwards of 20 cm beyond the dripline.

3.1.1.7 Fourwing Saltbush

Fourwing salt bush has a well-developed pronounced taproot and lateral root system with the greatest concentration of roots found within the uppermost 1.7 m of the soil profile (Figure 3-9). All along the taproot, numerous lateral roots extended another 20 to 50 cm. At 1.7 m, the primary taproot was yet 1.5 cm in diameter and descending to greater depth. Considering the thickness of the taproot at 1.7 m, it is estimated that the taproot may have extended another 100 cm and secondary, lateral roots probably extended even deeper. Based on the field observations, as well as earlier studies of this species (Dayton 1931, Nord et al. 1971), the root system of fourwing saltbush may extend 2 to 6 m below the surface and approximately 100 cm beyond the dripline.

3.1.2 Root Length Density

RLD was measured from total root biomass extracted from two pits, RLD-1 and RLD-2. RLD-1 was 1 x 1 m in area at the surface and 100 cm in depth (Figure 3-10). RLD-2 was excavated in the sidewall of a trench excavated to examine the root structure of sand sage. Total root biomass was extracted and collected at successive 10 cm intervals to 100 cm in depth. The soil from each interval was fed through a series of graduated screens of 4, 2, 1, and 0.5 mm mesh size (Figure 3-11). Roots were removed from each of these screens and bagged. The roots were floated to remove residual soil, then placed on a rack for one week and allowed to dry at an ambient temperature of 75 degrees Fahrenheit (°F) and a humidity of 10% to 15%. Root biomass from each interval was measured with a triple beam balance to an accuracy of 0.1 gram.

The distribution of total root biomass with depth from RLD-1 and RLD-2 is shown in Figure 3-12. The root biomass exhibits a high degree of correlation, perhaps due to the relative homogeneity of the dominant native plant species, black grama, within the study area. Black grama was the only native plant specie growing on the surface of the two excavated volumes. A very small portion of the root biomass encountered in RLD-1 was derived from a dead snakeweed plant that was located just outside of the plot. If the species composition within the study area were more diverse, the root biomass would likely exhibit greater variation. RLD-1 and RLD-2 represent single observations in a plant community where black grama accounts for nearly 62% of the total foliar coverage. There is very little variation in the composition or structure of the native plant community across the study area.

An additional factor that may contribute to root biomass correlation is the protracted drought. All of the native plants exhibited signs of stress. It is likely that root biomass is low in relation to what might be expected if the native plant community had not been subject to such a severe drought. As a result, variability between plots may have been lower than during years with more precipitation and greater root biomass. Rainfall and soil type dramatically affect the distribution and composition of the native plant community.

Finally, it should be noted that the observations of RLD recorded in this study are likely specific to the microhabitat conditions from which the data were collected. Factors such as variation in soil composition, aspect, rainfall patterns and proximity to soil moisture may affect not only the depth and lateral spreading of the roots but also the density of the roots within the various strata subtending the plant.

The labor and time to excavate and process 100,000 cubic centimeters (cm^3) samples from RLD-1 intervals 1, 2, and 3 proved prohibitive, so subsequent intervals were excavated in lesser volumes. A 25,000-cm^3 sample was excavated from intervals 4 and 5. A 12,500-cm^3 sample was excavated from interval 6. A 6250-cm^3 sample was excavated from interval 7 and 1576-cm^3 samples were excavated from intervals 8, 9, and 10 (Figure 3-13). RLD-2 was excavated in 5000-cm^3 samples from each successive interval. RLD-2 samples were floated, sifted, and dried in the manner described for RLD-1.

Total root biomass data from RLD-1 and RLD-2 are summarized in Table 3-1. Approximately 90% of the root biomass occurs within 50 cm of the surface and approximately 98% of the root biomass occurs within 80 cm of the surface.

Because the greatest concentration of roots for the most common perennial species within the study area are found between 0 and 80 cm of the soil profile, total root biomass from RLD-1 and RLD-2 is normalized for biomass measured between 0 and 80 cm. Normalized biomass data for RLD-1 and RLD-2 are summarized in Tables 3-2 and 3-3, respectively.

Assuming that the normalized root biomass is directly related to RLD, RLD can then be related to the depth below the surface (*z)* by the exponential equation

$$\text{RLD} = ae^{-bz} + c \tag{3.1}$$

where *a*, *b*, and *c* are coefficients that optimize the fit to the normalized root biomass data (Fayer 2000).

Normalized root biomass of RLD-1 and RLD-2 is shown related to Equation (3.1) in Figures 3-14 and 3-15, respectively. The root biomass data for RLD-1 and RLD-2 were fitted using the Levenberg-Marquardt algorithm for non-linear least squares fit of coefficients. The coefficients *a*, *b*, and *c* for RLD-1 are 0.5079, -0.0764, and 0.044, respectively, with r^2=0.979. The coefficients *a*, *b,* and *c* for RLD-2 are 0.5172, -0.0516, and 0.0032, respectively, with r^2=0.995. Combining the root biomass data for RLD-1 and RLD-2 in Figure 3-16 and again using the Levenberg-Marquardt algorithm for non-linear least squares fit of coefficients yields coefficients a = 0.5090, b = -0.0630, and c = 0.0262 with r^2=0.999. These coefficients optimize the exponential fit to the combined, normalized root biomass data of RLD-1 and RLD-2. The reader should be reminded that this root biomass distribution is representative of black grama due to the homogeneity and dominance of this native plant species within the study area. Over 95% of the root biomass is attributed to black grama. If the species composition within the study area were more diverse, the coefficients would likely differ.

To calculate the root density function (Fayer 2000), the values of RDL are multiplied by their respective root length to obtain the root density function value for each depth. Tables 3-2 and 3-3 contain the root density function values for RLD-1 and RLD-2, respectively, for roots to 80 cm.

3.1.3 Growing Season

The growing season is that period of the year during which the temperature of cultivated vegetation remains sufficiently high to allow plant growth. Growing season is commonly defined as the number of days between the average dates of the last killing frost in spring and the first killing frost of autumn (American Meteorological Society 2000). The U.S. Army Corps of Engineers "Wetlands Delineation Manual" (USACE 1987) formally defines the growing season as "the portion of the year when the soil temperature (measured at 50.8 cm below the surface) is above biological zero (5 degrees Celsius [°C] [41ºF])." This period is approximated by the number of frost-free days.

The growing season for Albuquerque was calculated based on weather data from the Albuquerque International Sunport, which lies at roughly the same elevation as the study area (1615 m vs. 1637 m [5300 ft vs. 5370 ft]). The Sunport is approximately 7 miles northwest of the study area. The Sunport weather station is a valuable source of data, as weather data has been recorded at this location since 1931. Based on the temperature record from August 1939 though December 1970, the Bernalillo County Natural Resource Conservation Service Soil Survey (USDA SCS 1977) estimated Albuquerque's growing season to be 196 days, with the average date of the last killing frost on April 16 and the first killing frost of autumn on October 29. Other estimates of Albuquerque's growing season range from 188 to 204 days.

Albuquerque's growing season varies spatially across the Albuquerque Basin (National Weather Service 2003). The growing season is shortest in the Rio Grande valley, where cool air drainage creates early freezes in the autumn and spring, and in the foothills of the Sandia Mountains, above 1829 m (6000 ft) in elevation. The growing season for the intermediary bajada, which includes the Albuquerque Sunport, KAFB, and SNL/NM, is longer in duration, as air temperatures are typically 5ºF higher than in the Rio Grande valley.

In addition, climatic evidence suggests that Albuquerque's growing season may be increasing over time. Weather data from the Albuquerque Sunport from 1931 through 1990 show an average growing season of 188 days. However, from 1991 through 2001 the average growing season has increased to 204 days (National Weather Service 2003). It is not clear whether this reflects a short-term trend or long-term climatic changes for the region. Nevertheless, it is believed that the NRCS estimate of 196 frost-free days is still a reasonable approximation of the growing season for the study area.

3.1.4 Leaf Area Index

LAI is broadly defined as the amount of leaf area in a vegetation canopy per unit land area. LAI is a key structural characteristic of vegetation and land cover because of the role of green leaves in a wide range of biological and physical processes. In the simplest terms, LAI can be described as the functional leaf area of a canopy standing above a defined ground area. LAI may be described as

$$\mathrm{LAI} = \frac{s}{G} \tag{3.2}$$

where *s* is the functional (green) leaf area of the canopy standing on the ground area, *G*. Because *s* and *G* are normally measured as areas square meters (m^2), LAI is dimensionless, although LAI is sometimes presented in units of m^2/m^2 (Scurlock et al. 2001).

Few comprehensive reviews of LAI data exist in the literature. Scurlock et al. (2001) provide the most recent LAI data for biomes from 1000 published estimates of LAI from nearly 400 unique field sites covering the period 1932 to 2000. The maximum and minimum LAI values for a desert biome are 2.84 and 0.59, respectively, with a mean of 1.31 and a standard deviation of 0.85.

Without directly measured LAI data, the literature was consulted on prior studies of LAI in desert biomes. Scurlock et al. (2001) present LAI data from two unique desert biomes in New Mexico, both of which are geographically close to and biologically similar to the TA-3 study area. The closest of these biomes is Sevilletta Wildlife Refuge, located approximately 45 miles south of TA-3. Much of the habitat of Sevilletta Wildlife Refuge is a mixture of scrubland and desert grassland. The desert grassland biomes of Sevilleta are very similar to those of TA-3. Scurlock et al. (2001) report an LAI range of 0.8 to 1.90 for Sevilleta. The second biome in New

Mexico occurs at the Jornada Research Station located approximately 35 miles north of Las Cruces, New Mexico. The Jornada Research Station is a large area composed of a mixture of Plains Mesa Sand Scrub, Closed Basin Scrub, and Desert Grassland (Dick-Peddie 1993). Dick-Peddie (1993) and Scurlock et al. (2001) report an LAI range of 0.8 to 3.90. In both of these New Mexico biomes, a minimum LAI value of 0.8 is reported.

3.1.4.1 Factors Affecting Leaf Area Index

Growth of the dominant species within the study area is seasonal, and to a large degree, depends on the availability of water. New Mexico experienced severe drought in 2003. As a result, during the 2003 growing season, there was little growth among the dominant perennial grasses in the study area and much of the vegetation was dormant. There was virtually no rainfall to stimulate growth until the arrival of the (very limited) monsoons late in the summer. Even then, only a few sprouts developed, leaving most perennial grasses dormant. Most of the leaves from prior years had been shredded or destroyed from wind action during the previous winter. Thus, there was little or no leaf area to measure during the 2003 growing season.

Many types of vegetation react to stress in the environment by producing canopies with lower than average leaf area. Thus, the leaf area of a particular biome, compared with typical values for such a biome, may serve as an indicator of stress, such as drought, nutrient deficiency, excessive heat or cold, and disease (Scurlock et al. 2001).

At any given time, LAI is a measure of the functional photosynthetic area of the leaves. As the growing progresses through the year, the size and abundance of leaves on any particular plant varies. As a result, LAI is not constant during the year, but varies throughout the growing season. LAI also varies from year to year depending upon annual climatic conditions. When the vegetative community is stressed, such as during the current drought, LAI is lower than when plants are thriving.

3.1.4.2 Growth Characteristics of Dominant Species

In order to address the effects of stress on the dominant species within the study area, an analysis of the growth characteristics of these species was conducted. These species include black grama, threadleaf snakeweed, galleta grass, and spike dropseed. These data were obtained from the USDA Forest Service Fire Effects Information Database (2003), from information provided by Reggie Fletcher, U.S. Forest Service Regional Ecologist (retired) (2003) and Paul J. Knight, Ecologist, Marron and Associates, Inc. (Knight and Ashton 2003).

Black Grama. Black grama, although a grass, almost behaves like a small shrub in that it maintains a large amount of standing living biomass throughout the year. The growth of black grama has been found to correspond with season and amount of precipitation. Paulson et al. (1962) found that precipitation received between July and September is more important than total annual precipitation, as most of the foliar growth occurs in the summer. The stems of black grama, which remain green throughout the year (Brown 1982, Brown et al. 1985), are maintained with carbohydrate reserves stored in the stem, root, and root crown (Herbel et al. 1969). The plants may be dormant for long periods of time during drought, but rapid development and growth occur under periods of relatively abundant moisture and warm nighttime temperatures (Canfield 1934).

Black grama may maintain green stems even in the winter months. However, it is unlikely that these stems would function below biological zero. Depending on available moisture, the standing biomass of black grama can rapidly turn green in the spring. Fletcher (2003) estimates that during a normal spring, the standing biomass of black grama available from past year growth can reach perhaps 70% of its total expected LAI for the year soon after the onset of the growing season in the spring. According to Fletcher (2003), the full potential for growth and leaf area on this species generally occurs immediately after the onset of the summer monsoon season.

Nelson (1934) found that in arid areas of southern New Mexico, the start of the growing season for black grama corresponds with the onset of the summer rainy period (usually in early July through August). Depending upon the availability of moisture, this growth can continue until the end of September or October. With the end of the growing season, the plants enter into a period of dormancy. Nelson (1934) reports that if fall, spring, and winter precipitation is high and if temperatures are not too low, the onset of new growth of leaves may start as early as March or April, and with continued moisture, growth may extend well into the summer growing period.

Threadleaf Snakeweed. Threadleaf snakeweed, like black grama, can retain green leaves throughout the winter in some areas of New Mexico. Comstock et al. (1988) reports that new terminal growth begins on basal stems from January through March. This growth continues through the spring, and depending upon available moisture, can continue into the summer. Flowering occurs in the spring and early summer. Fletcher (2003) estimates that the plants are probably at about 70% of their full LAI potential in the spring, and probably reach 100% of their LAI potential during the summer rainy season in July and August.

Galleta Grass. West et al. (1972) report that the availability of moisture is the limiting factor for vegetative growth in galleta grass and growth corresponds to periods of available moisture. Goodrich (1986) reports that the most common growing season for galleta grass is May to September. Fletcher (2003) notes that this species is completely dormant throughout the winter, but if there is sufficient moisture at the onset of the growing season, it can rapidly begin leaf development. Within the Albuquerque area, Fletcher (2003) reports occasional periods of dormancy in late June through July. With the onset of the summer rainy season, the plants green up to full LAI. Fletcher believes that by the end of the growing season, the functional LAI for this species drops to zero.

Spike Dropseed. Fletcher (2003) reports that the seasonal growth and development of spike dropseed is much like that of galleta grass. This species is generally completely dormant in winter, and depending on available moisture, can have an immediate response in the spring with rapid growth. During prolonged dry periods, moisture during the early growing season may be spotty, and as a result, spike dropseed will remain dormant (much like galleta grass). Fletcher (2003) estimates that during most years from May through July, this species may reach only 10% to 20% of its LAI. However, with the onset of the summer rains in late July and August, rapid growth occurs. Fletcher (2003) estimates that during normal precipitation years, the full LAI potential of this species is reached by August and continues into October.

3.1.4.3 Leaf Area Index and Growing Season Summary

The LAI of dominant and subdominant native plant species in the study area varies seasonally, reflecting complex interactions between the annual wet and dry cycles, and the ecological growth strategies for each species. Although LAI may vary significantly on a short-term basis among these species, there are predictable seasonal trends in growth and development among the species found in the study area (USDA Forest Service 2003).

Although evaporation from the soil continues year round, plants and transpiration are active only during the growing season of the established plant community. Within a single growing season, different species initiate and achieve peak growth at different times, depending on seasonal variation in precipitation, wind, atmospheric pressure, and temperature. The growing season begins when air and soil temperatures are high enough to allow plant growth, and ends when day length and temperature decrease below a metabolic threshold for vegetation.

