NEW MEXICO DEPARTMENT OF TRANSPORTATION

RESEARCH BUREAU

Innovation in Transportation

DEVELOPING AND IMPLEMENTING NATIVE SEED GERMPLASM FROM THE WILD FOR ARID LANDS

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16. Abstract:

This four-year study was designed to address the question "can we improve upon standard seed mixes (commercial seed sources used by NMDOT) by including local sources or alternate sources from less frequently used commercially available species or entirely novel species?" Five 1-acre research sites on DOT and private land near the Lordsburg Playa were secured, and 16 study plots installed at each site. An extensive literature review of 95 species identified species with dust mitigation attributes and suitable to a large-scale restoration study in the Chihuahuan Desert ecoregion. Baseline monitoring occurred in October 2019; the site preparation and experimental seeding took place in July 2020; post-seeding monitoring took place in April 2021 and in October 2021. Exceptional drought following the seeding experiment likely impacted restoration success as post-seeding vegetative cover in general was lower than expected at all sites. This poor establishment combined with low replication contributed to low power for finding statistical significance. However, the following results were statistically significant: seed mixes performed better than single-species seedings, target species cover was highest at DOT sites, and Atriplex obovata (mound saltbush), a novel shrub species, was one of the better performing species. Baileya multiradiata and Machaeranthera tanacetifolia tended to be the two most successful species seeded, having high cover in plots where they occurred and potential for higher cover in the future as evidenced by hundreds of healthy seedlings and the fact both species were flowering and setting seed in April and October. Restoration recommendations based on statistical findings, trends, and observations: 1. include Atriplex obovata in seed mixes; 2 increase the seeding rate for Baileya multiradiata, Machaeranthera tanacetifolia, and Bouteloua aristidoides; 3. continue to seed using mixes, rather than single species seedings; 4. continue to use hydromulch to cover seeding treatments; 5. add water harvesting topography during site preparation.

17. Key Words: dust mitigation, germplasm, Chihuahuan Desert, playa, soil stabilization, hydromulch, *Atriplex obovata, Baileya multiradiata, Machaeranthera tanacetifolia, Bouteloua barbatus, seed mixes, vegetative cover, seed production, drought effects.*	16. Distribution Statement Available from NMDOT Research Bureau 19. Security classification of report: None 20. Security Classification of this page: None
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Developing and Implementing Native Seed Germplasm from the Wild for Arid Lands

Final Report

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Report R918031

A Report on Research Sponsored by
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PREFACE

Native grasses, forbs, and woody shrubs play an extremely important role in the New Mexico Department of Transportation's (NMDOT) roadside soil stabilization efforts following construction, during maintenance, and in reestablishing critical habitats. There is a continued and increasing importance of this vegetation due to the historic long-term 'drying out' of New Mexico, which is exacerbated by rapid climate change. The NMDOT sought to answer the question "Can we improve upon our seed mixes by adding non-commercially available native species or better germplasm of already available species?" The four-year study identified and tested native plant germplasm possessing the following attributes: drought tolerant, quick-establishing, deep-rooted, and ability to reclaim and control dust-generating soils within the right-of-way, specifically in problem areas in southwestern New Mexico. Germplasm is living plant tissue such as a seed, leaf, pollen, cells, etc. that can be collected and used to produce new plants.

NOTICE

DISCLAIMER

ABSTRACT

This four-year study was designed to address the question "can we improve upon standard seed mixes (commercial seed sources used by NMDOT) by including local sources or alternate sources from less frequently used commercially available species or entirely novel species?" Five 1-acre research sites on DOT and private land near the Lordsburg Playa were secured, and 16 study plots installed at each site. An extensive literature review of 95 species identified species with dust mitigation attributes and suitable to a large-scale restoration study in the Chihuahuan Desert ecoregion. Baseline monitoring occurred in October 2019; the site preparation and experimental seeding took place in July 2020; post-seeding monitoring took place in April 2021 and in October 2021. Exceptional drought following the seeding experiment likely impacted restoration success as post-seeding vegetative cover in general was lower than expected at all sites. This poor establishment combined with low replication contributed to low power for finding statistical significance. However, the following results were statistically significant: seed mixes performed better than single-species seedings, target species cover was highest at DOT sites, and *Atriplex obovata* (mound saltbush), a novel shrub species, was one of the better performing species. *Baileya multiradiata* and *Machaeranthera tanacetifolia* tended to be the two most successful species seeded, having high cover in plots where they occurred and potential for higher cover in the future as evidenced by hundreds of healthy seedlings and the fact both species were flowering and setting seed in April and October. Restoration recommendations based on statistical findings, trends, and observations: 1. include *Atriplex obovata* in seed mixes; 2 increase the seeding rate for *Baileya multiradiata, Machaeranthera tanacetifolia*, and *Bouteloua aristidoides*; 3. continue to seed using mixes, rather than single species seedings; 4. continue to use hydromulch to cover seeding treatments; 5. add water harvesting topography during site preparation.

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INTRODUCTION

Native grasses, forbs, and woody shrubs play an extremely important role in the New Mexico Transportation Department's roadside soil stabilization efforts following construction, during maintenance, and in re-establishing critical habitats. There is a continued and increasing importance of this vegetation due to the historic long-term aridification of New Mexico, which is exacerbated by rapid climate change. The New Mexico Department of Transportation (NMDOT) seeks to answer the question "Can we improve upon standard seed mixes by adding non-commercially available native species or better germplasm of already available species?" (2017, NM DOT RFP #18-24). The objective of the four-year study was to collect and develop native plant germplasm possessing the following attributes: drought tolerant, quick-establishing, deep-rooted, and ability to reclaim and control dust-generating soils within the right-of-way, specifically in problem areas in New Mexico.

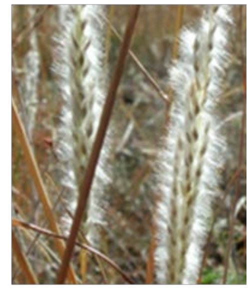
Revegetation efforts along roadways are of critical importance, as high winds and aridity in the state can cause airborne dust particles. Dust can present serious health problems, including respiratory illnesses. In addition, dust can create extremely hazardous road conditions that can lead to fatalities for motorists. Research is key to understanding what plant materials will be most successful and not only survive in challenging conditions but also mitigate for erosion and dust issues in New Mexico. Determining which germplasm is most successful not only improves revegetation practices, but also improves the availability of native plant materials by encouraging growers to produce these materials and share information regarding best ways to use the seed.

The study is intended to provide data that NMDOT can use to enhance their revegetation efforts along highways in southern New Mexico and other areas with similarly challenging soils while actively restoring problem areas in the region of the Lordsburg Playa. The project tested which species, seed mix, source, or plant material type is most effective at mitigating negative impacts to public safety.

Project deliverables/tasks include:

- Task 1: Literature review
- Task 2: List of plant species/sources with dust mitigation characteristics
- Task 3: Seed collection
- Task 4: Field experiment at five sites in the Lordsburg area to compare planting success
- Task 5: Statistical analyses
- Task 6: Coordination
- Task 7: Grower Interface

Task 1: Literature review

A. Background

- A literature review was the first activity conducted in May 2018 to identify the most promising species for the germplasm study. It was designed to identify species with desirable attributes including tolerance for poor soils and arid conditions, dust mitigation potential, and sufficient seed yields for use in a large-scale seeding study.

B. Accomplishments

- Literature review of 95 species and citations (Appendix A & B)
- Evaluation Rubric (Table 1)
- Technical Panel used rubric to prioritize species
- Species ranked, and lower priority species removed from the list
- Report summarizing literature search results and sources, organized by species and subject investigated.

C. Methods

- **Species evaluated:** Because the study is comparing standard NM DOT species used in the Lordsburg area (Zone 5: Southern Desertic Basins, Plains, and Mountains), several species from this list possessing required attributes identified in RFP #18-24 were selected. Then a suite of suitable novel species and genotypes were selected for literature review and evaluation. IAE conducted an extensive literature search for 95 species under consideration for this project. We first evaluated the NMDOT standard mix species list for the Lordsburg area (Zone 5: Southern Desertic Basins, Plains, and Mountains) to determine what species the Department is currently using that possess soil stabilization properties and other desirable attributes. To identify novel species and genotypes appropriate for this project, we evaluated lists of species native to the Chihuahuan Desert Ecoregion, prioritizing species associated with playas and adjacent upland habitats. Dave Dreeson, Agronomist, and Patrick Alexander, BLM Botanist Las Cruces office, from on our technical advisory team provided species recommendations for both lists. The potential of a given species to be farmed commercially in seed production fields was another consideration for evaluations.
- **Information sources:** SEINet, NRCS Fact Sheets, regional floras (*i.e.*, Allred 2012, Flora Neomexicana), Ecological Site Descriptions, Web Soil Survey and research papers were all used. When sufficient information is lacking for particular species, literature searches were conducted for related species in the same genus.
- **Sites and soils considerations:** All six potential research sites occur in the Chihuahuan Basins and Playas Level IV EPA Ecoregion. IAE evaluated soil characteristics using updated soil survey information as of June 15, 2018 for the Lordsburg Playa Area, portions of the Soil Survey of Hidalgo

County, New Mexico. These data were provided as a GIS layer from Dave White, NRCS Las Cruces Soil Survey Project Leader. IAE extracted the salinity, alkalinity, sodicity and texture information for each horizon as these factors play a role plant establishment and persistence.

- **Rubric scoring:** Each researched species was scored using a rubric, considering distribution and habitat, plant habit, tolerance for poor soils, drought tolerance, soil stabilization properties, and ability to establish and spread.
- **Ground-truthing:** The final step for species selection was ground-truthing to verify that each of the selected species are growing in the target habitats and demonstrating a strong ability to endure challenging conditions (i.e., poor soils, grazing, and drought), document growth habits of these species in the wild to assess dust mitigating properties, and to verify that populations of a given species are of sufficient size and producing the quantities of seed needed for a restoration-scale sowing. IAE incorporated scouting and collection data from the 2018 seed collection crew to ground-truth habitat compatibility and abundance of species, and evaluated the number of occurrences of each species in SEINet and in Patrick Alexander's (BLM Botanist, Las Cruces) plant occurrence database overlapping with the Chihuahuan Basins and Playas Level IV Ecoregion in GIS.

D. Key findings: Results

- While it was challenging to find any single species that possessed all the desired characteristics while also having the potential to yield sufficient seed to be included in the study, the Technical Team worked together to identify the most promising species.
- The initial prioritization based on the literature review and rubric scoring resulted in five grasses, four forbs, two shrubs for further consideration.

Resources

- Appendix A. Plant Attributes Table - Summary of Literature Review Results
- Appendix B. Information sources from literature review
- Table 1. Rubric used for scoring species
- Table 2. Final scores

Table 1. Rubric used for scoring species

Scoring	Distribution	Habit	Poor Soil Tolerance	Drought Tolerance	Soil Stabilization	Germination and Establishment	Collection feasibility
0	Not widespread, not in playa or comparable habitat	Small and minimal branching	None	None	Annual, poorly developed root system	Poor establishment and spread	<10 records in ChBasins and Playas ER, < 5 pops scouted
1	Widespread in S NM, but not associated with playas or comparable habitats	Short statured	Potential soil tolerance (i.e. playa adjacent), but none specifically documented	Low	Annual, taproot, or well developed root system	Special germination requirements, delayed germination	11-25 records in ChBasins and playas or > 5 pops scouted
2	Associated with playas but not widespread in S NM	Medium size, spreading annual, short-lived perennial	Some tolerance to fine textured soils, salinity, *or* alkalinity, but not all three, and/or not much information avaliable	Medium	Perennial, shallow to moderately developed root system	Med. establishment, no special germination requirements, good seed producer, lower veg. spread, inhibits other plants (allelopathy)	26-75 records in Ch Basins & Playas, or >10 populations scouted
3	Widespread in S NM, slightly less commonly associated with playas but can grow in comparable habitats	Bunch grass, bushy perennial grasses and forbs, or ground cover	Moderate to high tolerance to fine textured soils, alkalinity, *and/or* salinity	Predicted high tolerance or mixed results	Perennial, well developed root system	med-high establishment, good seed producer, moderate spread and competitor	76-100 records, or > 15 populations scouted
4	Widespread in S NM, associated with playas	Subshrub or shrub	Specifically adapted to fine textured soils, alkalinity, *and* salinity	Documented high tolerance	Perennial, dense mat and/or deep rooted	high establishment, prolific from seed; vegetative spread, strong competitor	>100 records in ChBasins and Playas or >20 pops scouted

Table 2. Final scores

Type	Species	Distribution	Habit	Tolerance for poor soils	Drought tolerance	Soil stabilization	Establishment & spreading	Collection feasibility	Score
grass	***Sporobolus airoides***	4	3	4	4	3	1	3	**22**
grass	***Sporobolus cryptandrus*** [1]	4	3	2	4	3	1	1	**18**
grass	***Bouteloua curtipendula*** [1]	1	3	2	4	3	3	2	**18**
forb	***Sphaeralcea coccinea***	3	2	2	4	4	1	0	**16**
forb	***Baileya multiradiata***	1	2	2	3	1	2	4	**15**
shrub	***Atriplex canescens***	4	4	4	4	4	4	4	**28**
grass	*Hilaria mutica (P. mutica)*	4	3	3	3	4	1	4*	**22**
grass	*Setaria leucopila*	4	3	4	4	3	1	1	**20**
forb	*Senecio flaccidus* [2]	4	4	2	4	4	2	1	**21**
forb	*Verbesina encelioides* [2]	4	2	3	4	1	3	4	**21**
shrub	*Atriplex obovata*	2	4	4	4	3	3	2	**22**

Task 2: List of plant species/sources with dust mitigation characteristics

A. Background

- A list of species with dust mitigation and soil stabilization characteristics was generated through literature review, scoring, and feedback from the Technical Committee.

B. Accomplishments

- Submitted the list of potential candidates and the top-scoring species to the Plant Technical Committee for feedback. The Technical Committee helped to make the final selections.
- List of species made available for crews to target during seed collection.

C. Methods

- We revised the final selection of species for establishment trials after further discussion with the Plant Technical Committee. All Plant Technical Committee members reviewed the list of potential species and submitted comments. All comments were considered in the final selection of target species. Target species were selected by the second quarter of the project.
- Final species selected possessed three or more of the desired characteristics, scoring higher than other species in at least one category.
- Backup species were also identified as targets for 2019 seed collection crews in case of issues with locating collectable populations or acquiring enough seed for the top-ranking species. Backup species ranked high in the initial scoring, and many were ultimately used in the seeding experiment.

D. Key Findings: Results

- Eight finalist plant species selected for target list based on multiple factors including dust mitigation potential:
    1. Alkali sacaton (*Sporobolus airoides*)
    2. Needle grama (*Bouteloua aristidoides*)
    3. Desert marigold (*Baileya multiradiata*)

4. Fourwing saltbush (*Atriplex canescens*)
5. Whorled dropseed (*Sporobolus pyramidatus*)
6. Feather finger-grass (*Chloris virgata*)
7. Indian rushpea (*Hoffmanseggia glauca*)
8. Mound saltbush (*Atriplex obovata*)

- Backup species selected:
  - Sideoats grama (*Bouteloua curtipendula*)
  - Sand dropseed (*Sporobolus cryptandrus*)
  - Tansyleaf tansyaster (*Machaeranthera tanacetifolia*)
  - Scarlet globemallow (*Sphaeralcea coccinea*)
  - Winterfat (*Krascheninnikovia lanata*)
  - Low woollygrass (*Dasyochloa pulchella*)
  - Streambed bristlegrass (*Setaria leucopila*)
  - Big sacaton (*Sporobolus wrightii*)
  - Nuttall's poverty-weed (*Monolepis nuttalliana)*
  - Golden crownbeard (*Verbesina encelioides*)
  - Mojave seablight (*Suaeda moquinii, aka S. nigra*)
  - Armed saltbush *(Atriplex acanthocarpa*)

E. Resources

- Same as Task 1

Task 3: Seed collection




A. Background

- Seed collection was necessary to provide local sources of seed for comparison as well as to obtain seeds from alternate, novel species not commercially available. Seed crews were tasked with collecting a minimum of 20 PLS pounds of seed from 8 target species plus backup species in the Chihuahuan Desert the first two years of the study. Two collection seasons were required to obtain enough seed.

B. Accomplishments

- Collection permits acquired
- Two (3 person) seed collection crews, one in 2018 and one in 2019, hired and trained

- 98 pounds of wild collected seed from 22 target species
- Seeds cleaned, data tracked, seeds kept in safe storage
- Seeds tested at New Mexico State University (NMSU) State Seed Lab
- Extra seeds delivered to NM DOT for restoration projects and to NMSU professor Dr. Akasha Faist for applied native seed-based research in Zone5

C. Methods

- Seed collection crews in 2018 (3 person, based in Las Cruces) and 2019 (3-person, based in Silver City) scouted and mapped potential collection sites in late June. Scouting was also necessary to assess seed readiness, estimate population size, collect voucher specimens, take photographs, and identify plants at different phenological stages.
- In mid-August, crews collected seeds using Seeds of Success (SOS) collection protocols.
- Data was collected at each site documenting habitat type, soil texture, latitude/longitude, associated species, ecological site description, land ownership, and distinguishing plant traits.
- Collected seed was then cleaned and dried and cold stored until ready for use.
- Each seed lot was sent to the New Mexico Department of Agriculture State Seed Laboratory to test for purity, germination, and Tetrazolium (TZ) viability. These tests were necessary to ensure viable seed was collected and to calculate Pure Live Seed (PLS) and convert bulk pound seeding rates to PLS seeding rates.

D. Key Findings

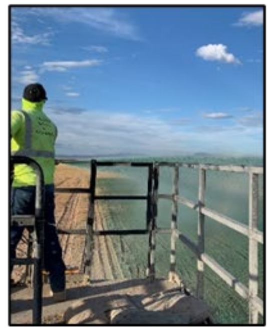
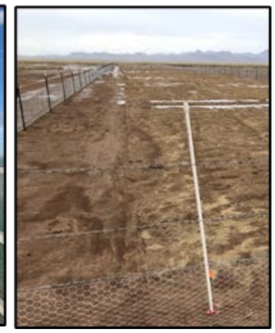
- Grazing on BLM land in Southern New Mexico and drought during both collection seasons made collections challenging, limiting the seed resources available.
- Crews working 2 seasons were able to collect sufficient seed for all local seeding treatments but one. Seeds for novel species were limited (only one species, *Atriplex obovata*, had sufficient seed to be included in monoseeded plots). However, all novel species collected were used in the experiment.
- Ploidy races in fourwing saltbush (*Atriplex canescens)* complicated collections for this species. Crews worked to keep 4X and 6X collections separate when morphological differences were apparent.

E. Resources

- Appendix C. Map of collection sites
- Appendix D. Wild seed collection – species and quantities
- Appendix E. Destinations of seed remaining following experimental seeding

Task 4: Field experiment at five sites in the Lordsburg area to compare planting success



A. Background

- Task 4 included site selection, plot installations, research design and revegetation plan, purchase of commercial seed, seed preparation and delivery, site preparation, seeding and hydromulch installation, fencing installation, and pre-treatment and post-treatment monitoring.
- The study was designed to identify if NM DOT seed mixes could be improved by using different sources or adding new native species not currently commercially available

B. Accomplishments

- Secured 5 sites suitable for the study based within the Lordsburg playa dust system
- Research design, monitoring protocol, and revegetation plan completed and approved
- 16 study plots (in 1-acre blocks) at 5 sites installed (measured, staked, mapped, & monumented)
- Completed baseline monitoring (October 2019)
- Purchased 64 pounds of commercial seed (7 species)
- Created seed lots and seed mixes for 16 treatments x 5 sites and delivered to project
- Site preparation complete at 5 sites (scarification)
- Installation of 256 treatment-specific seedings completed
- Seeding followed by crimping and 2 applications of hydromulch
- Fencing installed at all 5 sites
- Completed post-seeding monitoring (April 2021 and October 2021)

C. Methods

- **Site selection:** Five research sites (with a sixth as a backup) were selected following October site visits (Figure 1). NMDOT ensured environmental clearance and landowner permission. Selection criteria included: proximity to the Lordsburg playa, comparable challenging soils (Table 3) and plant community composition (to minimize variation among sites), ability to obtain environmental clearances within 2 years, landowner permission, sufficient access for large seeding equipment. Sites also needed to be large enough for Class A seeding, while also providing turnaround clearance for a seed drill and the required clearance from the highway for DOT sites.