The growing season and corresponding LAI data for the study area are summarized in Table 3-4 and shown in Figure 3-17. Growing season data were obtained from the plant species databases of the USDA Forest Service Fire Effects Information Database (USDA Forest Service 2003), Reggie Fletcher (U.S. Forest Service Regional Ecologist [retired] 2003), and Paul J. Knight and Tom S. Ashton (Marron and Associates, Inc. 2003). The LAI data were obtained from Scurlock et al. (2001) and Lewis P. Munk (2004).

3.1.5 Ground Cover

Ground cover, which may consist of live and dead plant material, rock, litter, and debris (ITRC 2003), was evaluated to determine PBA. Two methods were used to measure ground cover within the study area. The first method involved the use of linear transects and the second method involved the use of aerial digital photography. When comparing the two methods, the linear transect method provided the most accurate estimate of foliar coverage because foliar cover area was visually recorded by means of a tape measure at the ground surface.

3.1.5.1 Linear Transect Method

The linear transect method is commonly employed by botanists to determine the coverage and frequency distribution of plants and plant communities. In this study, the linear transect method was used to measure foliar coverage in the study area. Ten linear transects, each 50 m in length, were surveyed within the five-acre study area (Figure 3-18). Foliar coverage was measured along the entire 500 m length of linear transects (Figure 3-19).

The results from the linear transect method are shown in Table 3-5. Seventeen species were identified along the transects, with a measured foliar coverage of 22.5%. Perennial species accounted for 19.2%. Black grama represented the most abundant species with an individual coverage of 13.8%. Annual species accounted for only 3.3%.

3.1.5.2 Aerial Digital Photography Method

The second method employed to measure ground coverage utilized aerial digital photography. This method yielded estimates of both foliar coverage and basal coverage (the percent of area comprised by the root crown). Five digital photography surface plots (DP-1 through DP-5), each 4 x 4 m in area, were randomly selected within the five-acre study area (Figure 3-20). The root crowns of perennial grasses and shrubs in each surface plot were outlined with white flour, which was applied using an Irwin straight-line marking chalk bottle (Figure 3-21).

Digital photographs were then taken from 9 m (30 ft) above each surface plot to delineate foliar coverage. The photographs framed the perimeter of each surface plot and clearly identified vegetation in contrast to bare ground. The photographs were imported into Adobe Illustrator 8.0, where the basal coverage (the boundaries of the root crowns) was outlined in red and the foliar coverage was outlined in yellow. The digital images where then transferred to a computer aided design system, where the foliar and basal coverage was digitized and recorded. The digital photographs, with basal coverage delineated in red and foliar coverage delineated in yellow, are shown in Figures 3-22 through 3-26. Figure 3-23 also shows the location of RLD-1 (Section 3.1.2, Figure 3-10). The results from the digital photography method are summarized in Table 3-6.

The total foliar coverage of the five plots was estimated to be 22.5% by the linear transect method and 26.1% by the digital photography method. The foliar coverage estimate from the digital photography method (26.1%) is higher than the foliar coverage estimate from the linear transect method (22.5%) (Table 3-5). This higher foliar coverage estimate is believed to be due to shadows and pockets of plant litter which could not be distinguished from standing vegetation on the digital images. For this reason, the linear transect method is considered more accurate than the digital photography method.

Basal coverage is often much more difficult to obtain than foliar coverage, particularly within grassland communities. However, the severe drought conditions simplified the collection of basal coverage data, as small clumps of bunch grass had succumbed to the drought, leaving behind well-defined clumps of grass. In addition, the drought and action of the wind had reduced much of the standing foliar cover, so that in many cases, the root crowns of the grass clumps were either directly visible or only partially covered by standing vegetation.

3.1.5.3 Percent Bare Area

PBA was calculated using foliar coverage data (Table 3-5) from the more accurate linear transect method. Assuming a total foliar coverage of 22.5%, the PBA was calculated as:

PBA = (100% – % total foliar coverage)
PBA = 77.5%

The 2003 growing season during which these foliar coverage data were collected represented severe drought conditions, with stressed plant communities. As a result, the drought inevitably reduced the plant coverage in the study area, resulting in high estimate for the PBA.

During normal climatic conditions, PBA may be significantly lower in the study area. The estimated PBA of 77.5% is thus considered conservative, resulting in higher estimates of percolation through a cover than might occur under normal climatic conditions when higher levels of standing biomass and greater ground cover might be expected.

4. Recommended Species for Vegetative Soil Covers

Plants play a major role in the design of a vegetative soil covers. Plants promote sustainability, minimize maintenance of the cover, and utilize transpiration to move water from the root zone to the atmosphere. One of the overall objectives of this study was to recommend appropriate plant species for vegetative soil covers at SNL/NM and KAFB.

4.1 Plant Considerations

Plant species selected for vegetative soil covers will depend on a number of factors, including soil characteristics, climate, dominant species in the area, rooting depths and cover thickness. The mix of species should maximize the days of growth and the amount of transpiration by plants, and should include a combination of warm-weather and cold-weather species. Other factors which may also influence selection include landfill type and the long-term land use for the site.

Species diversity of the selected plant mix is important for the long-term performance of the vegetative soil cover. Species diversity helps reduce susceptibility of the plant community to disease or blights, and better emulates the natural, climax ecosystem by encouraging wider environmental diversity within the restored habitat. By including a variety of warm-weather and cold-weather plants in the species mix, one can ensure that the plants will continue to grow and promote transpiration throughout the year (ITRC 2003).

Although transpiration will occur once the plants on the vegetative soil cover begin to grow and develop, maximum transpiration will occur only after a climax plant community has been established. A climax plant community within the grassland habitat found in the study area may take up to five years or more to develop.

An inventory of plant species in less-disturbed areas can provide an initial list of species for consideration in seed mixes for vegetative covers. Relict or undisturbed areas can be useful for determining common native plant species adapted to the area. Species easily established and very competitive with other species should be included in the mix at a lesser percentage than less-easily established types. A mixture of bunch grasses and rhizomatous species may be desirable for optimum soil stabilization, particularly where water erosion is a problem (ITRC 2003).

The Technical and Regulatory Guidance for Design, Installation, and Monitoring of Alternative Final Landfill Covers (ITRC 2003) also suggests conducting a soils mapping program as part of the cover design effort. Once soils have been identified, ITRC (2003) recommends consulting local experts to determine appropriate plant species for each soil type. Plant species should be matched to the soil type planned for the cover.

In some situations, ITRC (2003) recommends conducting a “seeding trial” for vegetative soil covers, whereby a plot is seeded using a baseline seed mix of the proposed species. The plot can be monitored for the ease of establishment for individual species, as well as competitiveness between species, persistence of each species, etc. The proposed seed mix can then be modified, additional seeding trials conducted, and the final seed mix formulated.

Root anatomy is a major consideration when selecting plants for vegetative soil covers. Plants with large, deep tap roots are not as desirable as those with shallow, fibrous root systems concentrated in the upper part of the cover (ITRC 2003).

In this study, plants with deep taproots have been identified and recommended for exclusion or removal from vegetative soil covers as part of the long-term monitoring activities. A detailed discussion of the recommend plants for vegetative soil covers at SNL/NM and KAFB is presented below. A discussion of those plants which are not recommended is also presented.

4.2 Vegetation Recommendations

Based on the field survey and coverage data, the dominant species within the study area is black grama. Subdominant species include threadleaf snakeweed, galleta grass, and sand sage, and to a lesser degree, spike dropseed and ring muhly. The native grasses in the study area were found to have relatively shallow roots e.g., most less than 100 cm. Of the grasses, black grama had the deepest roots, with fine roots observed 1.3 m below the surface. None of the grasses studied in the area are likely to have roots extending deeper than 1.5 m.

4.2.1 Species Recommended for Vegetative Soil Covers

Based on the root depths of the plants studied and the climax community for the study area, five native plant species are recommended for vegetative soil covers at SNL/NM and KAFB. Four of these species, black grama, galleta, spike dropseed, and ring muhly, grow in soils in the study area. Of these four species, spike dropseed and ring muhly are only minor components of the plant community. One additional species, sand dropseed, grows abundantly in other parts of TA-3, but was not found within the study area. Because sand dropseed is ecologically very similar to spike dropseed (with similar rooting depths and soil requirements), sand dropseed is also recommend for vegetative soil covers at SNL/NM and KAFB.

4.2.2 Species Not Recommended for Vegetative Soil Covers

Several shrubs in the study area showed the potential for deep roots under certain conditions and are not recommended for planting on vegetative soil covers. These shrubs include sand sage, threadleaf snakeweed, and fourwing saltbrush.

Sand sage was observed to have a pronounced tap root, extending to depths of 1.5 m below the surface. Secondary roots from this species may extend to depths of 2 m or deeper.

Similarly, threadleaf snakeweed also showed pronounced tap roots, extending vertically to depths of 40 to 60 cm, before branching into secondary roots extending another 20 to 30 cm. Fletcher (2003) observed threadleaf snakeweed roots extending to depths of 1.8 to 2.4 m in sandy soils.

Fourwing saltbush was observed to have a deep taproot, extending to an estimated depth of 2.7 m, with secondary roots extending even deeper. Earlier studies confirm the deep rooting system of fourwing saltbush. Nord (1971) observed a fourwing saltbush only 1.07 m tall with a root system extending 2 m below ground, and 3 m laterally. Dayton (1931) observed fourwing saltbush plants with root systems nearly 6 m below the surface. Thus, data from this study and earlier studies suggest that fourwing saltbush is not favorable for vegetative soil covers.

4.3 Species Ecology and Planting Requirements

The following is a general discussion of the species ecology, habitat requirements, seed availability and planting criteria for each of the recommended species.

4.3.1 Black Grama—Species Ecology and Habitat

Much of the north-central portion of TA-3 is dominated by black grama grassland. Black grama is a long-lived native perennial with wiry, spreading stems reaching upwards of 60 cm in length. The crown foliage of this species is compact, and produces dense ground shade. Once established, black grama is tolerant of short droughts. Under prolonged periods of drought, its tufts dry out from the center, eventually breaking into smaller tufts. With the return of moisture and new growth, these tufts often coalesce (USDA Forest Service 2003, Nelson 1934).

Black grama reproduces principally asexually through tillering and stoloniferous expansion. The parent plants provide support to new plants during their establishment. The use of stoloniferous expansion as a reproductive method increases black grama coverage slowly. At least a year of growth is required for the production of stolons. Under favorable conditions, the stolons will develop roots on the following year. Black grama stolons develop roots most successfully in a surface soil consisting of loose sand that is high in organic matter (USDA Forest Service 2003, Canfield 1948). Once established, black grama plants may survive several decades through stoloniferous reproduction (USDA Forest Service 2003, Bridges 1941).

4.3.2 Black Grama—Planting Requirements and Availability

Black grama does not seed well naturally because the majority of spikelets produce sterile florets (USDA Forest Service 2003, Jackson 1928). However, the Los Lunas, New Mexico, Plant Materials Center has developed black grama seeds that have an 80% germination rate. This seed is available on a limited basis from several commercial suppliers, and approximately 3 pounds per live seed (pls) of black grama per acre is recommended for planting. The Los Lunas, New Mexico, Plant Materials Center suggests that the seed be drilled to a depth of 0.6 to 1.3 cm. They also recommend a mulch rate of 2 tons per acre spread in a single layer (1 comb thick) across the site.

The planting window for black grama is narrow (approximately 3 weeks), occurring July through August, at the onset of the monsoon. The seeds should not be sowed too late into the season or the black grama seedlings may be damaged by frost in the fall.

4.3.3 Black Grama—Soil Criteria

The establishment of suitable soil conditions for black grama is important. Black grama prefers well-drained, sandy and gravelly soils, and is rarely found on clay loams or in argillaceous soils. The upper 30 cm of loamy sand and sandy loam topsoil at the study area are ideal for black grama. If the soil from the study area is utilized for a landfill cover, it is important that during the borrow operation, the soil not be excavated too deeply, causing mixing with underlying soils.

The existing topsoil layer of the study area is of a different texture than the underlying soils. Below about 30 cm, soils within the study area showed a substantial increase in clay content. If the sandy clay loam soils found from 30 to 100 cm below the surface were incorporated into the surface soil layer, less-favorable species such as burro grass (*Scleropogon brevifolius*) would be more likely to establish themselves on the cover, limiting the establishment of favorable species such as spike dropseed and black grama. In addition, the topsoil from the borrow area is likely to contain a variety of micronutrients, organic material and cryptogamic species which may be important components in establishing a natural ecosystem and native plant community.

It is recommended that the topsoil from the borrow area be harvested and stockpiled. The excavated material should be spread across the landfill cover and minimally-compacted to form the top layer of soil for the cover.

4.3.4 Galleta Grass—Species Ecology and Habitat

Galleta is a rhizomatous perennial that often grows in bunches, but under some conditions, can form a sod. According to Hassell and Oaks (USDA Forest Service 2003), galleta may persist for at least 5 to 7 years. Galleta reproduces through seed as well as rhizomes. Galleta may produce seed several times within a growing season, depending upon the frequency and amount of summer precipitation.

Galleta tolerates a wide range of soils. It is well adapted to alkaline soils, and will grow in sandy, loamy, and clay soils (USDA Forest Service 2003). Galleta is often used to stabilize areas vulnerable to surface erosion. It is used for mine reclamation, fire restoration, and on construction projects, as well as for residential lawns. Once established, galleta is extremely drought tolerant, requiring little maintenance (USDA Forest Service 2003).

4.3.5 Galleta Grass—Planting Requirements and Availability

Galleta is readily available from numerous commercial seed companies both in Albuquerque, New Mexico, and in the southwestern United States. The seeding specifications are similar to black grama. The Los Lunas, New Mexico, Plant Materials Center recommends that this species be planted in July through August. It should be drilled from 0.6 to 1.3 cm below the surface and mulched with native grass hay. Recommended seeding rates range from 6 pounds pls of galleta per acre to upwards of 20 pounds pls per acre.

4.3.6 Galleta Grass—Soil Criteria

The soil criteria for galleta are the same as those for black grama. It is recommended that the topsoil from the borrow area be harvested and stockpiled. This material should be spread across the landfill cover and minimally compacted to form the top layer of soil for the cover.

4.3.7 Spike Dropseed and Sand Dropseed—Species Ecology and Habitat

Spike dropseed and sand dropseed are warm-season perennial bunch grasses. These species are generally found in open, sandy areas, and often grow well in areas of surface disturbance. Spike dropseed and sand dropseed flower from June to September. Within the study area, spike dropseed grows in loamy, sandy soils, particularly where the sandy clay loam soil substrate lies 40 cm or more below the surface. Sand dropseed is found in similar soils elsewhere in TA-3.

4.3.8 Spike Dropseed and Sand Dropseed—Planting Requirements and Availability

Spike dropseed has limited availability. It has been produced by the Los Lunas, New Mexico, Plant Materials Center. The Los Lunas Plant Materials Center recommends that spike dropseed be planted in July through August. Approximately 0.5 to 1 pound pls per acre should be drilled from 0.6 to 1.3 cm below the surface and mulched with native grass hay. Spike dropseed tolerates limited soil disturbance better than black grama, and might best be planted along the edges of a vegetative soil cover.

Sand dropseed is widely available from a number of seed sources. The seeding mix and planting methodology would be similar to spike dropseed. If spike dropseed is unavailable, it could be substituted with sand dropseed.

4.3.9 Spike Dropseed and Sand Dropseed—Soil Criteria

Both spike dropseed and sand dropseed prefer deep sandy soils. It is recommended that the topsoil from the borrow area be harvested and stockpiled to provide a suitable soil base for this species. Based on observations from the study area, spike dropseed and sand dropseed will grow best in areas where the vegetative soil cover has a higher percentage of sand, particularly in areas of loamy sand soils.

4.3.10 Ring Muhly—Species Ecology and Habitat

Ring muhly is a low sod grass that tends to grow in rings. As the basal tufts enlarge with growth, the central area of the tuft dies back leaving a ring. This grass often thrives on disturbed soils (Gould 1993). It typically flowers from July to September, during the monsoon season. Ring muhly may not tolerate severe drought as well as black grama, a more drought-tolerant species.