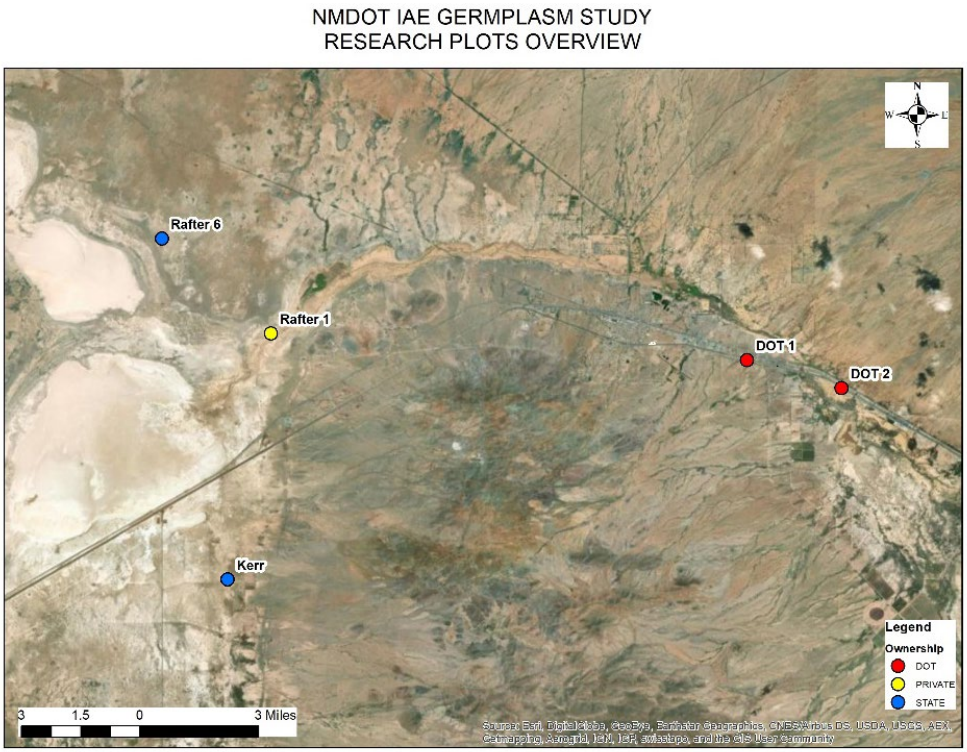


Figure 1. Location of six potential research sites submitted to DOT for environmental clearance.

Table 3. Soil characteristics of research sites

Site	Map unit name	Series	Salinity	Alkalinity/sodicity	Texture
Rafter 1	Highlonesome, nonsaline surface-Mimbres complex, 0 to 3 percent slopes	• Highlonesome, nonsaline surface 40% • Mimbres 30% • Minor components 30% (Highlonesome, severaly erodible; Sodic Haplocalcids; Hondale;	Slightly saline	Neutral to moderately alkaline and +/- sodic	Fine
Rafter 3, Rafter 6	Highlonesome-Vado complex, 0 to 3 percent slopes	•Highlonesome 65% •Vado 20% •Minor components 15% (Highlonesome, severely erodible; Yturbide)	Non-saline to slightly or strongly saline	65%: mod-v strongly alkaline and +/- sodic 20% slightly alkaline	65% fine 20% gravelly
Kerr	Highlonesome-Hondale, nonsaline surface complex, 0 to 1 percent slopes	•Highlonesome 65% •Hondale, nonsaline surface 35%	Non-saline to strongly saline	65% strongly alkaline and sodic 35% mod-strong and sodic	Fine
DOT 1, DOT 2	•Hondale 75% •Minor components 3% (Glendale, Playa, Mimbres, Hondale, Hondale loam, Verhalen)	Fine, mixed, superactive, thermic Typic Natrargids	Slightly-strongly saline	Mod-v. strongly alkaline	Fine

* sources: David White, NRCS Las Cruces Draft -Provisional Data; Web Soil Survey

Plot installations: In October 2019, sixteen (16) plots were measured, marked, monitored for baseline conditions at five different research sites. Metal rebar stakes were installed at the four corners of the 1-

acre blocks and long nails were buried at each of the plot corners for relocation with metal detectors. Plot location maps on aerial photos were created for each site, available to NM DOT. Fences with gates were installed around all plots following the seeding treatments.

- **Research design:** The research design was produced and finalized in April 2020. The design captured a commercial, local, and alternate sources (several of which were novel) and included different functional groups (grass, shrub, forb) for comparison. In addition, it compared seeding with a single species only to seeding with a mix of species. Some modifications were made to the original proposed research design. See "Adaptive management needed" under Key Findings below. In addition, a descriptive Monitoring Protocol was developed and approved by the technical committee that included type of cover estimates, plant counts, traits to measure, soil sampling, etc. and methodology for each. A Monitoring Protocol was necessary to ensure consistent data collection among observers and from one year to the next.
- **Revegetation plan:** Thus, the order of operations was to scarify soil (which also removed any existing vegetation), then hydro-seed, no-till drill/crimp treatment, and finally hydro-mulch. On July 1st – 3rd, 2020, all five sites were scarified, seeded, crimped, and mulched.
- **Seed purchase:** We worked with Granite Seed Company, one of the largest and most frequently used native seed vendors in the Southwest, to purchase our commercial sources for DOT standard treatments. Species purchased included: *Baileya multiradiata* (desert marigold)-NV source, *Sporobolus airoides* (alkali sacaton)-OK source, *Bouteloua curtipendula* (sideoats grama)-AZ source, and *Atriplex canescens* (fourwing saltbush)-CO sourced, *Machaeranthera tanacetifolia* (tansyleaf aster)-CA sourced, *Bouteloua aristidoides* (needle grama)-AZ sourced, *Elymus elymoides* (bottlebrush squirreltail)- CO sourced, field produced in WA. Granite provided seed tests, and all seed was purchased based on PLS pounds.
- **Seed preparation & delivery:** Staff calculated PLS quantities available, weighed amount needed for each site and each treatment, including mixes, and sealed each treatment in separate, labeled bags. Wild collected seeds from different sources were pooled. On July 1, 2020, treatment (seed) bags were delivered to their corresponding plots for seeding.
- **Site preparation:** Site preparation was a scarification treatment that helped to create a seed bed by loosening the soils and also served to remove any existing vegetation. Most sites had significant bare ground, so the amount of vegetation removal was minimal. *Salsola* (tumbleweed) was present at one DOT site, but it was manageable without the use of herbicides.
- **Seeding and hydromulch installation:** Installation of 256 treatment-specific seedings completed. After each seeding treatment, a crimping machine was used to roll over the seeds to improve soil contact. Seeding rates followed the NMDOT Zone 5 guidelines of 10.28 pounds per acre. For mixed seeding, 73% of the mix was grasses, 20% forbs, and 7% shrubs. Seeds were pushed into the soil at a ¼ - ½ inch depth with the no-till drill/crimper equipment. Hydromulch with tackifier was then sprayed over the treatments to secure seeds and provide mulch benefits. Two treatments of hydromulch were applied for optimal coverage.
- **Fencing installation:** The last step for the seeding was installation of herbivore exclusion fencing. The fence was designed to exclude both cattle (since 3 of the sites are located on cattle ranches) and rabbits and other rodents. As such, the fence design was 5' tall with barbed wire and 3' of chicken wire at its base. A half foot of chicken wire was folded out and buried to deter digging animals. The fence included a 15' buffer around seeded research plots for greater protection of plots from edge effects and inadvertent trampling of plants by researchers. The buffer also provided adequate space for larger equipment entry in the event that adaptive management is necessary. Access gates were installed at all 5 sites. Materials were ordered locally in Animas, and Ed Kerr, fencing contractor, and

his team started installing fencing at all 5 plots immediately after hydro-mulching was complete. Fence installation is complete and took approximately 2.5 weeks.

- **Pre-treatment and Post-treatment monitoring methods overview:** Baseline data were collected over a three-week period in October 2019. Site conditions and weed pressure were recorded and species composition, overall vegetative cover and soil surface stability were quantified within each plot separately. Water-stable soil aggregates at 8 stratified-random locations within each plot were also recorded, to include equal sampling of bare soil and soil associated with vegetation.

  Post-seeding monitoring was conducted in April 2021 documented species establishment and cover estimates for each plot, identifying early trends. Post-seeding monitoring was conducted again in October 2021 at several different scales, plot-level, quadrat level, and plant level (Figure 2). At this visit, 16 treatment plots were relocated at each of the 5 study sites. Eight (1-meter square) quadrats/plot/site were permanently established using a random numbers generator for coordinates. Data was collected at a total of 640 quadrats across all sites. Data collected included photo points, species lists, species cover, soil stability, plant counts, reproduction, and plant traits. In quadrats, percent cover of each plant species (including weeds and other volunteers) was estimated. The number of target plants flowering or fruiting within the 8 1-meter quadrats per site was recorded to provide an estimate of the reproductive potential and the ability of the species to provide greater cover and dust mitigation in the future. The total number of individuals of each target (sown) plant species rooted within the quadrat was counted. Target plants that were clearly too big to be a progeny of the seeding treatment were not counted. A census sown species was included because is a more accurate measure of establishment rates than % cover. From each plant, plant height and width were measured to assess wind breaking and dust abating ability. Using the Jornada aggregate stability kit (Herrick and Jornada Experimental Range 2005), soil stability at the soil surface was measured from 8 locations in each plot: 4 locations at the base of target plants and 4 locations in the interspace between plants. This test measures the soil's stability when exposed to rapid wetting, and sampling from both the base of target plants and the interspace provides information about how soil stability is affected by the presence of the target species. When target plants were present, the soil sample was taken 2 cm from the base of the nearest target plant at the bottom right corner.