4.3.11 Ring Muhly—Planting Requirements and Availability

There is little information available on planting requirements for ring muhly. Because ring muhly is generally not used for forage, there are no local sources for the seed. As ring muhly is a sod grass, it may be possible to plant plugs of this species cut from plants in the grasslands adjacent to the project area. These plugs could be planted along the periphery of a vegetative soil cover. Ring muhly is only a minor component of the vegetative community within the study area, and may be eliminated from the planting list if it is too laborious to collect plugs or seed for planting.

4.3.12 Ring Muhly—Soil Criteria

Ring muhly prefers sandy loam soils. Within the study area, ring muhly was found in direct association with black grama. The soil requirements for ring muhly are similar to those for black grama and galleta. It is recommended that the topsoil from the borrow area be harvested and stockpiled. This material should be spread across the cover and minimally compacted to form the topsoil layer for the cover.

4.4 General Recommendations for Planting

Based on this vegetation study, five native plant species are identified as appropriate for planting on vegetative soil covers at SNL/NM and KAFB. These species are black grama, galleta grass, spike dropseed, sand dropseed, and ring muhly. This plant assemblage is compatible with soils in the study area and should be compatible with most soils at SNL/NM and KAFB. These plants are well-adapted to the environmental conditions of the study area, with minimal irrigation, maintenance and pest-control requirements, increasing their chances for survival. However, to ensure the highest probability for success, the following recommendations are made for planting:

- Prior to construction, a specialist in arid land restoration should be consulted to finalize the restoration approach for the site.

- Develop and install an irrigation system for the landfill cover. This system will be used to initially establish the vegetation, and may also be effective for sustaining the vegetation during drought conditions.

- If an irrigation system is installed, care should be taken not to over-irrigate the cover. Irrigation should be carefully controlled to simulate natural precipitation, and the water content of the cover soil should be monitored during and after irrigation. Over-irrigation of the cover may result in excess percolation through the cover, and could promote development of deeper root systems extending below the cover and into the underlying soils.

- Enclose the cover with rabbit-proof fencing. The use of irrigation for the cover, and the subsequent development of lush green growth on the topsoil layer will attract small herbivores such as rabbits. Rabbits can do considerable damage to developing vegetation, and should be precluded from the site. This is particularly true during drought conditions when the foliar cover of the surrounding community may be reduced. Consequently, rabbits should be precluded from the entering the area.

- Ensure that seeds planted on the cover are from local sources so that the vegetation is well-adapted to local environmental conditions.

- Ensure that the seed is pure live seed and is certified as weed free.

- Ensure that a complete understanding of the composition of the surface soils is acquired before planting, and that any cap soils placed on the site are conducive to the growth of the desired vegetation on the site. Even micro-variations in the composition of the top 15 cm of the soil can have profound effects upon the species of grasses which are likely to occupy the site. Within the general study area it was noted that a minor shift from a sandy clay loam to a clay loam resulted in the difference between having a dense stand of black grama or a near monospecific stand of burrow grass. Similarly a shift from a sandy clay loam to a sandy loam resulted in dominance of dropseed rather than black grama.

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FIGURES

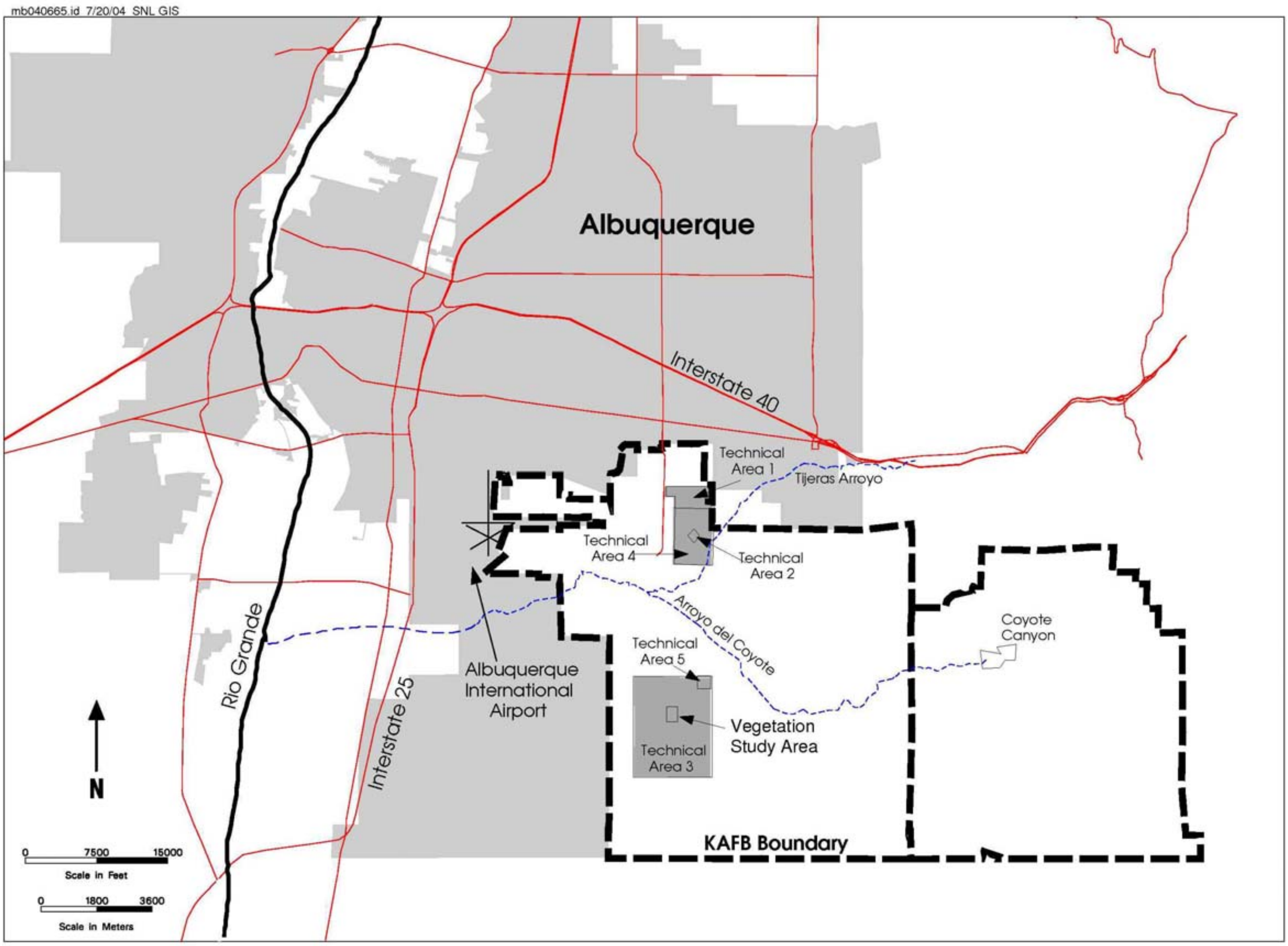

Figure 1-1 Location of Sandia National Laboratories, Kirtland Air Force Base and the Vegetation Study Area

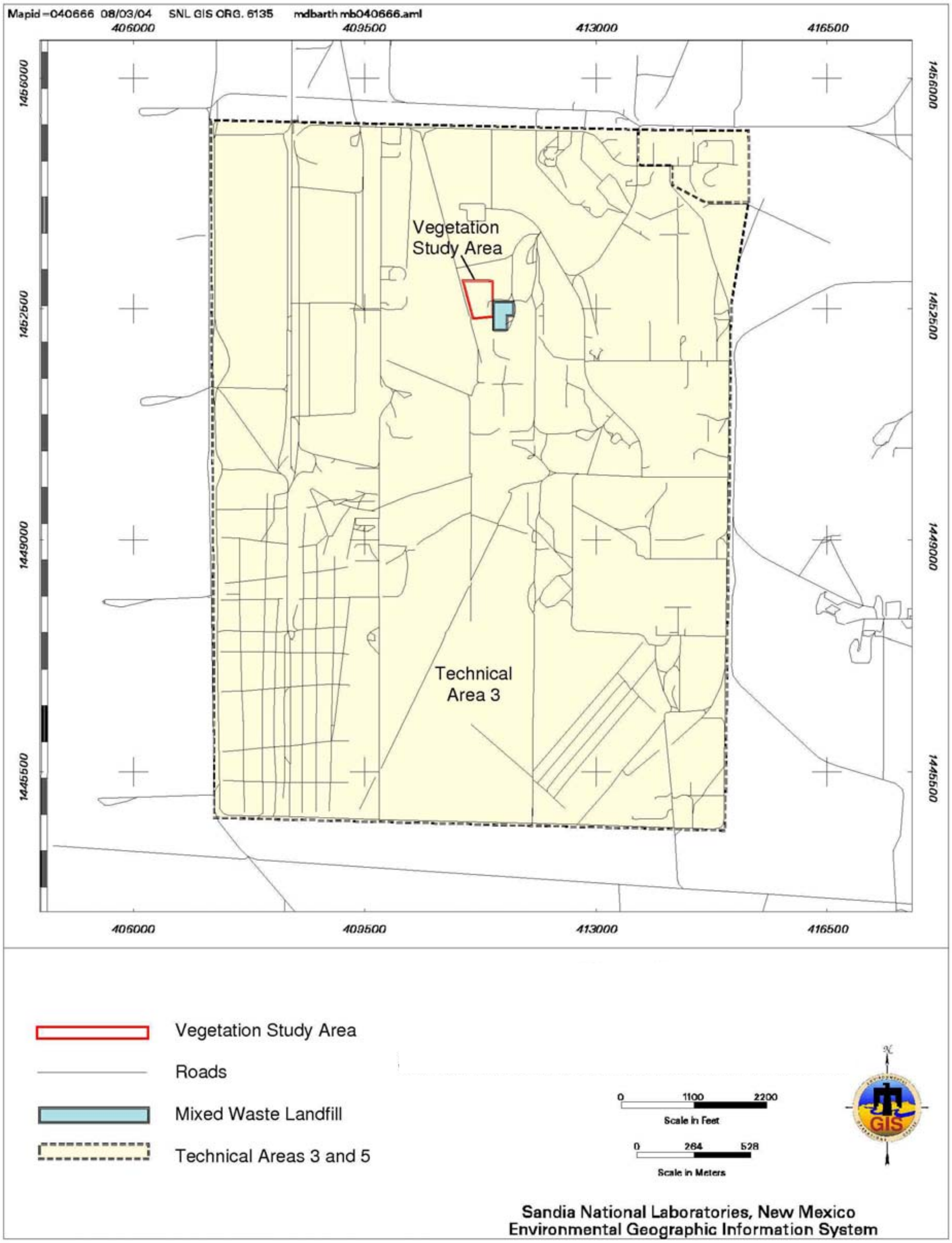

Figure 2-1 Location of the Vegetation Study Area within Technical Area 3 at Sandia National Laboratories