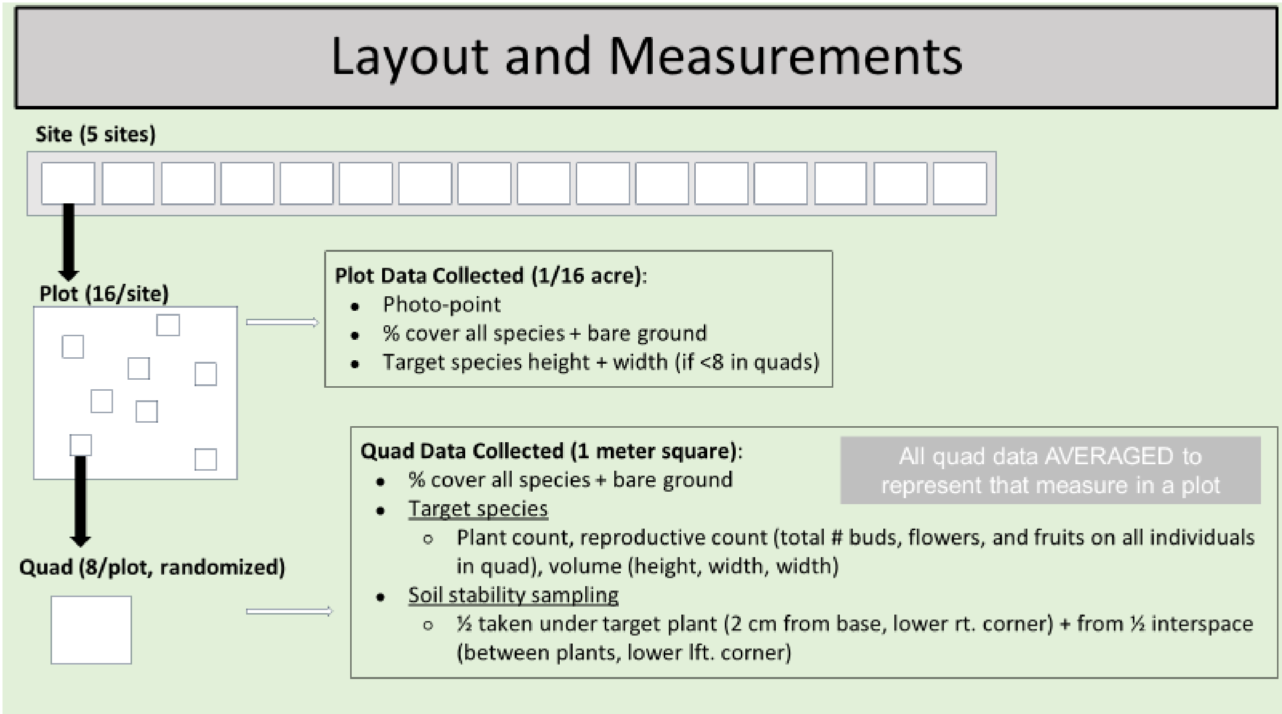


Figure 2. Plot layout and measurements

D. Key Findings: Adaptive management needed

- **BAMU Local plot size reduced.** Because wild collections of the high priority forb, desert marigold (*Baileya multiradiata*), did not result in enough wild collected seed to sow (1/16th acre + mixes x 5 sites) using the desired seeding rate of 10.28#/acre, the Technical Committee voted to seed desert marigold at the standard seeding rate of 10.28#/acre, but to reduce the size of the seeding area (to 30%) for this species to accommodate the smaller quantity of seed available. The remainder of the plot was utilized opportunistically to conduct hand-seeding trials for *Atriplex canescens-hexaploid, Machaeranthera tanacetifolia, Sporobolus wrightii, Atriplex obovata, Sporobolus airoides*, and *Setaria leucopila*. Hand-seeding trials could provide an observational comparison of establishment success by application technique and seeding rate.
- **Tall pot treatment removed.** IAE originally proposed a tall pot treatment to compare *Atriplex canescens* seedings with nursery stock plantings in deep pots. Through discussions with NM DOT, IAE learned that this type of planting was not typical and likely not practical for NM DOT. Given this information and greater familiarity with the water limitations at the sites, the tall pot treatment was removed. An Alternate16 treatment was substituted in its place which took advantage of wild collections of smaller quantities from numerous species. Combining these seeds together in a mixed seeding treatment allowed for full seeding of the plot at the 10.28#/acre seeding rate. This treatment also made it possible to test sixteen additional species including: *Atriplex canescens* (hexaploid), *Sporobolus wrightii, Bothriochloa barbinodis, Bouteloua aristidoides, Bouteloua barbata, Chloris virgata, Digitaria californica, Sporobolus flexulosus, Aristida purpurea, Scleropogon brevifolius, Hopia obtusa, Hoffmannseggia glauca, Thelesperma megapotamicum, Verbesina encelioides, Xanthisma gracile,* and *Machaeranthera tanacetifolia*.
- **Class A seeding changed.** NM DOT opted to use a low impact (no-till) approach instead of the Class A seeding required in the specs. Richie Caldon (owner, Caldon Seeding) recommended a

hydro-seed followed by a no-till drill/crimp treatment instead of using a no-till seed drill and bulking agent for better coverage of 1/16 acre plots (approved by NMDOT June 2020).

E. Resources

- Appendix H. Soil characteristics of research sites
- Appendix I. Final seeding design NMDOT germplasm project
- Appendix J. Seeding rates by species by treatment
- Q12 Report: Monitoring Protocol
- Request from IAE: Pre and post treatment photos each plot, each site

Task 5: Statistical analyses

A. Background:

- Using quantitative monitoring data collected in September 2021, IAE's Conservation Research Director, Dr. Scott Harris, conducted statistical analyses to answer the following questions:
  1. Can we improve upon standard seed mixes (commercial seed sources used by NM DOT) by including local sources or alternate sources from less frequently used commercially available species or completely novel species?
  2. Which species, seed mix, source (commercial, local, or alternate) is most effective at mitigating dust?
- Descriptive statistics and field observations are also included in this section.
- Environmental/growing conditions during the study: According to drought.gov, the southwestern corner of New Mexico maintained extreme drought levels for months following the restoration seeding application. For the majority of the 2021 growing season, plants experienced low rainfall. These conditions have negative ramifications for seed germination and plant establishment and survival.

B. Accomplishments: Statistical methodologies and analyses completed available in reports along with summary and discussion of results and recommendations.

C. Methods:

Treatments were organized and analyzed by mix type, functional group, and species (Table 4).

Table 4. Treatments. The 16 treatments that were applied at each of five sites for this study. The treatment code, used throughout this section of the report, indicates target species.source.mix type.

				Target Species in the Mono Seed Mix		
Source	**Mix Type**	**Functional Group**	**Treatment Code**	**Common Name**	**Scientific Name**	**Code**
commercial	mono	forb	BAMU.COM.1	desert marigold	*Baileya multiradiata*	BAMU
commercial	mono	perennial C4 grass	BOCU.COM.1	sideoats grama	*Bouteloua curtipendula*	BOCU
commercial	mono	perennial C4 grass	SPAI.COM.1	alkali sacaton	*Sporobolus airoides*	SPAI
commercial	mono	shrub	ATCA.COM.1	fourwing saltbush	*Atriplex canescens*	ATCA
commercial	4-species	grass-forb-shrub	MIX.COM.4	various	*various*	n/a
local	mono	forb	BAMU.Local.1	desert marigold	*Baileya multiradiata*	BAMU
local	mono	perennial C4 grass	BOCU.Local.1	sideoats grama	*Bouteloua curtipendula*	BOCU
local	mono	perennial C4 grass	SPAI.Local.1	alkali sacaton	*Sporobolus airoides*	SPAI
local	mono	shrub	ATCA.Local.1	fourwing saltbush	*Atriplex canescens*	ATCA
local	4-species	grass-forb-shrub	MIX.Local.4	various	*various*	n/a
alternate	mono	forb	MATA.Alt.1	tansyleaf aster	*Machaeranthera tanacetifolia*	MATA
alternate	mono	perennial C3 grass	ELEL.Alt.1	squirreltail	*Elymus elymoides*	ELEL
alternate	mono	annual C4 grass	BOAR.Alt.1	needle grama	*Bouteloua aristidoides*	BOAR
alternate	mono	shrub	ATOB.Alt.1	mound saltbush	*Atriplex obovata*	ATOB
alternate	4-species	grass-forb-shrub	MIX.Alt.4	various	*various*	n/a
alternate	16-species	grass-forb-shrub	MIX.Alt.16	various	*various*	n/a

Key to terminology in Table 4

- Source (commercial, local, alternate, alternate16)
  - Commercial (generally available for sale in commercial marketplaces)
  - Local (wild collected seed from Zone 5/Chihuahuan Desert ecoregion near project sites)
  - Alternate (novel species and alternate commercial species)
  - Alternate16 (16 novel species in the mix)
- Site (DOT1, DOT2, Rafter1, Rafter6, Kerr)
  - DOT1 and DOT2 (NM DOT right of way sites adjacent interstate 10)
  - Rafter1, Rafter6, Kerr (private land ranch sites in upland edges of playa)
- Mix type (single-species seed mix or "mono", 4-species seed mix, or 16-species seed mix)
- Functional group (shrubs, forbs, or grasses)

Cover, as a measure for establishment success (question 1) as well as dust mitigation potential (question 2), was compared for differences depending on where the seeds came from (source), the site where they were seeded (site), or whether they were seeded as part of a mix or seeded alone (mix type). Percent cover was calculated for commercial, local, alternate sources and compared across functional groups. Cover data was then also compared within functional groups to detect any subtle differences in cover, comparing for example, commercial-sourced shrubs to-local sourced shrubs and alternate-shrubs etc.

Data for individual **species** that established and their frequency was used to guide recommendations for species to use in restoration projects and or to enroll in commercial production, if not already commercially available (question 1). A higher frequency for a species would indicate a higher success rate. Because the seeding was followed by an exceptional drought year for the Lordsberg area, any level of establishment for a given seeded species demonstrates a potential for success. Species Frequency in the results section is a from raw data, counts of individual plants in each quadrat where these species were seeded.

Soil stability is a measure of dust mitigation potential depending on source (question 2). Soil stability was calculated for commercial, local, alternate sources and compared across functional groups.

While **plant traits** (reproduction and size – height and width) were measured when a target species appeared in a quadrat where it was seeded, a statistical analysis for this data was not warranted at this time because the seedlings that established were still immature at the time of monitoring as only two species reached reproductive maturity and one year is not enough time for most species to reach their natural expected sizes (maximum height 65 cm, maximum width 60 cm). Measuring plant traits addresses both question 1 and question 2, because reproductive potential is associated with a project's long-term seeding success and plant size parameters are anticipated to play a role in ability to capture airborne dust. Suggested methods and opportunities for making the most out of plant trait measures are provided below under "Recommendations for future studies."

Statistical analyses were completed in March 2022. Tests utilized included:

- Kruskal-Wallis (a non-parametric alternative to ANOVA) to compare
  - plant cover by source
  - plant cover by mix type
  - plant cover by site
  - soil stability by source
- Kruskal-Wallis to compare
  - plant cover within each functional group (shrub, forb, grass) by source (commercial, local, alternate, alternate mix) and by mix type (mono-seeding, mixed seeding)

D. Key Findings: Results

Baseline results

- Research plots all had a high proportion of bare ground, with plots at each site averaging from 63% bare (DOT 2) to 96% bare (Rafter 6). Percent bare ground differed significantly among research sites ($F= 27.781$, $p < 0.0001$) due to the difference of each of the two DOT sites within the right-of-way (ROW) of Interstate 10 from the other three sites on state and private lands far from roads. The two ROW sites were more vegetated than the other three sites, with DOT 1 having the highest median vegetative cover as well as the greatest variability among plots.
- The average soil stability class among plots at each site ranged from 2.54 to 5.37 on the scale from 1 to 6, which 1 being the least stable and 6 being the most stable. Soil stability differed significantly between sites ($F= 82.67$, $p<0.0001$) but the random effect of plot had no influence on between-site differences ($p= .9984$), suggesting that differences among seeded plots will not be confounded by within-site variation.
- Species richness varied by site ($F= 18.3175$, $P <.0001$), with DOT 1 and DOT 2 having the most plant diversity while Kerr and Rafter have the least.

Percent cover

Mean percent plant cover was low for all sites. Mean percent cover for target species ranged from 0 to 0.1%. These levels were too low for meaningful statistical testing. Total plant cover (sum of covers of all species observed) by treatment ranged from 1.1 to 8.0%. Therefore, total plant cover was used for the following cover analyses.