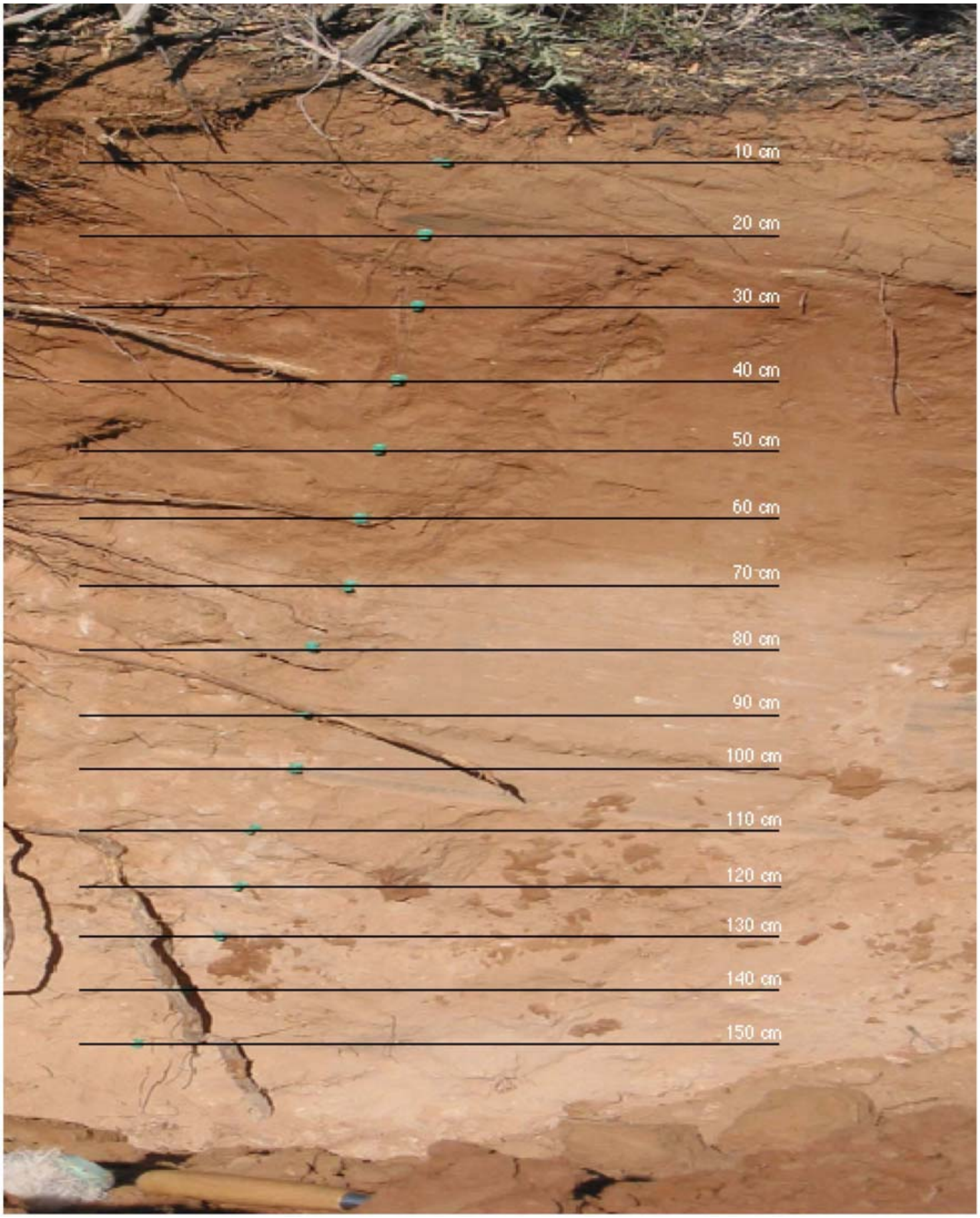

Figure 2-2 Typical Soil Profile

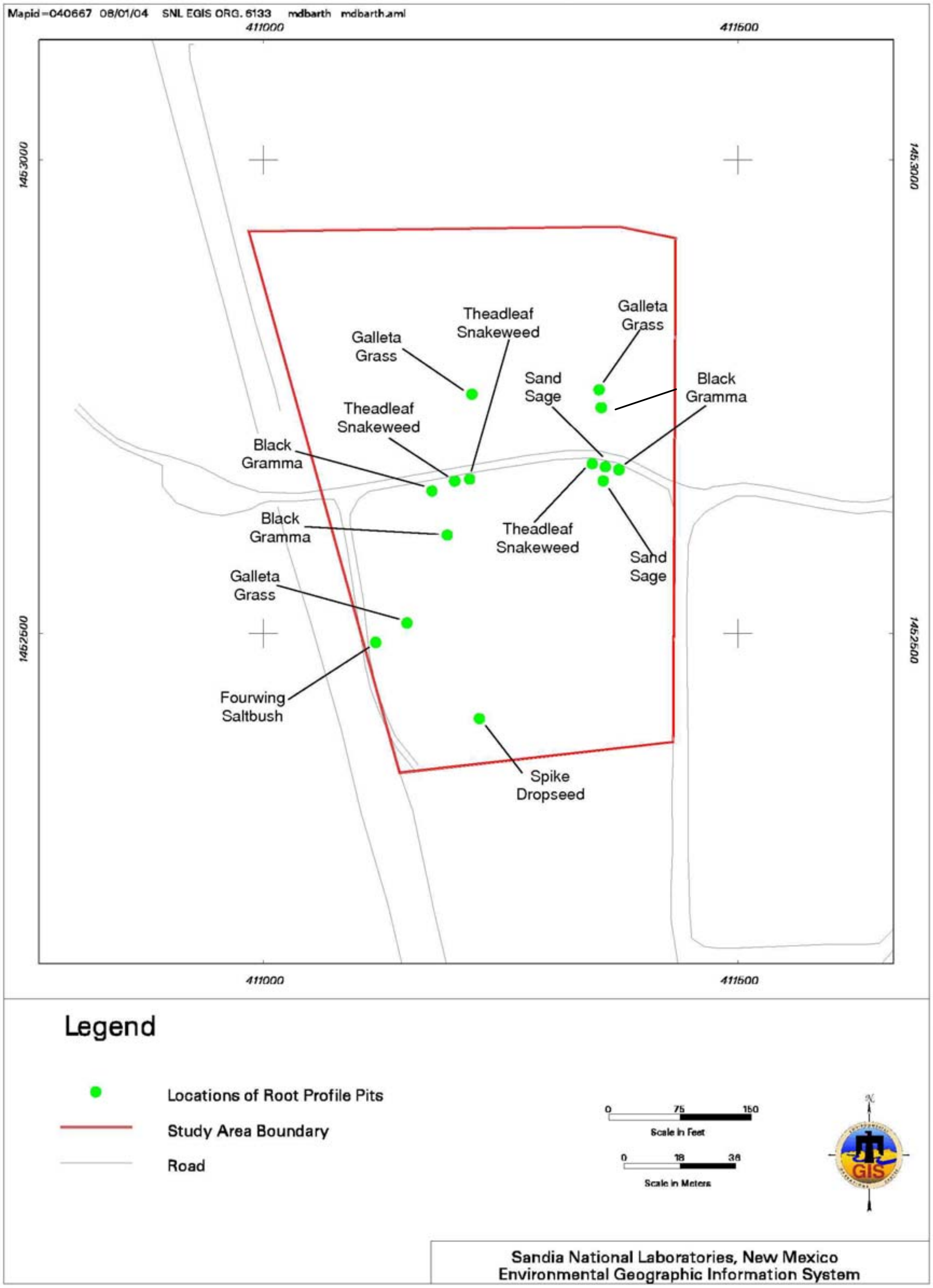

Figure 3-1 Location of Root Profile Pits

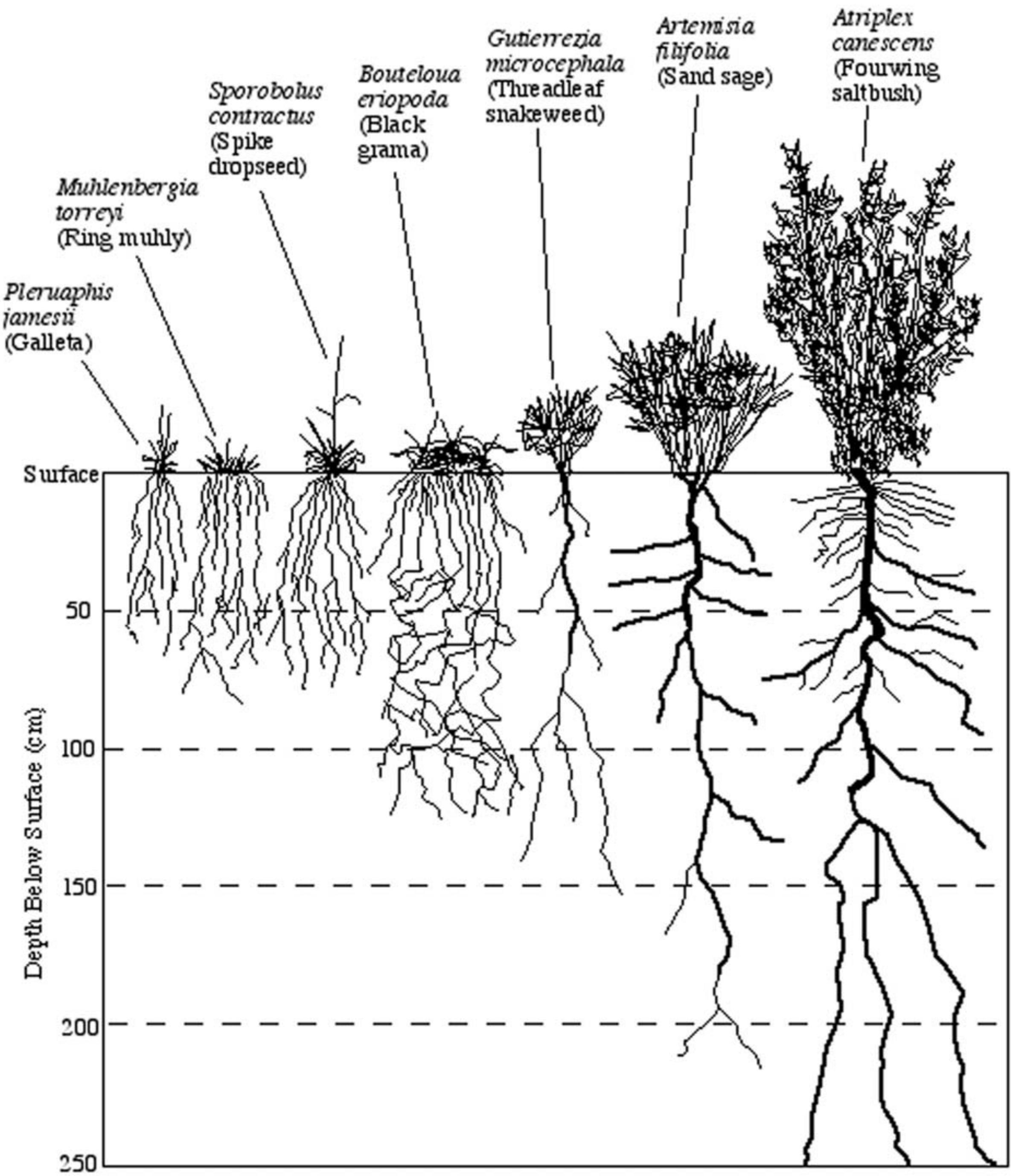

Figure 3-2 General Root Structure and Root Depth of Species Profiled in the Study Area

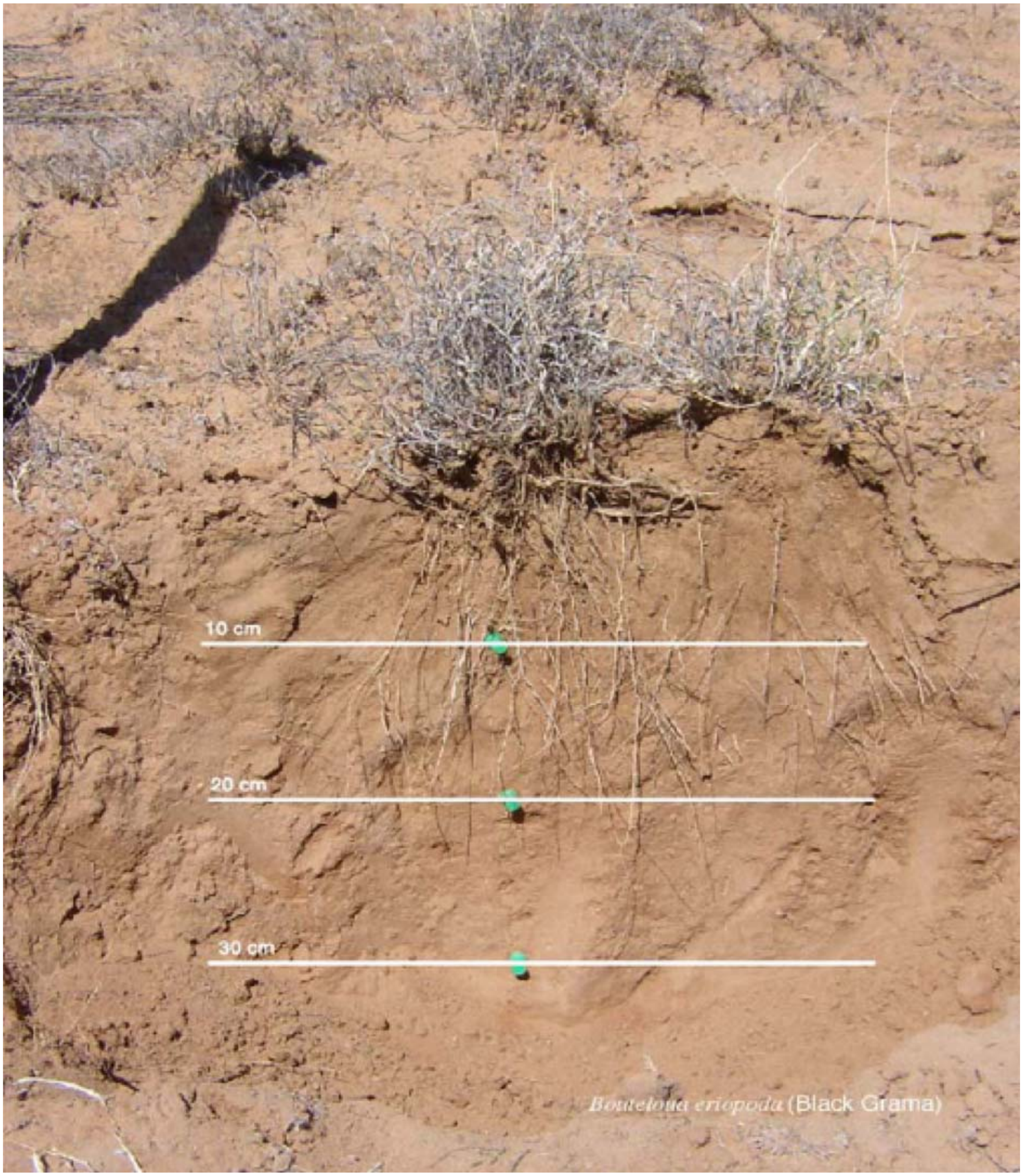

Figure 3-3 Root Depth and Density of Black Grama

Figure 3-4 Root Depth and Density of Threadleaf Snakeweed

Figure 3-5 Root Depth and Density of Galleta Grass

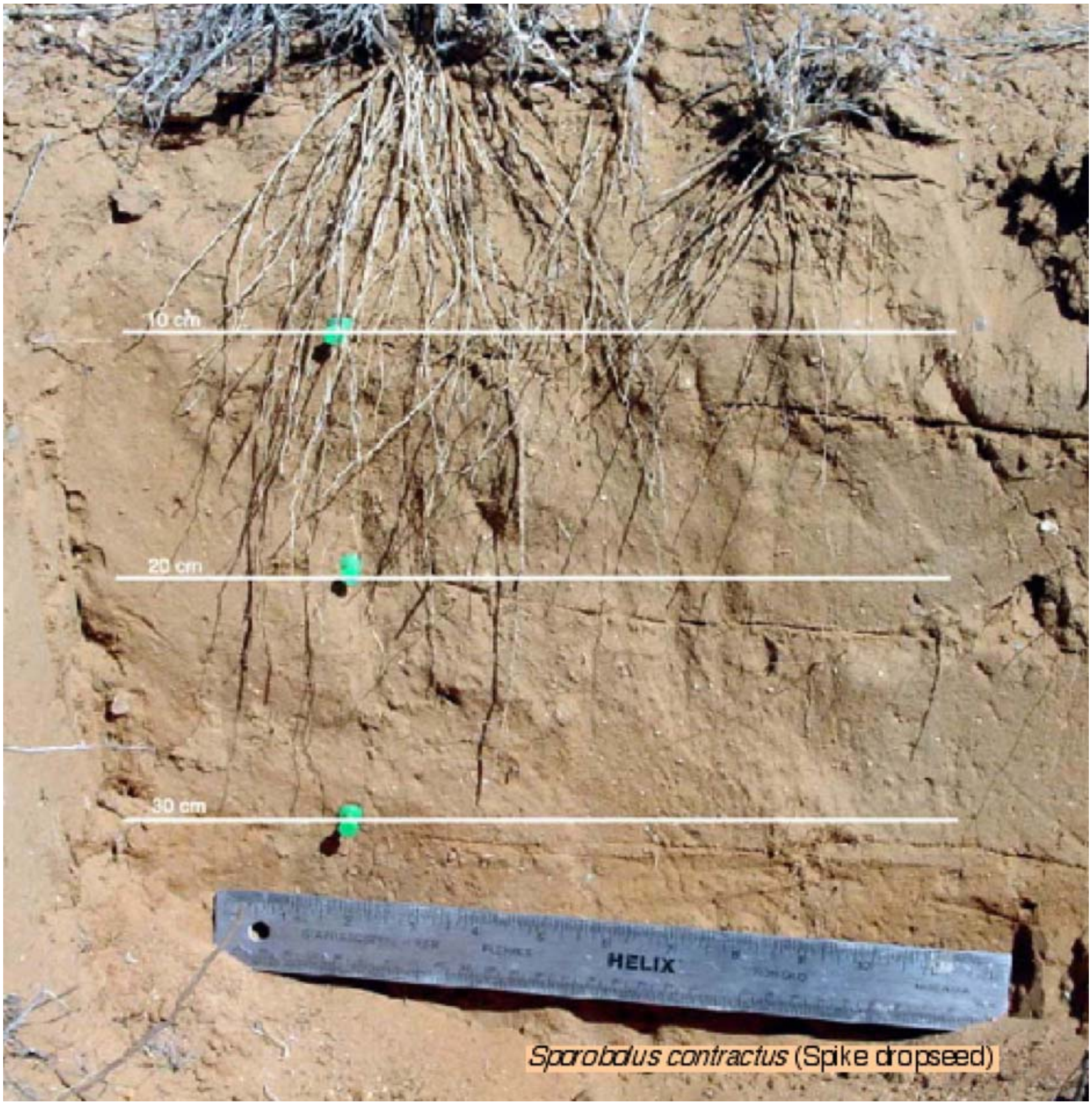

Figure 3-6 Root Depth and Density of Spike Dropseed

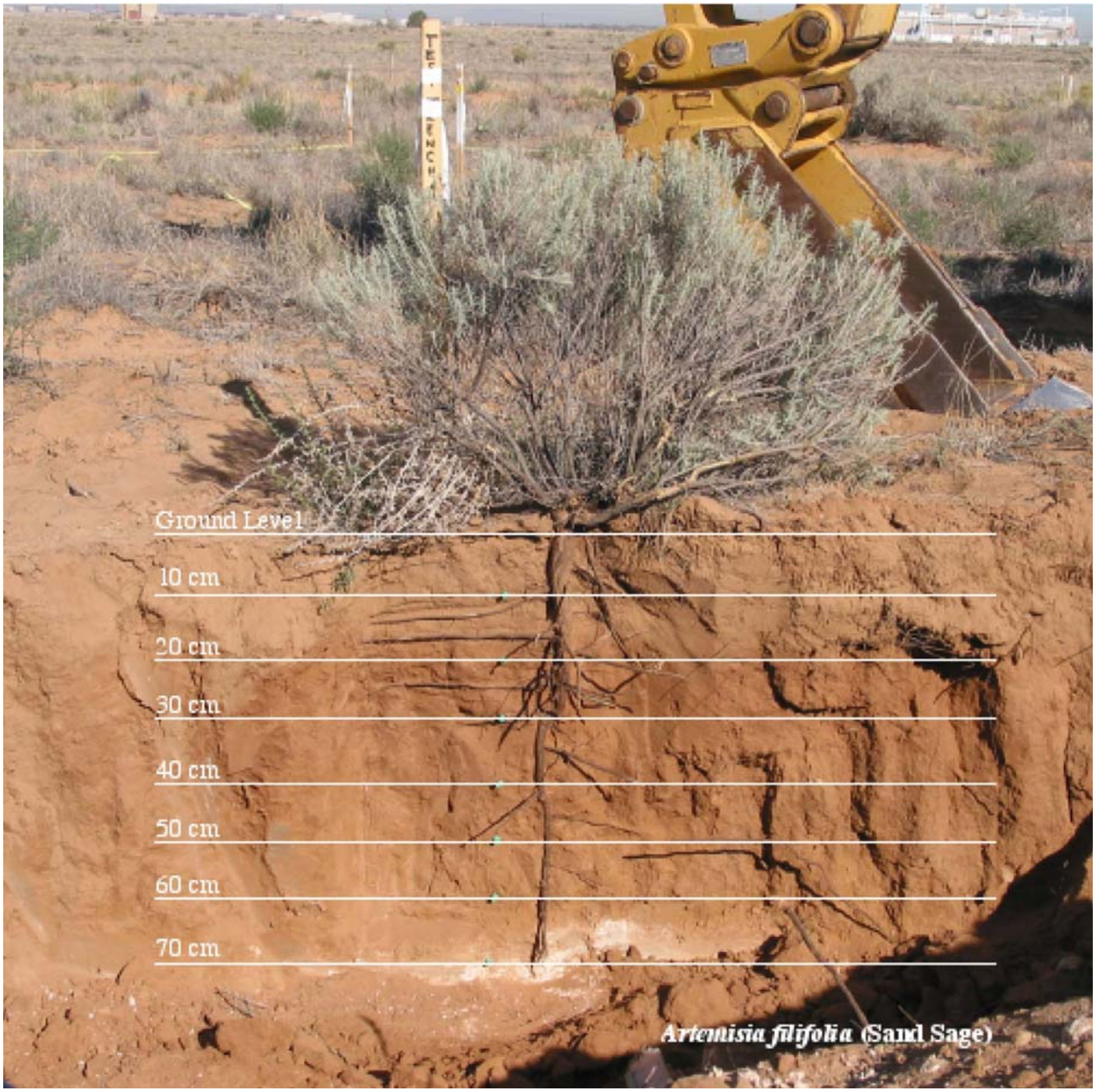

Figure 3-7 Root Depth and Density of Sand Sage

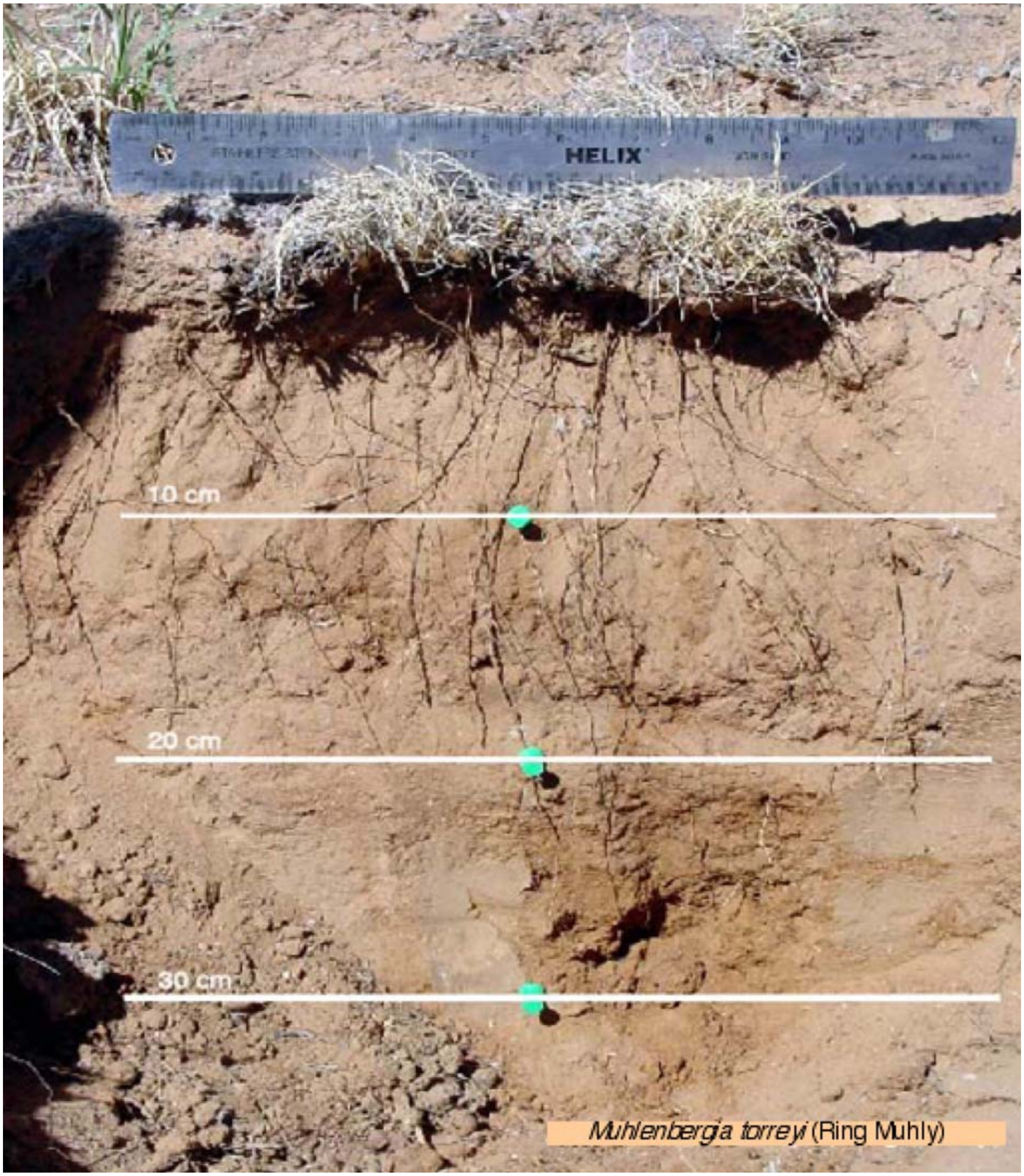

Figure 3-8 Root Depth and Density of Ring Muhly

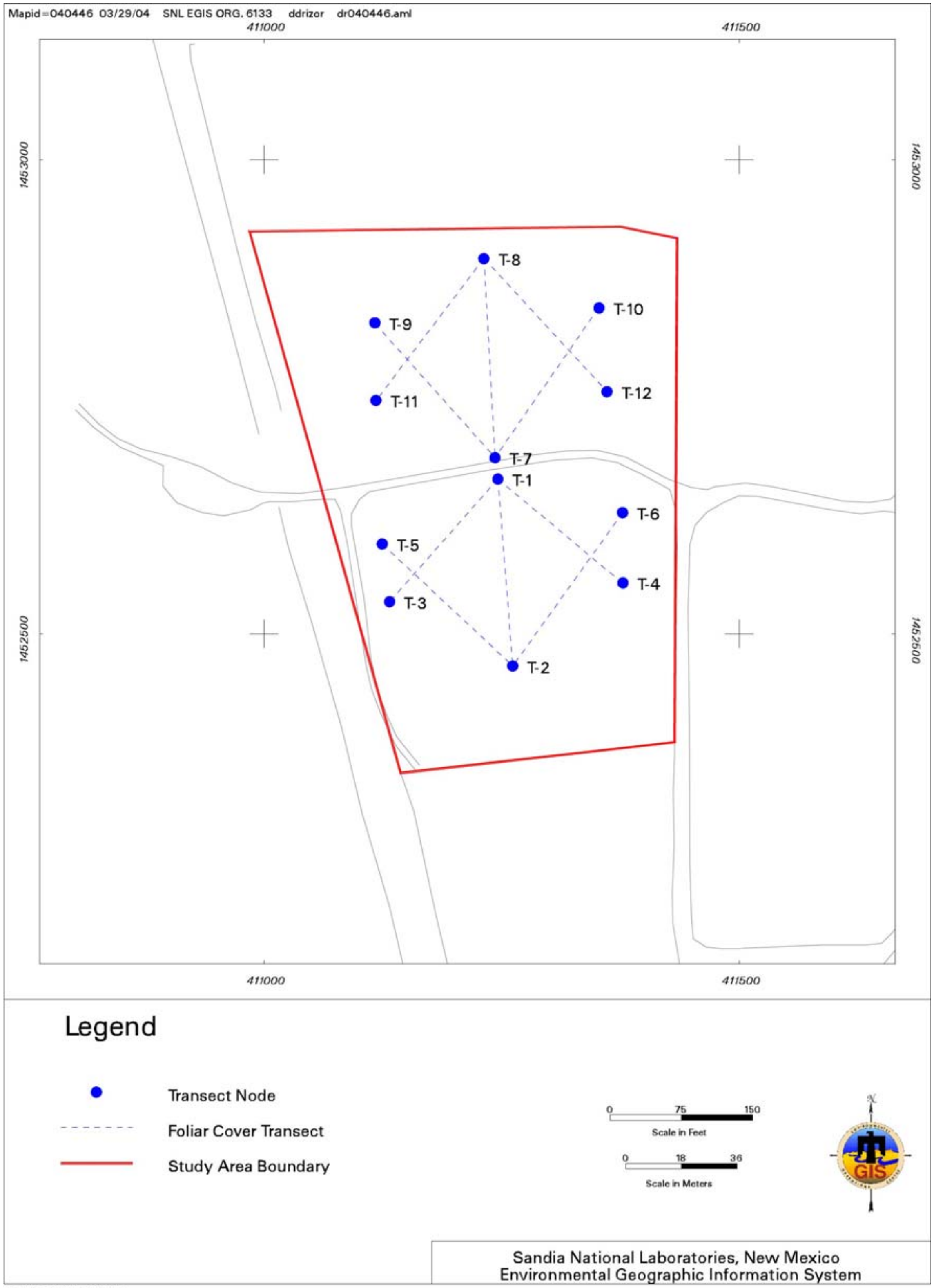

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Figure 3-18 Location of Foliar Cover Linear Transects within the Study Area

Figure 3-19 Measurement of Foliar Coverage Along Linear Transect

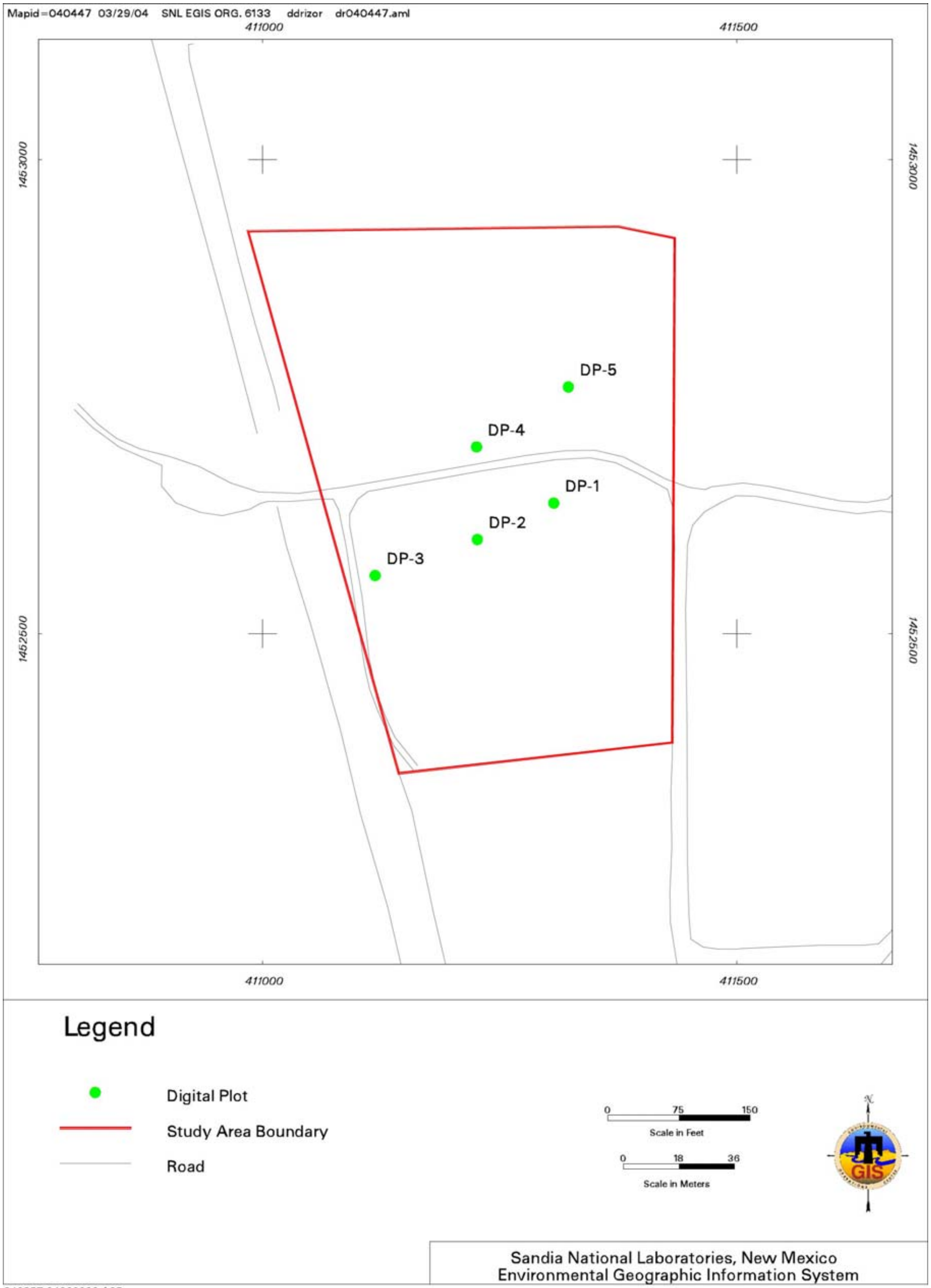

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Figure 3-20 Location of Digital Photograph Surface Plots

Figure 3-21 Outline of Root Crowns Using White Flour and an Irwin-Marking Chalk Bottle