- **By source** – There was no difference in total percent cover (p=0.94) between commercial, local, or alternate sources (Figure 3).

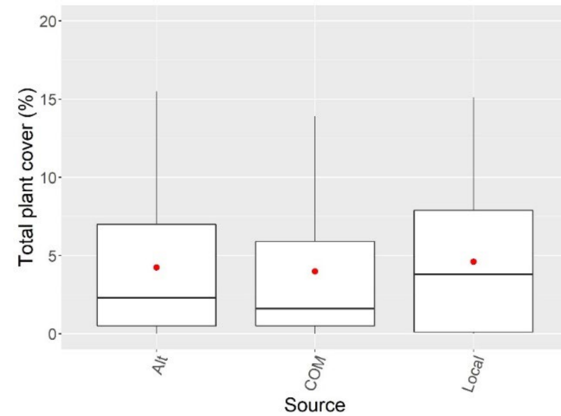


Figure 3. Total plant cover for each source. Treatments were pooled so that n= 25 for each source. The red dot indicates the mean value and the horizontal bar indicates the median value.

- **Within functional groups** – There were no statistical differences (see Figure 4) between commercial, local, and alternate sources within shrub seeding (p=0.88), within the forb seeding (p=0.21), nor within the grass seeding (p=0.36). The two grass treatments for each source were pooled (e.g., SPAI.com.1 and BOCU.com.1 were pooled as the commercial grass seeding). While differences between sources within functional groups were not significant at the 0.10 significance level, the little support for differences in the forb and grass groups suggest that an experiment with more replication and higher cover response may show more support for a significant difference. If true, then the average percent cover shown in Figure 4 suggest that local and alternate forbs may perform better than the commercial, while the commercial grass may perform better than local and alternate. See Appendix K to assess the contribution of the target species to the total cover values (quadrat level). Therefore, total plant cover as shown in Figure 2 was used to assess facilitation interactions between species in a plot.

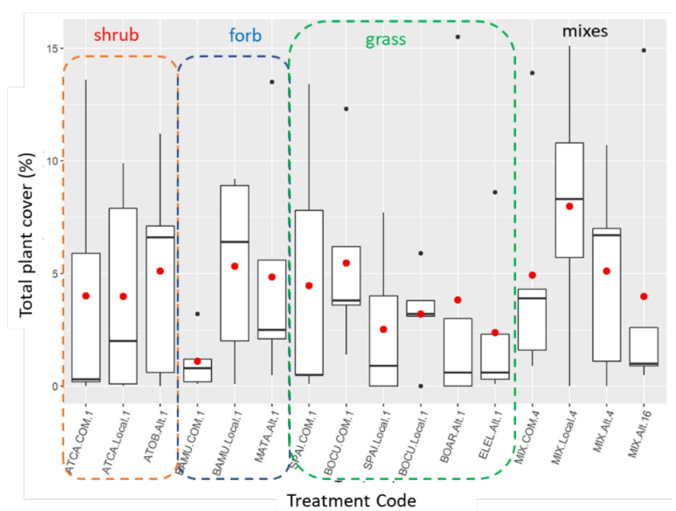


Figure 4. Total plant cover for each treatment. Box plots indicate the range across all 5 sites (n=5 for each treatment). The red dot indicates the mean value and the horizontal bar indicates the median value.

- **By site** – The difference in total percent plant cover by site (Figure 5) was statistically significant ($p<0.001$). The two DOT sites (DOT1 and DOT2) had the highest percent cover and the private land sites (Kerr, Rafter1, and Rafter6) had significantly lower cover with Kerr having the lowest (<1% cover).

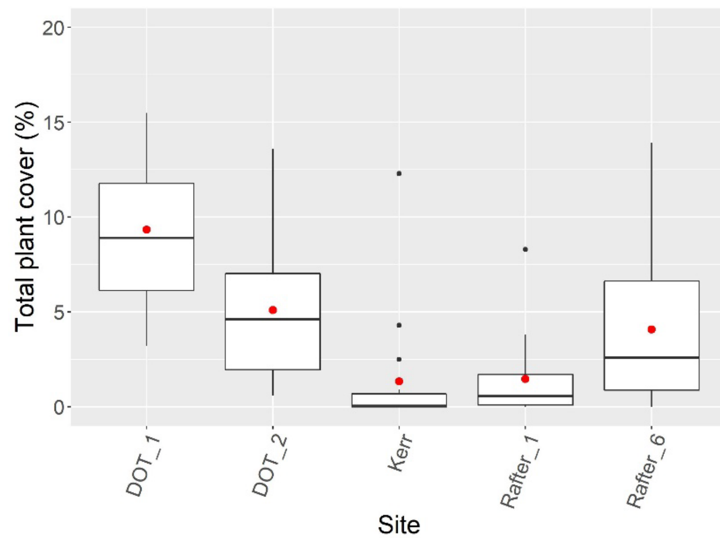


Figure 5. Total % plant cover at each site (n=5). The red dot indicates the mean value and the horizontal bar indicates the median value.

- **By mix type** – Multiple species mixes had higher percent cover than mono-seeded species ($p = 0.10$, Figure 6).

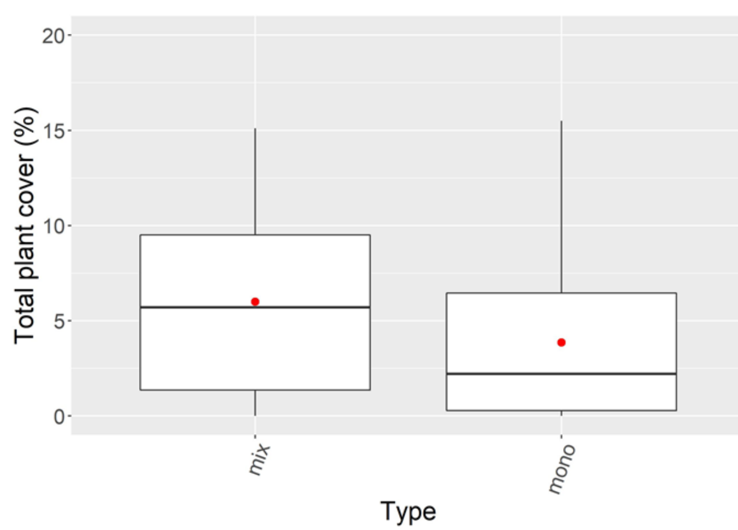


Figure 6. Total plant cover at mix type (n=20 for mix and n=60 for mono). The red dot indicates the mean value and the horizontal bar indicates the median value.

Species Frequency. Counts of each seeded species for all treatments revealed high establishment (8 to > 16 occurrences in quadrats) for *Baileya multiradata* commercial and local, *Bouteloua curtipendula* commercial, *Chloris virgata* alternate16, *Atriplex obovata* alternate, *Bouteloua aristidoides* alternate, *Macaeranthera tanacetifolia* alternate. Medium establishment (1-7 occurrences in plots where seeded) was documented for *Atriplex canescens* commercial and local, *Sporobolus airoides* commercial and local, and *Bouteloua curtipendula* local. No establishment documented for *Elymus elymoides* commercial or the following alternate16 species: *Aristida purpurea, Bothriochloa barbinodis, Bouteloua barbata, Digitaria californica, Hoffmannseggia glauca, Hopia obtusa, Scleropogon brevifolius, Sporobolus flexulosus, Sporobolus wrightii, Thelesperma megapotamicum, Verbesina encelioides*, and *Xanthisma gracile*.

Soil stability

- **By source –** Soil stability did not differ by source (p=0.30, Figure 7)

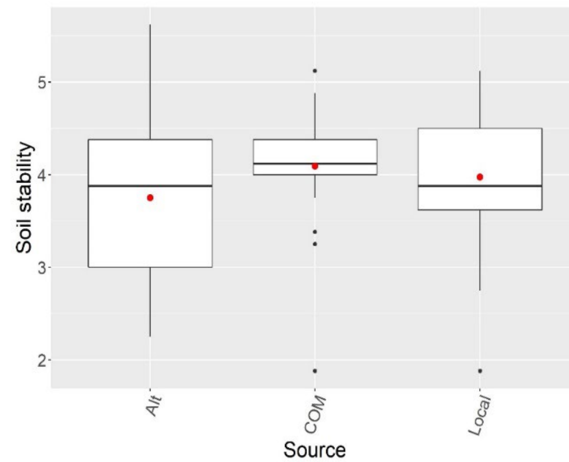


Figure 7. Jornada soil stability score by source. The red dot indicates the mean value and the horizontal bar indicates the median value.

- **before and after seeding –** Post-seeding soil stability across sites (Figure 8) was lower than pre-seeding values (p = 0.102), but higher than expected in 2021 given the high level of disturbance from the soil scarification site preparation treatment. Average baseline soil stability was a 4.5 Jornada score, while post seeding soil stability was 3.9. Observations during the 2021 quantitative monitoring documented when random sampling "hit" hydromulch remnants, the stability class was high (4-6), and when random sampling "missed" the hydromulch, the stability class was low (1-3).

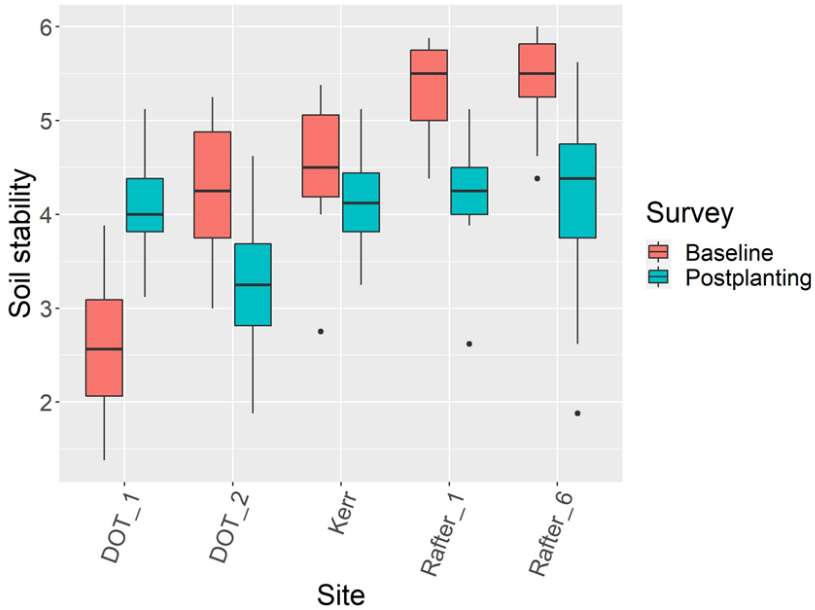


Figure 8. Jornada soil stability mean by site, before and after seeding. Before (baseline) data was collected October 2019 and after (post-planting) data was collected late September 2021.