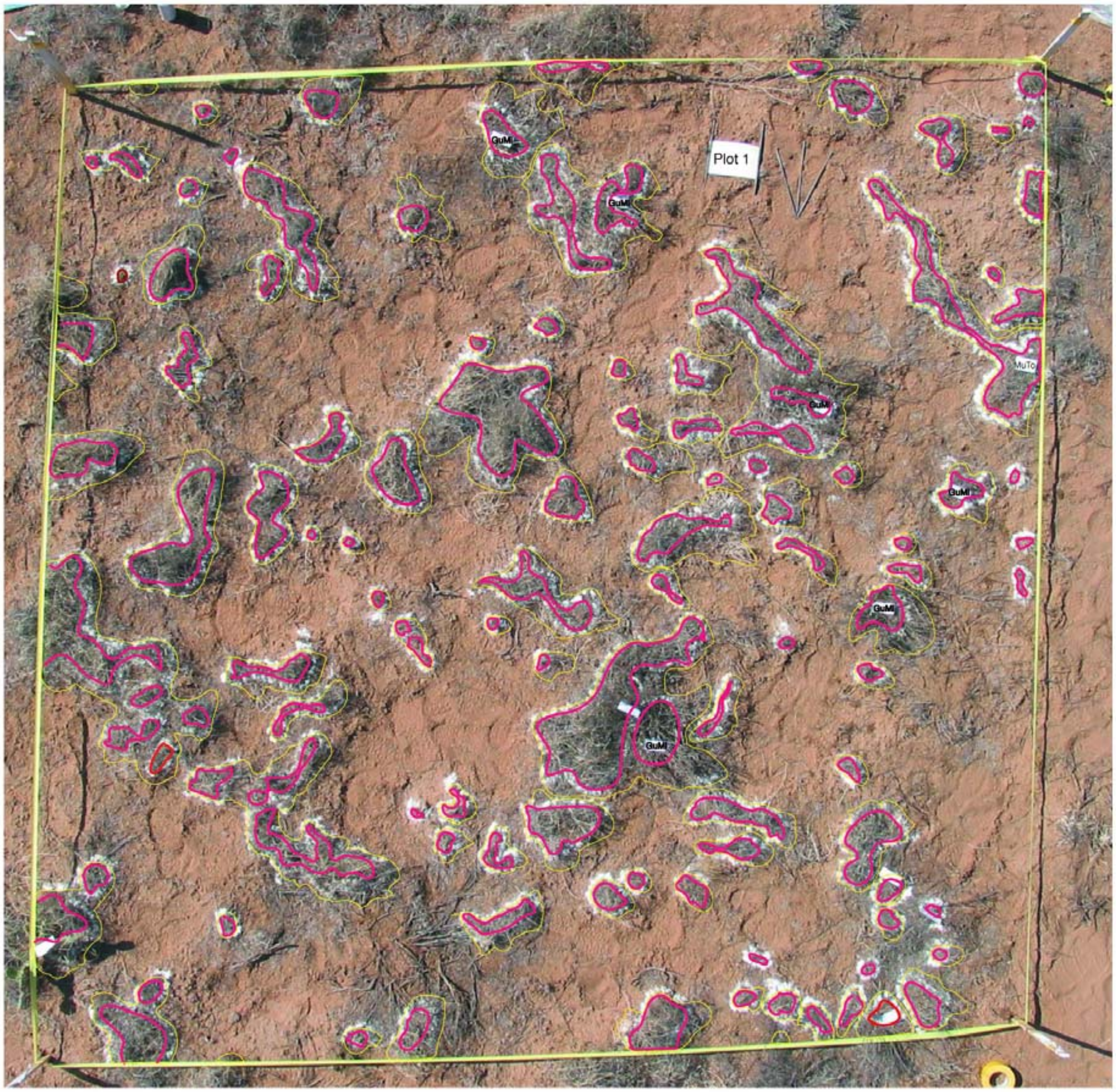

Figure 3-22 Digital Photograph DP-1

Figure 3-23 Digital Photograph DP-2

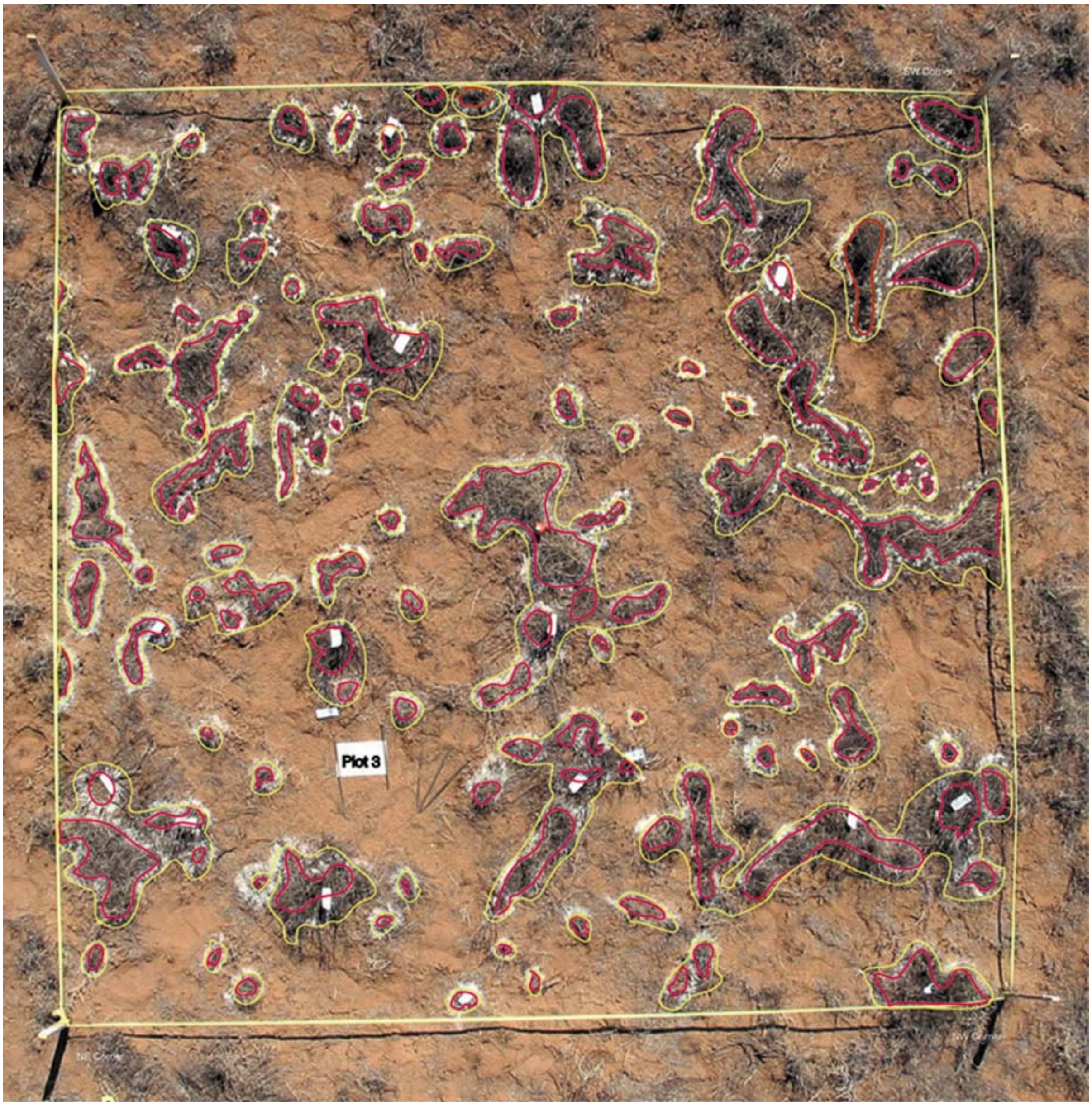

Figure 3-24 Digital Photograph DP-3

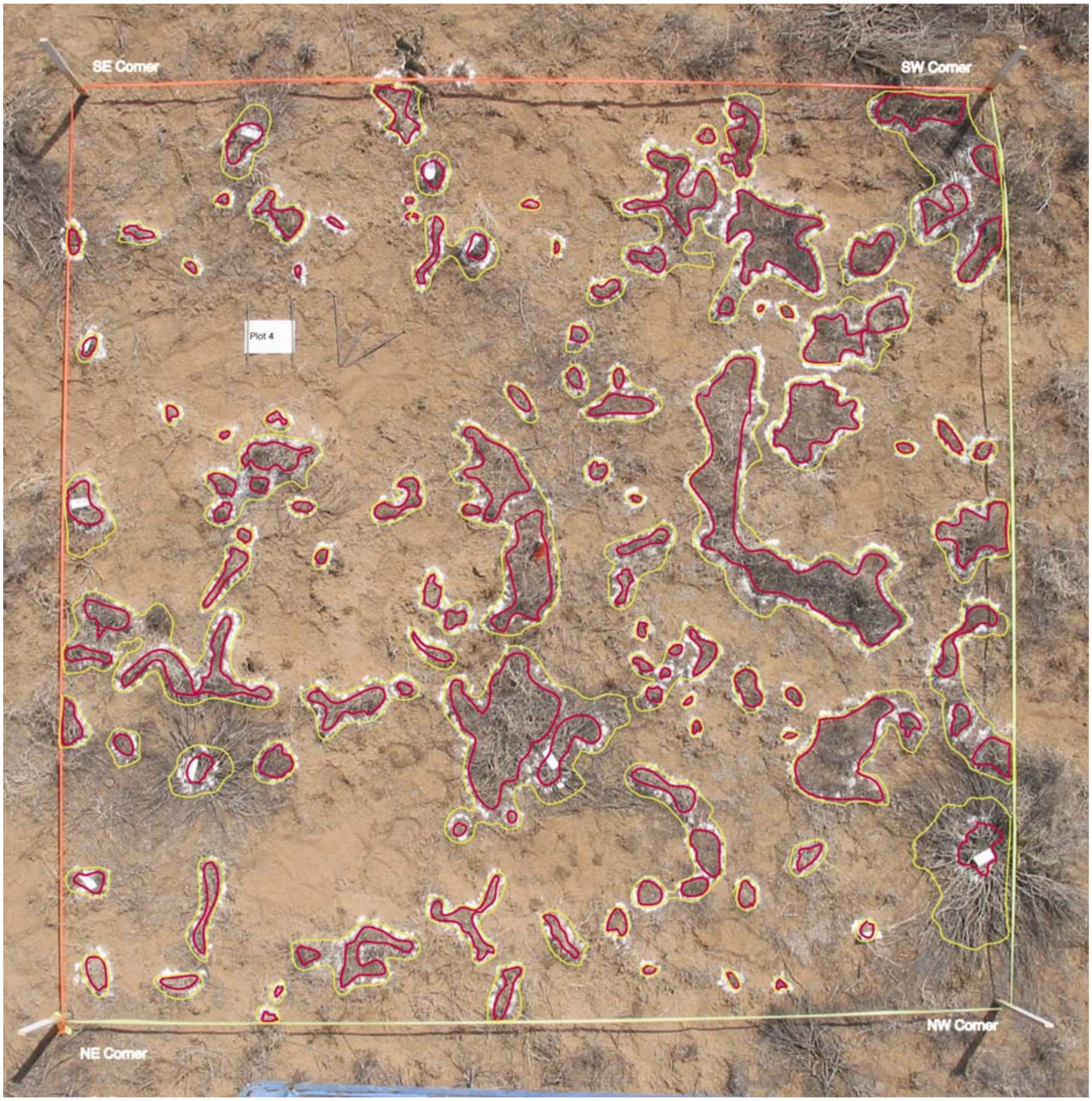

Figure 3-25 Digital Photograph DP-4

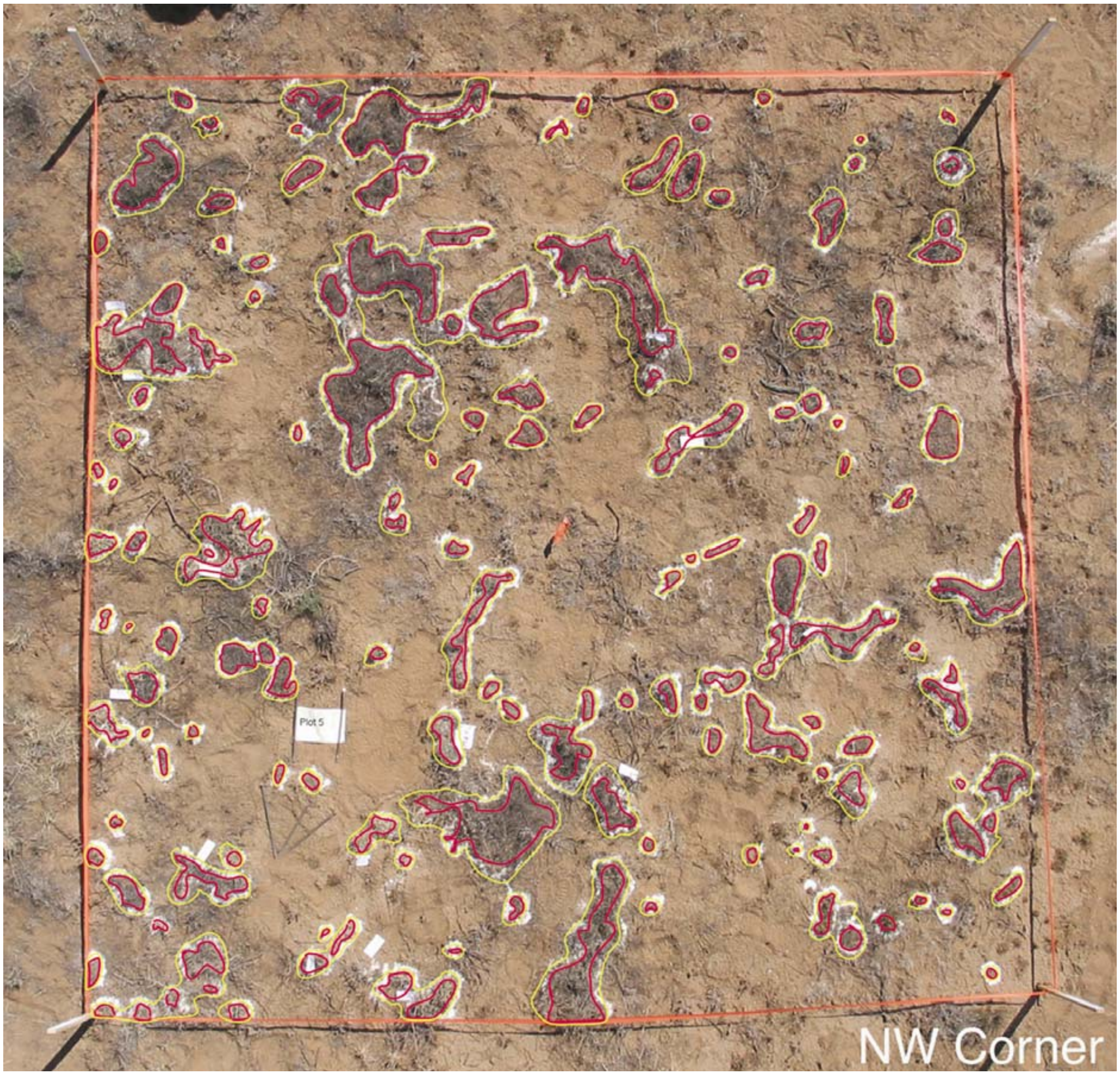

Figure 3-26 Digital Photograph DP-5

Figure 3-9 Root Depth and Density of Fourwing Saltbrush

Figure 3-10 Excavation of RLD-1

Figure 3-11 Sieving of Soils from RLD-1 to Recover Root Biomass

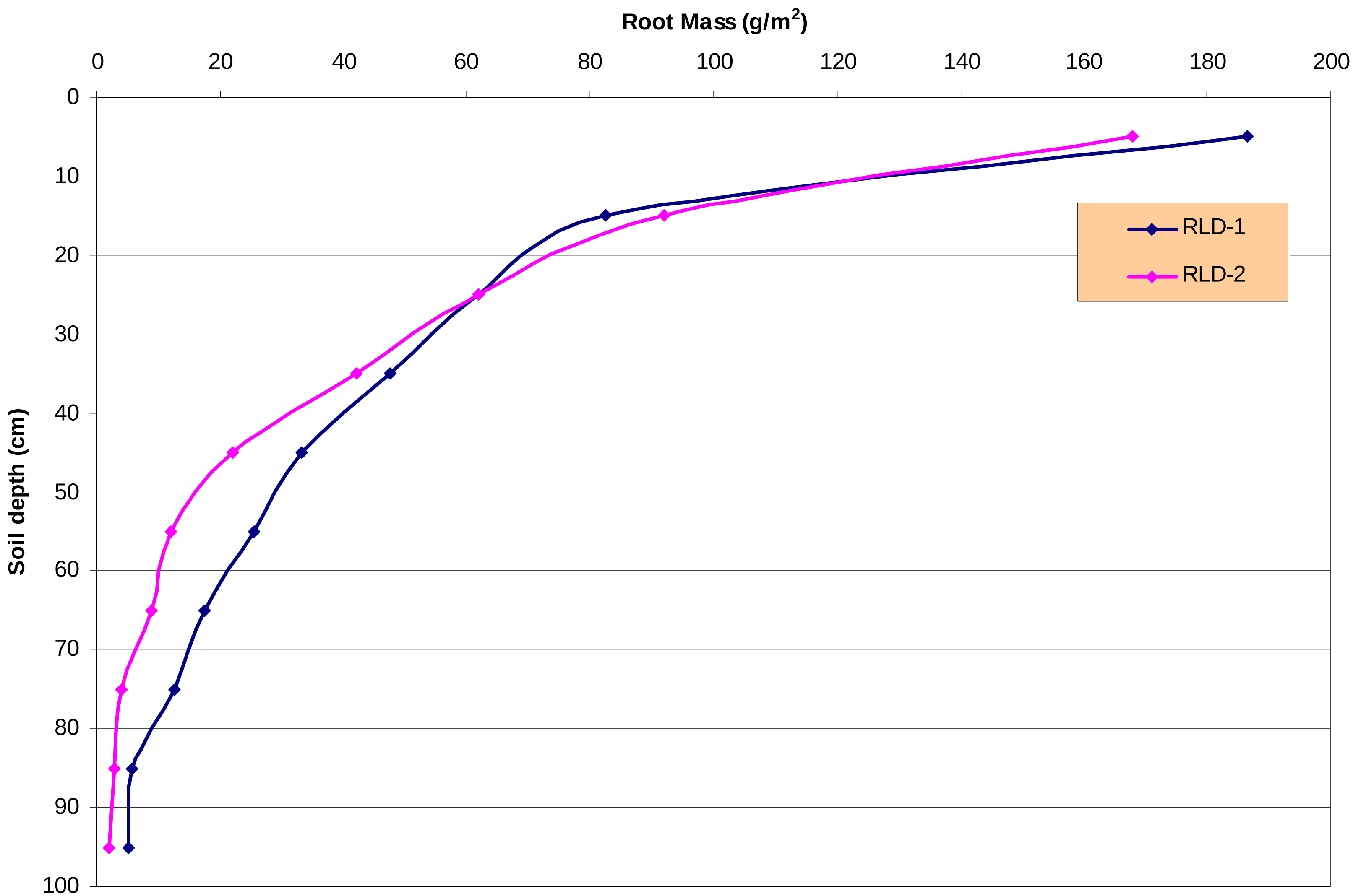