Plant traits

- Reproduction – 100% of the species measured for plant traits during the September 2021 monitoring visit were flowering. Species included Tahoka daisy (*Machaeranthera tanacetifolia),* *n*eedle grama (*Bouteloua aristidoides),* desert marigold (*Baileya multiradiata),* feather windmill grass (*Chloris virgata),* and mound saltbush (*Atriplex obovata).*

Conclusions and Discussion

Study limitations: Very few replications and poor establishment at all sites, exacerbated by exceptional drought (highest drought ranking for 6 months following seeding 2020-21) were study limitations. These factors contributed to low power for finding statistical significance, and made some analyses not possible, such as an analysis comparing cover of target species.

1. *Can we improve upon standard seed mixes (commercial seed sources used by NM DOT) by including local sources or alternate sources from less frequently used commercially available species or completely novel species?*

   Yes, in general the study revealed approaches that NM DOT could use to potentially improve current seeding practices. The study also confirmed several seeding practices already being used by NM DOT are effective at achieving either higher cover or soil stability.

   Improvement 1 – add novel species *Atriplex obovata*. The results indicated that including *Atriplex obovata* (mound saltbush) in seed mixes would be beneficial since this was the most successful shrub seeded. Mound saltbush is a *novel* alternate species because it is not included in the NM DOT 2017 Zone 5 Seed Mix and is not commercially available. This species was one of the first species to germinate following seeding, and hundreds of individuals were apparent early post-seeding observations and photographs in October 2020. During the drought, most of these seedlings died, but enough individuals survived that the species still showed up as one of the better performers. Presumably in a year where drought conditions are less pronounced or absent, this species would be even more likely to persist and provide significantly more cover. This species is not currently commercially available. This species will now be added to the SWSP target species list for collection and production. Because it is not a traditional crop for seed production fields, it may take a couple of years to find a suitable grower and develop any specialized equipment or technology needed. NM DOT can use hand harvested seed in select locations while this is being developed.

Improvement 2 – prioritize or increase seeding rate for 3 species. Several species already included on the NM DOT 2017 Zone 5 Seed Mix performed well. When purchasing commercially available seed mixes for Zone5, prioritize tansyleaf aster (*Macranthera tanacetifolia)* and needle grama (*Bouteloua aristidoides*). If local sources of desert marigold (*Bailea multiradata)* are not available, prioritize this species in commercial purchases from the next closest ecoregion. It is notable that needle grama was present in 15 of the 16 treatment plots (Appendix H). This indicates that our seeding alone did not result in establishment of this species, and the species is likely ubiquitous in the area and seeds abundant in the soil seed bank and potentially encouraged by the site preparation activities and may not need supplemental seeding.

Increasing the seeding rate for these species is another opportunity for improvement. In the NM DOT Zone 5 2017 species list, the recommended seeding rates for desert marigold and tansyleaf aster are 0.1 and 0.3#/acre respectively. Interestingly the NM DOT standard Zone 5 seeding rate recommended for needle grama is 0.3#/acre, while 1.75#/acre is what is recommended for bottlebrush squirreltail (*Elymus elymoides*) and western wheatgrass (*Pascopyrum smithii*). Squirreltail was one of the seeding treatments in this study (used in both mono and mix seeded plots), and it did not establish at all. And western wheatgrass was not included in the study because the technical committee determined that it was not suited for playas of the Chihuahuan desert. Given that desert marigold and tansyleaf aster were the two most successful species seeded, increasing the percentage of forbs in the seed mix could improve the mix, assuming this is not cost prohibitive. Currently forbs only comprise 20% while grasses comprise 73% of the Zone 5 Seed Mix. Seed mixes may be more successful if seeding rates for tansyleaf aster, needle grama, and desert marigold are increased.

Continue practice of mixed seeding. One of the clearest statistically significant results was the difference between mono-seeded plots and mixed seeded plots, where mixed seeded plots performed better than plots seeded with only one species. NM DOT seeds with a diversity of species with seed mixes that typically include 20 different species. Continuing the of practice seeding mixes is anticipated to be most successful.

Inconclusive results – local vs commercial sources. A common recommendation is to obtain local sourced material to increase restoration success. However, the comparison of local vs commercial sources in this study was inconclusive likely due to low cover overall. Based on other studies with statistically significant findings (Germino et al, 2019 and Leimu and Fischer 2008), using local sources of seed is still recommended.

Water harvesting recommendation based on field observation. While the site preparation did not specifically include any water harvesting techniques, most sites had incidental changes in topography, such as very shallow depressions, where equipment would transition from one plot to the next. These areas often had higerh cover (of predominately annual grasses) and data for this area was not reported in the study because it was at the periphery of the plot. Microtopographic benefits were most apparent at sites known for almost 100% bare ground cover (Rafter6, Rafter1, and Kerr). This observation suggests that creating microtopographic diversity during site preparation, such as imprinting, could increase seedling establishment and cover.

2. Which species, mix type, source (commercial, local, or novel) is most effective at mitigating dust?

Species – While the answer to this research question from field data is inconclusive because more time was time needed for seeded plants to mature and exhibit dust mitigation attributes, the literature review for 95 species conducted during Phase I and intensive rubric scoring by experts on the technical committee identified species with the highest potential for dust mitigation. The Chihuahuan Desert species identified during this evaluation process as having the highest soil stabilization included scarlet globemallow (*Sphaeralcea coccinea)*, fourwing saltbush (*Atriplex canescens*), tabosagrass *(Pleuraphis mutica), and* threadleaf ragwort *(Senecio flaccidus).* The species with the best establishment and spreading was fourwing saltbush (*Atriplex canescens*), followed by sideoats grama (*Bouteloua curtipendula*). The species with the best tolerance for poor soils (common in playas) was alkali sacaton (*Sporobolus airoides*), mound saltbush (*Atriplex obovata*), and streambed bristlegrass *(Setaria leucopila).* Shrubs, such as saltbush *(Atriplex canescens)* and large grasses, such as big sacaton *(Sporobolus wrightii*), were generally recognized as having the stature and type of above ground structures needed to capture airborne dust.

Soil stability – Similarly, the field results for soil stability depending on species, mix type, or source were inconclusive due to underdevelopment of seeded plants and low cover. However, as illustrated in Figure 8, soil stability was relatively high before and after treatments despite soil disturbance during site preparation activities. Higher baseline stability values are likely attributed to a natural crust (physical and/or biological), while high post-planting stability values are likely attributed to the hydromulch application that included both a fibrous material and tackifier. The hydromulch was still present, and presumably supporting soil stability, 1.5 years later. This indicates the NM DOT practice of applying a hydromulch treatment over seedings should be continued to support soil stability while plants are establishing. BLM funded monitoring of these sites in 2022 will document if hydromulch is able to maintain the same levels of soil stability and if new plant cover and growth further support stability.

Site selection – Prior to this experiment it wasn't clear if a species with a particular set of attributes could withstand the poor soil and harsh environmental conditions present in the playa and adjacent upland habitats. The DOT sites and private land sites were all located within the same ecoregion, same DOT veg zone, and same dust impacted areas for the Lordsburg playa identified by NM DOT. However, the private land sites were located within the playa system and had significantly lower cover than the DOT roadside sites. The study showed that while it is possible for some species to establish in a harsh environment, such as the Chihuahuan Desert during an exceptional drought year, that growing plants in a playa system under these conditions is highly unlikely to result in dust mitigation. While site selection is not always an option for NM DOT, locations for vegetative dust barriers may need to be placed in strategic locations where plants have a chance of growing and where plants can also vegetatively create barriers for dust. If alternate locations are not available, other suggestions include soil amendments, abiotic dust mitigation structures (such as con mods), hydrological enhancements, and experimentation with gravel mulch.

E. Resources:

- Appendix H. Mean percent cover all quads within treatment plots

RECOMMENDATIONS

Detailed recommendations provided in the Implementation Plan.

Recommendations for future studies:

- One of the benefits of this project was it was designed to be at a restoration-scale with sufficient acreage for a NM DOT Class A seeding. The Class A seeding requirement in the RFP made the project more practical and comparable to typical NM DOT practices. The disadvantage of the large-scale (1 acre) study blocks with 16 treatments was it limited the number of replications possible. Given that a minimum 20 replications are typically recommended for statistical analyses, the project cost would have been at least 4 times more expensive, making it cost prohibitive. Further obtaining 4 times the quantity of wild collected seed would not have been possible, particularly over a two-year period. Lastly, securing 20 sites with environmental clearances would have been extremely challenging. A future study with smaller treatment areas, fewer treatments, and more replications would provide more precise and statically significant data.
- Because it takes much longer than two years for seeded plants, especially shrubs, to mature to their full height and reproductive potential, assessments of dust mitigation potential via plant trait measurements were not meaningful yet. An alternate approach for assessing dust mitigation potential of target species would be taking measurements on fully grown, mature individuals of these plants growing naturally in wild populations and conduct soil stability tests adjacent to mature plants as well.
- Many native species, particularly those in highly arid desert environments, have strong seed dormancy. They only germinate when conditions are right. When feasible, longer duration studies would allow more time for conditions to encourage germination and may more accurately reflect seeding success.
- Alternate species to consider for future seeding studies that are also novel include *Sporobolus pyramidalis* (SPPY) and *Panicum hirticaule* (PAHI) as these two species occurred frequently and contributed to the majority of vegetative cover present. *Sporobolus pyramidalis* was documented 154 times and *Panicum hirticaule* was documented 61 times.

Summary of Restoration Seeding Recommendations:

1. Include mound saltbush (*Atriplex obovata*) and increase the seeding rate for desert marigold (*Baileya multiradiata*, tansyleaf aster (*Machaeranthera tanacetifolia*), and possibly needle grama (*Bouteloua aristidoides*) in NM DOT Zone 5 seed mixes.
2. Avoid using only a single species in restoration seedings (continue mixed seeding approach).
3. Continue to use hydromulch for improved soil stability following disturbance created by site preparation activities.
4. Identify strategic planting locations for dust abatement in playa systems where soils and hydrologic conditions are more likely to support germination and survival. Rafter and Kerr sites in Table 3 for examples of soils less likely to support plants.
5. Since drought was a major complicating factor for this project and will likely continue to be an issue for the Southwest due to climate change, future projects should plan for drought. One approach, if feasible, is to provide supplemental watering 2-3 times during the normal time of year when rain would occur in a non-drought period. Another approach is to use microtopography/water harvesting techniques such as imprinting.
6. Add abiotic dust mitigation structures (such as con mods) to trap seeds and materials and increase local humidity, while also suppling a dust mitigation structural element.