Figure 3-12 Distribution of Root Biomass for RLD-1 and RLD-2

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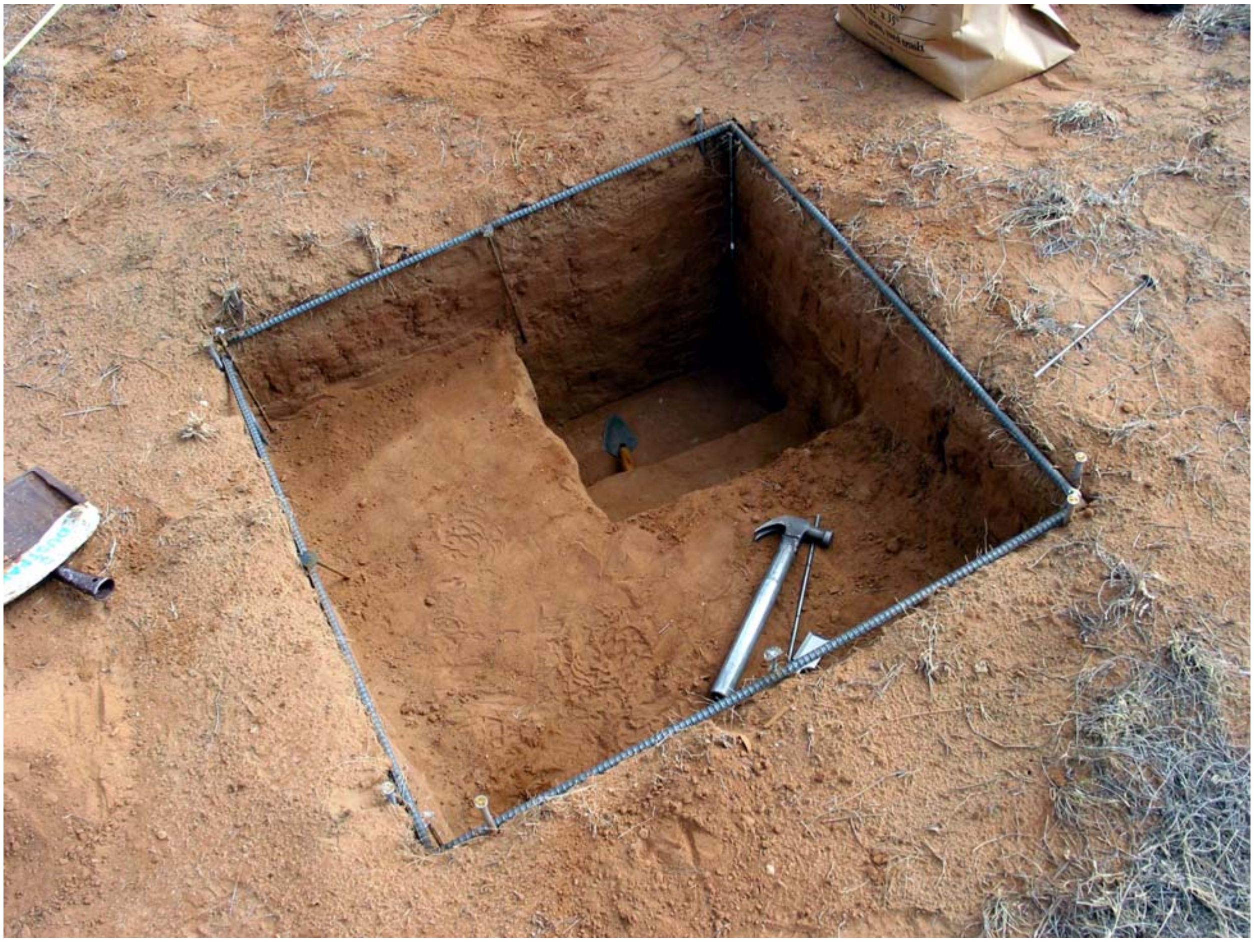

Figure 3-13 RLD-1 Showing Excavated Inter

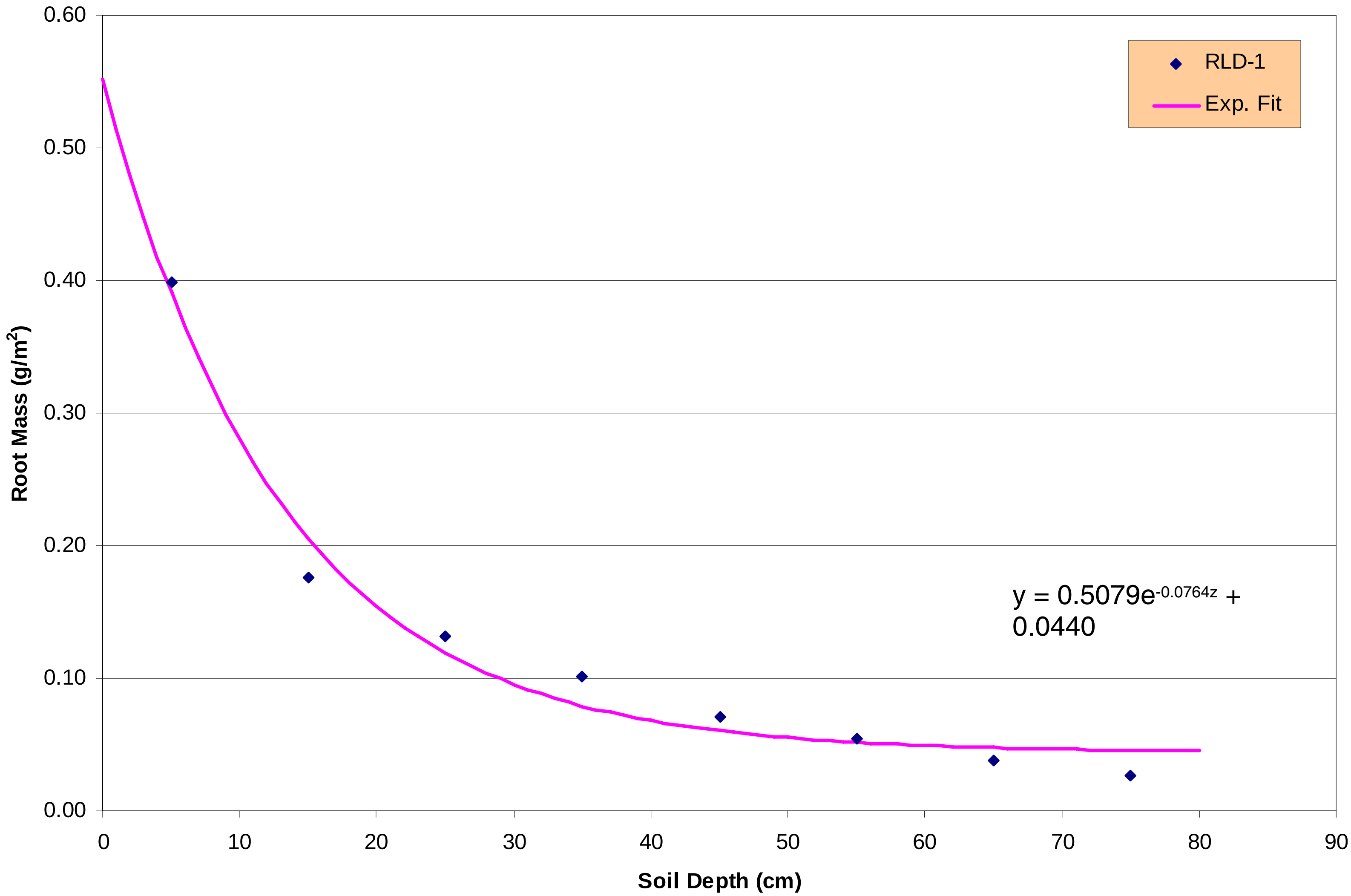

Figure 3-14 Exponential Fit of Normalized Root Biomass for RLD-1

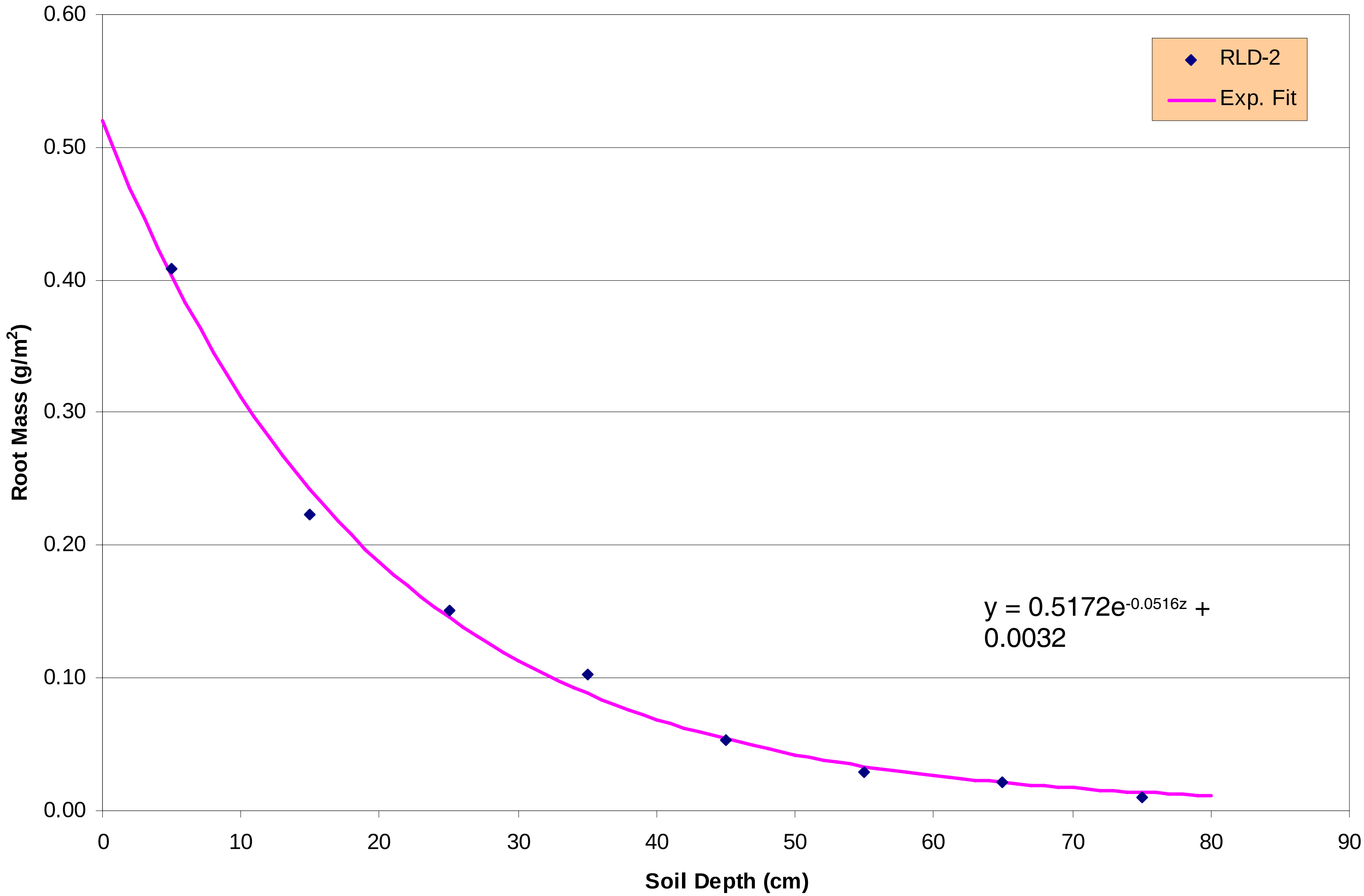

Figure 3-15 Exponential Fit of Normalized Root Biomass for RLD-2

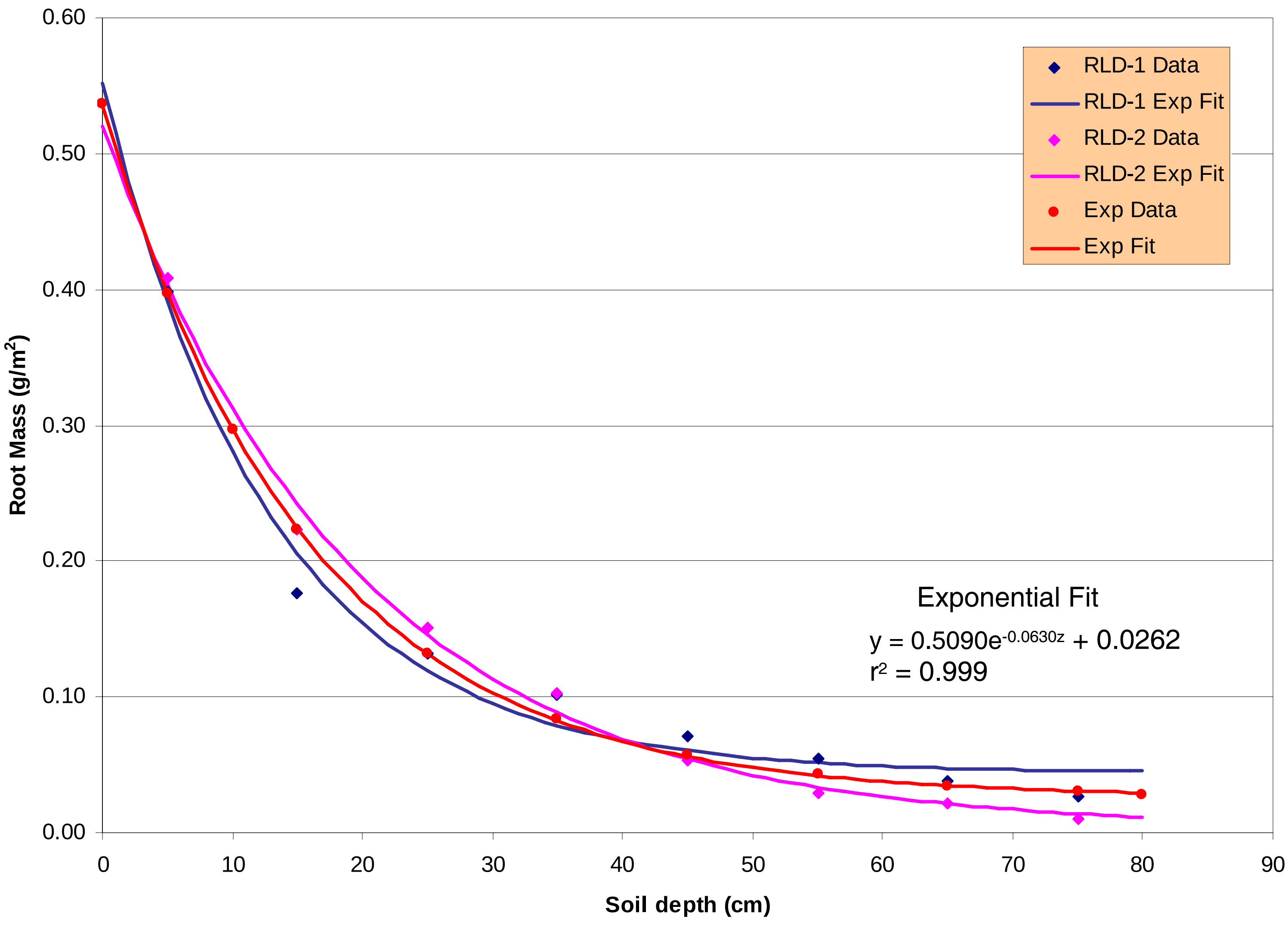

Figure 3-16 Exponential Fit of Combined Normalized Root Biomass for RLD-1 and RLD-2

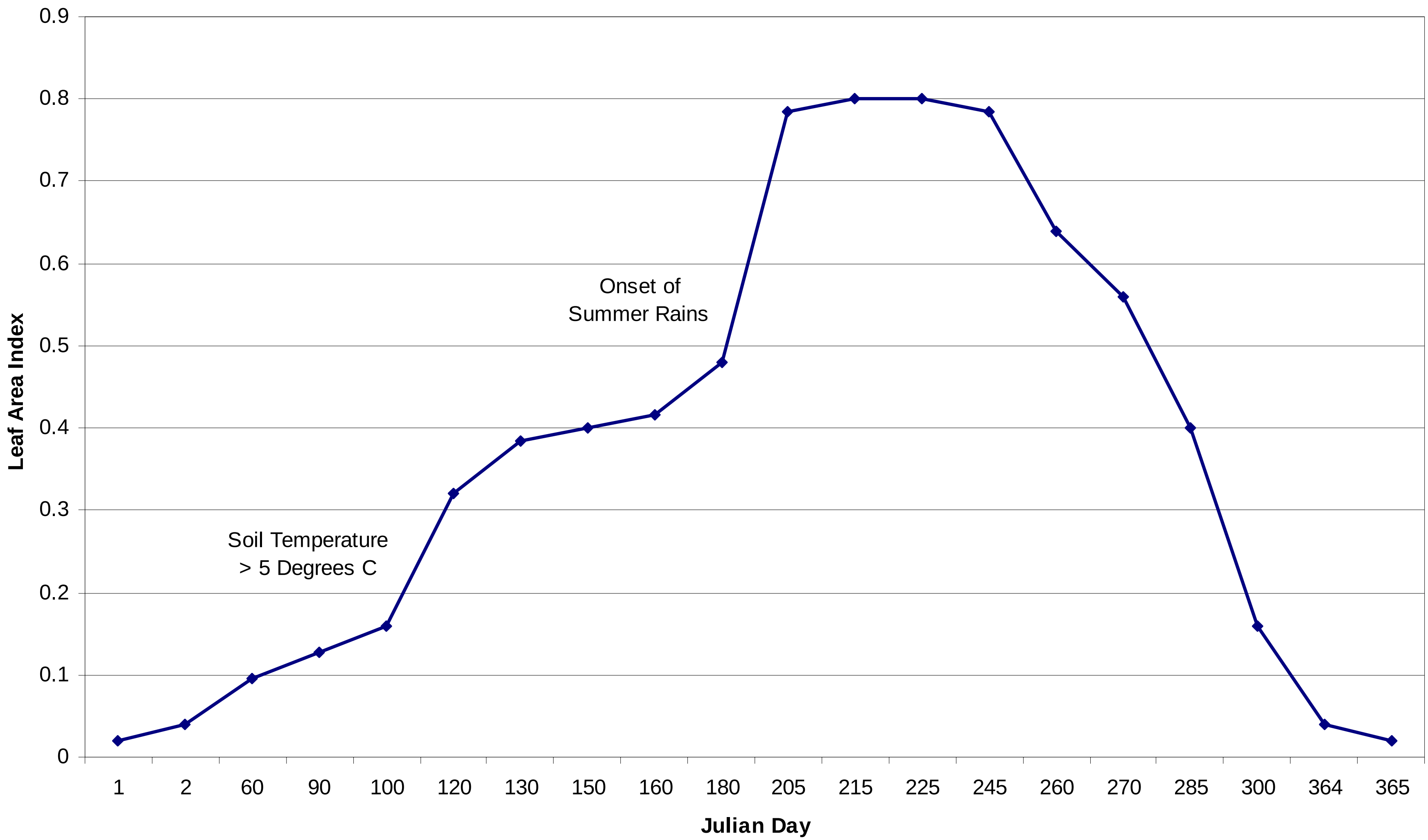

Figure 3-17 Growing Season and Leaf Area Index

TABLES

AGAVACEAE (Agave Family)

Yucca baccata Torr. (banana yucca)
Yucca glauca Nutt. (small soapweed)

ANACARDIACEAE (Cashew Family)

Rhus trilobata Nutt. (skunkbush sumac)

APIACEAE (Parsley Family)

Cymopterus acaulis (Pursh) Raf. var. *fendleri* (Gray) Goodrich (Fendler's springparsley)

ASTERACEAE (Sunflower Family)

Acourtia nana (Gray) Reveal & King (desert holly)
Artemisia bigelovii Gray (Bigelow's sagebrush)
Artemisia filifolia Torr. (sand sagebrush)
Baccharis wrightii Gray (Wright's baccharis)
Baileya multiradiata Harvey & Gray ex Gray (desert baileya)
Chaetopappa ericoides (Torr.) Nesom (rose heath)
Cirsium neomexicanum Gray (New Mexico thistle)
Erigeron divergens Torr. & Gray (spreading fleabane)
Erigeron flagellaris Gray (trailing fleabane)
Gaillardia pinnatifida Torr. (red dome blanketflower)
Gutierrezia microcephala (DC.) Gray (threadleaf snakeweed)
Gutierrezia sarothrae (Pursh) Britt. & Rusby (broom snakeweed)
Machaeranthera canescens (Pursh) Gray (hoary aster)
Machaeranthera pinnatifida (Hook.) Shinners ssp. *pinnatifida* (lacy tansyaster)
Malacothrix fendleri Gray (Fendler's desertdandelion)
Melampodium leucanthum Torr. & Gray (plains blackfoot)
Senecio flaccidus Less. var. *flaccidus (*threadleaf groundsel)
Stephanomeria pauciflora (Torr.) A. Nels. (brownplume wirelettuce)
Thymophylla acerosa (DC.) Strother (pricklyleaf dogweed)

ASCLEPIADAEAE (Milkweed Family)

Asclepias asperula (Dcne.) Woods. (spider milkweed)

BORAGINACEAE (Borage Family)

Cryptantha cinerea (Greene) Cronq. var. *jamesii* Cronq. (James' cryptantha)
Cryptantha crassisepala (Torr. & Gray) Greene (deertongue)
Cryptantha fulvocanescens (S. Wats.) Payson (tawny catseye)

Lappula occidentalis (S. Wats.) Greene var. *occidentalis* (desert stickseed)

BRASSICACEAE (Mustard Family)

Descurainia incana (Bernh. ex Fisch. & C.A. Mey.) Dorn (mountain tansymustard)
Dimorphocarpa wislizeni (Engelm.) Rollins (spectacle pod)
Lesquerella fendleri (Gray) S. Wats. (Fendler's bladderpod)

CACTACEAE (Cactus Family)

Echinocereus fendleri (Engelm.) F. Seitz (pinkflower hedgehog cactus)
Escobaria vivipara (Nutt.) Buxbaum var. *arizonica* (Engelm.) D.R. Hunt (Arizona spinystar)
Opuntia clavata Engelm. (club cholla)
Opuntia cymochila Engelm. & Bigelow (grassland pricklypear)
Opuntia imbricata (Haw.) DC. (walkingstick cholla)
Opuntia macrorhiza Engelm. var. *macrorhiza* (twistspine pricklypear)
Opuntia phaeacantha Engelm. var. *phaeacantha* (tulip pricklypear)
Opuntia polyacantha Haw. (plains pricklypear)
Opuntia polyacantha Haw. var. trichophora (Engelm. & Bigelow) Coult. (hairspine pricklypear)
Sclerocactus papyracanthus (Engelm.) N.P. Taylor (paperspine fishhook cactus)

CUCURBIDACEAE (Gourd Family)

Cucurbita foetidissima Kunth (buffalogourd pumpkin)

CHENOPODIACEAE (Goosefoot Family)

Atriplex canescens (Pursh) Nutt. (fourwing saltbush)
Chenopodium fremontii S. Wats. (Freemont's goosefoot)
Krascheninnikovia lanata (Pursh) A.D.J. Meeuse & Smit (winterfat)
Salsola tragus L. (prickly Russian thistle)

CUSCUTACEAE (Dodder Family)

Cuscuta megalocarpa Rydb. (bigfruit dodder)

EPHEDRACEAE (Mormon Tea Family)

Ephedra torreyana S. Wats. (Torrey's jointfir)

EUPHORBIACEAE (Spurge Family)

Chamaesyce fendleri (Torr. & Gray) Small (Fendler's sandmat)
Chamaesyce micromera (Boiss. ex Engelm.) Woot. & Standl. (Sonoran sandmat)
Chamaesyce serpyllifolia (Pers.) Small ssp. *serpyllifolia* (thymeleaf sandmat)

FABACEAE (Bean Family)

Astragalus feensis M.E. Jones (Santa Fe milkvetch)
Astragalus lentiginosus Dougl. ex Hook. var. *diphysus* (Gray) M.E. Jones (freckled milkvetch)
Astragalus nuttallianus DC. (smallflowered milkvetch)*Caesalpinia jamesii* (Torr. & Gray) Fisher (James' holdback)
Dalea formosa Torr. (feather dalea)
Psoralidium tenuiflorum (Pursh) Rydb. (slimflower scurfpea)
Senna bauhinioides (Gray) Irwin & Barneby (twinleaf senna)

FUMARIACEAE (Dutchman's Breeches Family)

Corydalis aurea Willd. (golden corydalis)

HYDROPHYLLACEAE (Waterleaf Family)

Nama hispidum Gray (bristly nama)
Phacelia crenulata Torr. ex S. Wats. var. *corrugata* (A. Nels.) Brand (cleftleaf wild heiotrope)

LINACEAE (Flax Family)

Linum australe Heller var. *australe* (southern flax)

LOASACEAE (Loasa Family)

Mentzelia albicaulis (Dougl. ex Hook.) Dougl. ex Torr. & Gray (whitestem blazingstar)

MALVACEAE (Globemallow Family)

Sphaeralcea angustifolia (Cav.) G. Don (copper globemallow)
Sphaeralcea coccinea (Nutt.) Rydb. (scarlet globemallow)
Sphaeralcea fendleri Gray (Fendler's globemallow)
Sphaeralcea incana Torr. ex Gray (gray globemallow)

NYCTAGINACEAE (Four o'clock Family)

Abronia fragrans Nutt. ex Hook. (snowball sand verbena)
Allionia incarnata L. (trailing windmills)
Mirabilis multiflora (Torr.) Gray (manyflowered four-o'clock)

ONAGRACEAE (Evening Primrose Family)

Calylophus hartwegii (Benth.) Raven (Hartweg's sundrops)
Gaura coccinea Nutt. ex Pursh (scarlet gaura)
Oenothera albicaulis Pursh (halfshrub sundrop)
Oenothera primiveris Gray ssp. *primiveris* (desert evening-primrose)

OROBANCHACEAE (Broomrape Family)

Orobanche ludoviciana Nutt. (Louisiana broomrape)

PEDALIACEAE (Pedalium Family)

Proboscidea althaeifolia (Benth.) Dcne. (devils claw)

PLANTAGINACEAE (Plantain Family)

Plantago patagonica Jacq. (woolly plantain)

POACEAE (Grass Family)

Achnatherum hymenoides (Roemer & J.A. Schultes) Barkworth (Indian ricegrass)
Aristida purpurea Nutt. (purple threeawn)
Aristida purpurea Nutt. var. *longiseta* (Steud.) Vasey (red threeawn*)*
Bouteloua barbata Lag. (sixweeks grama)
Bouteloua eriopoda (Torr.) Torr. (black grama)
Bouteloua gracilis (Willd. ex Kunth) Lag. ex Griffiths (blue grama)
Elymus elymoides (Raf.) Swezey ssp. *brevifolius* (J.G. Sm.) Barkworth, comb. nov. ined. (squirreltail)
Eragrostis mexicana (Hornem.) Link (New Mexico lovegrass)
Erioneuron pilosum (Buckl.) Nash (hairy woollygrass)
Hesperostipa neomexicana (Thurb. ex Coult.) Barkworth (New Mexico feathergrass)
Muhlenbergia porteri Scribn. ex Beal (bush muhly)
Muhlenbergia torreyi (Kunth) A.S. Hitchc. ex Bush (ring muhly)
Munroa squarrosa (Nutt.) Torr. False buffalo grass
Pleuraphis jamesii Torr. (galleta grass)
Scleropogon brevifolius Phil. (burrograss)
Setaria vulpiseta (Lam.) Roemer & J.A. Schultes (plains bristlegrass)
Sporobolus contractus A.S. Hitchc. (spike dropseed)
Sporobolus cryptandrus (Torr.) Gray (sand dropseed)
Sporobolus flexuosus (Thurb. ex Vasey) Rydb. (mesa dropseed)

POLEMONIACEAE (Phlox Family)

Gilia rigidula Benth. ssp. *acerosa* (Gray) (Wherry (bluebowls)
Gilia sinuata Dougl. ex Benth. (rosy gilia)

POLYGONACEAE (Milkwort Family)

Eriogonum sp. (wild buckwheat)
Rumex hymenosepalus Torr. (canaigre dock)

RANUNCULACEAE (Buttercup Family)

Delphinium wootonii Rydb. (Organ Mountain larkspur)

SOLANACEAE (Nightshade Family)

Solanum elaeagnifolium Cav. (silverleaf nightshade)

ULMACEAE (Elm Family)

Ulmus pumila L. (Siberian elm)

VERBENACEAE (Vervain Family)

Verbena bracteata Lag. & Rodr. (bigbract verbena)

ZYGOPHYLLACEAE (Caltrop Family)

Larrea tridentata (SessÈ & Moc. ex DC.) Coville (creosotebush)
Tribulus terrestris L. (puncturevine)

APPENDIX A
Vascular Plant Species in the General Study Area

DISTRIBUTION:

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1	1089	T.J. Goering, 6135
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