Task 6: Coordination

A. <u>Background</u> (n/a)

B. <u>Accomplishments</u>

- Kickoff meeting on June 25, 2018, included all project partners. Progress update meetings 2-4 times per year 2018-2022 with NM DOT, Technical Team, and partners.
- Regular coordination with multiple partners during all phases of the project. Partners included NM DOT, germplasm project Technical Team, State Land Office, private landowners (Rafter JL Ranch and Kerr Ranch), NM BLM, Las Lunas and Tucson NRCS Plant Materials Centers, contractors (Ed Kerr, Caldon Seeding and Reclamation), expert botanists, vendors (including Granite Seed Company and fencing material vendors), NMSU, seed producers, seed certification, NMSU seed testing lab, permitting offices, Jornada, and the Native Plant Society of New Mexico.
- Internal coordination with seed collection crews in 2018 and 2019, monitoring crews in 2019 and 2021 and the IAE Conservation Research program in Corvallis.

C. Methods (n/a)
D. Key Findings (n/a)
E. Resources (n/a)

Task 7: Grower Interface

A. Background

- The NM DOT contract with IAE required interfacing with a minimum of three (3) qualified commercial seed production growers, providing the first step to commercial availability of germplasm researched during this project. IAE interfaced with existing Southwest Seed Partnership farmers including Bamert Seed Company, Curtis and Curtis Seed, Texas Native Seed, and Granite Seed as well as several new farmers such as Elk Mountain and Paul Ross (located in Isletta and Albuquerque respectively). IAE coordinated several scoping meetings with the Natural Resources Conservation Service in Los Lunas to facilitate growing this germplasm at the farm in Los Lunas.

B. Accomplishments

- Through the Southwest Seed Partnership, IAE initiated 5 production fields (4.25 acres) in 2021 for Chihuahuan Desert-sourced species (at Bamert Seed Company and Elk Mountain Farms). The 5 species (*Sporobolus flexuosus- 1 acre, Setaria leucopila- 1 acre, Baileya multiradiata 1-acre, Schizachyrium scoparium- 0.125 acre, and Ratibida columnifera- 0.125 acre*) were considered promising candidates for the germplasm study during the DOT evaluation process. Production funding provided by the NM BLM.

C. Methods:

- IAE collected, cleaned, weighed, and inventoried seeds.
- Target species prioritized, seeds available by seed zone assessed.
- Contracts initiated with two producers, accessions built, and seeds delivered.
- Seeds grow and plugs and out planted into production fields. Seeds are harvested and stored.
- Fields inspected each year.

D. Key Findings:

- IAE/SWSP learned that desert marigold in 2021 most likely needs to be direct sown into production fields (rather than started as plugs) since it did poorly in nursery production.
- IAE/SWSP learned that streambed bristlegrass (*Setaria leucopila*) is vulnerable to ergot. IAE and NM BLM partnered with Bamert Seed Company to test different management techniques for this pathogen.

E. Resources:

- IAE Virtual Native Plant Materials Conference recording: SWSP Grower Panel

VALUE ADDED

- $45,500 in external funding was secured for this germplasm project. The New Mexico Bureau of Land Management provided $20,000 in funding for the project to continue with post-seeding monitoring and statistical analysis in 2022-23; $20,000 to extend the 2019 seed collection crew 2 months longer in the season because early season collections were hampered by unseasonably late rains, technical labor staff to assist with 2021 quantitative monitoring and preliminary analyses; and $4,000 for Bamert Seed Company conduct experiment testing different treatments for ergot control in one of the priority species for the germplasm project, *Setaria leucopila*. The Native Plant Society of New Mexico awarded IAE a $1,500 grant for testing seeds in the germplasm project.
- 99# of extra project seeds - 75# delivered to NM DOT for use in restoration projects in February 2021, and the remaining 14# of seed delivered to Dr. Akasha Faist at New Mexico State University (NMSU) for a study identifying barriers to restoration success in the Chihuahuan Desert.
- Production contracts initiated for 4.25 acres with two farmers for six Chihuahuan Desert species with restoration potential evaluated for this project.
- NM DOT specs guide contractors purchase certified seed when it is available. In 2020, IAE partnered with NMSU and BLM to develop the state's first PreVariety Germplasm (PVG) seed certification program, making it possible for growers of source-identified native seed to have these lots inspected for certification. Because Source Identified germplasm has not undergone intentional selection, this germplasm is less likely to experience reduced genetic diversity from this process. PVG seed certification also provides transparency of information regarding seed provenance, helping restoration practitioners match seeds to the sites where they would most likely be adapted.
- IAE assisted NMDOT with project site coordination and selection. IAE located private land sites for the project and developed landowner relationships.
- Publication in Farmer's Almanac: Gisler, M., Mullins M., and Hutchinson, W., 2021. *Developing Native Plant Materials for Roadside Dust Mitigation in Southern New Mexico*; The New Farmer's Almanac (Vol V); The Grand Plan, Greenhorns; pp. 287-289.
- Herbarium voucher specimens and seed collection data are available to NM DOT (on request) for each of the species that were included in 201819 seed collections.
- IAE provided a multimedia presentation at the Society for Ecological Restoration, Southwest conference in 2019, sharing the methods and initial findings of Native Seed Germplasm Study and Development Project.
- A hand-seeding trial was conducted at the 5 research sites (utilizing the unseeded portion of the BAMU plot). This trial provided seeding coverage for the plot and piloted the technique of hand-seeding using heavy seeding rates.
- Fourwing saltbush seed collection targeted to capture the hexaploid (6X) Vallis Race. The hexaploid is expected to be better adapted to the arid playa (Dreeson, personal communication, 2018) and is characterized by smaller seeds and wider leaves and is adapted to bottomlands (Sanderson, 2011).

APPENDICES

Appendix A: Plant Attributes Table - Summary of Literature Review Results

Dust Mitigation and Ecological Attributes for Researched Species: Standard NMDOT Zone 5, 2017 Seed List (p. 1 of 4)

DOT Species	Habit & Distribution	Soil Tolerance (alkalinity, sali	Drought Tolerance	Soil Stabilization	Establishment and Spread	Collection Feasibility	Miscellaneous
Desert marigold **Baileya multiradiata** Asteraceae	Short annual, biennial, or short-lived perennial. Widespread in S NM including on desert plains.	Can grow on fine-textured, clay soils. No information on alkalinity tolerance. Common on sandy plant community where vegetation is adapted to high salinity in Chaves County.	Drought tolerance implied by occurrence at Jornada Experimental Range. Grows in sandy or gravelly soils in dry areas.	Annual from a taproot. Forms mounds, has densely branched base. Often used in revegetation seeding in Southwestern deserts and desert grasslands (James).	No seed treatment for fall sowing; spring sown seeds need a moist chilling period.	168 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 3 collections and 7 collectable populations scouted by 2018 seed crew.	Valuable to native bees. The desert marigold moth (Schinia minima) specializes on BAMU. Toxic to sheep and goats.
Tanseyleaf tansyaster ***Machaeranthera tanacetifolia*** Asteraceae	Annual or biennial, from a taproot. Widespread in S NM including desert shrublands.	Maximum pH of 8.5, and low salinity tolerance but common on sandy plant community where vegetation is adapted to high salinity in Chaves County. Grows best on well-drained sandy or rocky soils, but can also grow in medium loam, clay loam, or clay.	Sparse information indicates medium drought tolerance.	Annual from a taproot.	Valued in restoration because it has high viability, is tolerant of most germination conditions, and is less affected by cheatgrass than the other species. Reproduces by seed and persists under heavy grazing.	45 records in the Chihuahuan Basins & Playas Level IV Ecoregion. Produces large amounts of seed.	Supports pollinators.
Alkali sacaton ***Sporobolus airoides*** Poaceae	Warm season perennial bunchgrass. Widespread, including on clay plains, playas, floodplains. On target ESD lists.	Tolerant of salinity and pH 9.0. Grows in all soil textures. Often a primary invader of saline soils; dominates floodplain and playa beds.	Tolerant of drought and inundation (but perhaps not prolonged inundation).	Often used for seeding and stabilizing disturbed areas, especially saline.	Reproduces via seeds and tillers - produces abundant seed that remains viable for many years. Seeds do not need to be scarified as they are more permeable than other *Sporobolus* seeds (USDA Fact Sheet, Jackson 1928). Seeds require a 9-month after-ripening/dormancy period	73 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 8 collections and 29 collectable populations scouted by 2018 seed crew. Beware of cultivars - 'Salado' released by Los Lunas Plant Materials Center in 1982 in central New Mexico (USDA Fact	Good forage for livestock and wildlife. Fire tolerant but can be killed in a severe fire (USDA Fact Sheet, USFS FEIS). Polyploids races as high as 14x have been reported
Sand dropseed ***Sporobolus cryptandrus*** Poaceae	Warm season perennial bunchgrass. Widespread, including in salt-desert scrub. On Salt Flats ESD list.	Moderate alkalinity and fine textured soil tolerance; collected throughout CO on sandy loam, loam, clay loam, and silty clay loam and pH up to 9.0. Low salinity tolerance.	Extremely drought tolerant due efficient water extraction efficient and reduced surface area evapotranspiration.	Has fine roots that can rebranch to form a dense, sand binding network. Often used in erosion control in sandy areas.	Extremely prolific seeder and large contributor to the seed bank. Pioneer in areas suffering from water stress. Seeds require scarification. Seedlings can have low vigor, but are drought tolerant once established.	20 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 5 collectable populations scouted by 2018 seed crew.	Fair to good forage for livestock and wildlife. Polyploidy; Evidence of local adaptations in phenology and phenological plasticity.
Sideoats grama ***Bouteloua curtipendula*** Poaceae	Perennial, warm season rhizomatous or bunchgrass. Widespread in S NM. Grows in a variety of habitats, no playas mentioned.	Adapted to moderately alkaline soils. Low salinity tolerance. Broad range of texture tolerance from sandy to clayey texture soils. Least tolerant of loose sands and dense clays. The best stands are found on medium to fine texture upland soils.	Medium to high. High drought resistance has been reported in the Midwest but limited data on drought resistance available for the Southwest.	Many coarse, fibrous roots to 2-4 feet down and 1-1.5 feet laterally in the top 2-4 inches of soil. Recommended in grass mixtures for bank stabilization, considered fair to good for erosion control. Forms large, continuous patches.	Fair seed production but relatively low viability. Seedling vigor is good to excellent and seedlings are somewhat drought tolerant. Improved success with moisture and mulch. Field germination, emergence, and establishment are better than other Bouteloua species.	27 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 6 collections and 17 collectable populations scouted by 2018 seed crew. Beware of cultivars.	Important range species, also provides forage for antelope, deer, and elk (USDA Plant Guide, USDA Fact Sheet).
Needle grama ***Bouteloua aristidoides*** Poaceae	Short annual bunch grass. Widespread in S NM, including on alluvial plains and on playa fringes.	Little information available. Occurrence on playa fringe shows *potential* for salinity, alkalinity, and/or fine textured soil tolerance. Possesses salt glands to excrete salts, which is an adaptation to saline soils.	Little information available. May have evolved autogamy and annuality to avoid drought. Present on a list of low water and drought tolerant plants from the Arizona Department of Water Resources.	Small annual with weakly developed roots Weak-stemmed and short-lived.	Very little information available. Reproduces by seed, growth increases after summer rains and lasts about two months, then deteriorates rapidly.	78 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 2 collections and 1 collectable populations scouted by 2018 seed crew.	Low grazing forage value - short green period and plants easily uprooted.
Fourwing saltbush ***Atriplex canescens*** Chenopodiaceae	Shrub, moundlike, up to 8'. Widespread in S NM, including in desert shrublands.On Salty Bottomland and Salt Flats ESD lists.	High alkalinity tolerance up to pH 9.5, adapted to all soil textures. Adapted to all soil textures, high salinity tolerance. Especially useful on saline-sodic soils (USDA Fact Sheet).	Extremely drought tolerant, intolerant of high water tables or late winter inundation.	Root system provides excellent erosion control, used extensively for reclamation of disturbed sites. Root systems are branched can reach depth of 20 feet. The deep roots help stabilize soils.	No prechilling requirements but seed may require 10 months after-ripening. Seedling vigor is often outstanding. Usually spreads via seed production, but may also root sprout following wildfire or if covered with sand. 3-4 y to establishment, then fairly competitive.	225 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 15 collections and 17 collectable populations scouted by 2018 seed crew. Several cultivars.	Valuable browse plant for most livestock as well as wildlife. Ploidy variation (4x, 6x, 8x, 10x, 12x, 14x, 20x) may be associated with adaptation to soil texture.

Dust Mitigation and Ecological Attributes for Researched Species: Novel Species (p. 2 of 4)

Species	Habit & Distribution	Soil Tolerance (alkalinity, sali	Drought Tolerance	Soil Stabilization	Establishment and Spread	Collection Feasibility	Miscellaneous
Threadleaf ragwort ***Senecio flaccidus*** Asteraceae	Perennial subshrub to 2 m tall. Widespread in S NM, including on plains, bajadas. On Salty Bottomland ESD list.	Occurs on a wide range of soil types. Var. douglasii and var. flaccidus occasional in grasslands adapted to high salinity in Chaves County. Var. flaccidus also in a fine-textured silt marsh in West Texas.	Drought tolerant/low water usage.	Taprooted perennial subshrub, can achieve a quick ground cover in a natural succession process - helps stabilize soils for longer-lived perennials to eventually become established.	No information on germination or production. Produces numerous flower heads and grows rapidly; quickly invades open disturbed areas, and lives 3-6 years.	17 records from Chihuhuan Basins & Playas Level IV Ecoregion, no 2018 collections or scouted populations.	Toxic to cattle, sheep, horses, and goats, increase as a result of overgrazing.
Golden crownbeard ***Verbesina encelioides*** *Asteraceae*	Annual forb, 10-50 cm tall. Common in S NM, including on plains, washes, arroyos, around playa lakes. Present on 1 research plot.	Adapted to medium and fine textured soils, pH up to 8.5. Can germinate in a variety of soil textures and habitats, including alkaline, and up to 50% clay. No salinity tolerance , yet is abundant in disturbed plant comm unities adapated to high salinity in Chaves County.	Drought tolerant.	Annual from a taproot.	Can germinate in fine textured soils up to 50% clay, optimally at 21% soil moisture. Reproduces exclusively by seed but invasive outside of native range, fast growing, with high reproductive potentia; pioneer in disturbed habitats	17 records from Chihuhuan Basins & Playas Level IV Ecoregion, no 2018 collections or scouted populations.	Toxic to livestock due to chemical galegine.
Indian rushpea ***Hoffmannseggia glauca*** Fabaceae	Perennial subshrub, 15-30 cm tall. Widespread in S NM, including on alkaline soils and desert scrub.	Sandy or loamy sandy soil. Alkaline soil. Saline soil.	Wide tolerance to drought, high water transport efficiency in root system.	Deeply buried, creeping rhizome. Aboveground stems are renewed annually or seasonally. Can form large colonies, good soil binder .	High seed production but low germination; mainly vegetative reproduction through tubers and root borne buds. Weedy and agressive, formings large colonies . Early development of extensive root system.	142 records in the Chihuahuan Basins & Playas Level IV Ecoregion; no collections or collectable populations scouted by 2018 seed crew. Fabaceae can have high seed predation.	
Southern goldenbush ***Isocoma pluriflora*** Asteraceae	Woody perennial forb or subshrub. Widespread in NM. Grows on floodplains, flats, seepy ground. On Salt Flats ESD list.	Can occur on clay soils, dry mesas and plains on saline and/or alkaline soils.	Little information available, but occurrence on floodplains, flats, bajadas, seepy ground, ditches, and drainages suggests medium drought tolerance.	Little information avaliable. Perennial subshrub with a woody caudex or root stalk.	Little information avaliable. However, it is an aster with many flowering heads, so it likely produces a lot of seed. It is also a common invader of depleted rangelands and oil fields - disturbed areas and seems to spread well.	16 records in the Chihuahuan Basins & Playas Level IV Ecoregion; no collections or collectable populations scouted by 2018 seed crew. Can be difficult to key from *Ericameria nauseosa* .	Toxic range plant.
Burroweed ***Isocoma tenuisecta*** Asteraceae	Widespread in S NM including clay badlands in desert brush, alluvial plains. On Salty Bottomlands and Salt Flats ESD lists.	Can occur on fine0textured soils. No information on salinity or alkalinity tolerance.	Susceptible to drought and often dies following drought periods. However, following droughts, may increase in number.	Deep, relatively unbranched, 3-6 m long root system.	No information avaliable on germination and establishment. Resilient to disturbance.	41 records in the Chihuahuan Basins & Playas Level IV Ecoregion; no collections or collectable populations scouted by 2018 seed crew.	Toxic to livestock - livestock avoid it unless there is nothing else to eat.
Mojave seablite ***Suaeda nigra*** Chenopodiaceae	Annual or perennial forb or shrub. Widespread in S NM, including in saline, alkaline, clay flats, playas.	Found in saline and alkaline wetlands, clay flats, and playas. Genus has high salinity tolerance.	Obligate wetland plant in the arid West; drought-intolerant. Requires water within 1 m of the surface, or at the surface. Can occur in dry soil near the water table or on playa edges.	Most hygro-halophytes have shallow, fibrous root systems to absorb water near the surface.	Reproduces by seed. Grew well in restoration trials in CA (Borders et al. 2009). Seed dimorphism related to germination success in varying soil salinities and temperatures.	20 records in the Chihuahuan Basins & Playas Level IV Ecoregion; no collections or collectable populations scouted by 2018 seed crew. Lookalikes: *Kochia californica; K. scoparia* (invasive).	In New Mexico, a short-leaved, densely villous phenotype can grow on gypsiferous soils.
Lemonscent ***Pectis angustifolia*** Asteraceae	Annual forb, usually 2-5 (20) cm high. Widespread in S NM, including canyon bottoms, desert bush scrub.	Sparse information. Widespread and abundant in some years among saline-adapted plant cmty in Chaves County. Occurrence on saline, alkaline, clay flats and playas suggests tolerance.	High drought tolerance.	Short annual, bushy or single stemmed, weakly developed root system.	Requires relatively high soil temperatures to germinate (50ºC for 14 days in greenhouse). Germination maximal when seeds covered and moist. No evidence of genetically-fixed innate dormancy. Slow seed spread rate and medium seedling vigor.	108 records in the Chihuahuan Basins & Playas Level IV Ecoregion; no collections or collectable populations scouted by 2018 seed crew. Very low to the ground, might be difficult to collect.	

Dust Mitigation and Ecological Attributes for Researched Species: Novel Species (p. 3 of 4)

Tobosagrass ***Hilaria mutica*** *(Pleuraphis mutica)* Poaceae	Perennial warm season rhizomatous, 30-60 cm. Widespread in S NM, incl. playa-associated. On Salt Flats and Salty Bottomlands ESD lists.	Typical on mildly to strongly alkaline soils to pH 8.8; tolerates mildly saline soils. Clay soil indicator. Prefers moist, fine-textured soils, including clays and loams, can grow around playas.	Grows best on moist soils, but drought tolerant. Rapidly returns to pre-drought levels. Not readily killed by severe 3-year and 5-year droughts in the 1910s and 1950s, at Jornada.	Rhizomatous, with short internodes resulting in a tufted habit. Thick, hard base and dense, coarse, fibrous roots that are usually shallow (< 2') but mayup to 6 ', lateral spread <2'. Sod-forming with moisture, tufted when dry.	Mainly rhizomatous with low seed production and viability. Germination variable; best under moist, warm conditions, with scarification. Seedling survival generally low; few seedlings in wild. Monotypic or co-dominant with other competitive grasses.	Seed can be provided by Tucson PMC. 100 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 29 populations scouted by 2018 seed crew.	Can accumulate large amounts of slowly decaying litter that can limit production.
Streambed bristlegrass ***Setaria leucopila*** Poaceae	Perennial, warm season bunchgrass, to 40". Widespread in S NM, generally on bottomlands, alluvial flats, loamy bottomland, clay flat, and saline range.	Adapted to fine textured soils - most often found on clay to clay loam sites, clay flats, loamy bottomlands. Common on alkaline soils. Common on saline range sites.	Extremely drought tolerant - generally found in dry rangelands in the Southwest with an annual rainfall of 10-26 inches.(Lordsburg averages 10.76 to 12.36")	Long-lived, densely tufted with fibrous roots, useful for highway right-of-ways and ecosystem restoration	Good seed produce but difficult to germinate due to physical or chemical dormancy; best to scarify seed. Mainly seed reproduction; highly weedy and invasive; adaptable colonizer. Decreases rapidly under grazing.	23 records in the Chihuahuan Basins & Playas Level IV Ecoregion. Very difficult to differentiate from *Setaria macrostachya* , but more common. May hybridize with *S. texana, S. vulpiseta,* and *S. scheele.* Watch out for culviar 'Stevan', which was developed in Tuscon for use in AZ, NM, and TX	Should not be grazed in the first year, but fair to good forage for livestock and wildlife. Seeds can provide a food source in upland-bird habitats.
Arizona cottontop ***Digitaria californica*** Poaceae	Perennial warm season bunchgrass, 1.5-2'. Widespread in S NM; Plains, foothills, bajadas, slopes, and open areas.	Tolerates pH up to 8.3, can grow on moderately alkaline soils and on bottomland saline and sodic soils. Can tolerate strongly saline soils (to 36 dS/m). Can occur on clay soils.	Seedlings need moisture, but once plants are established they are drought hardy - populations are maintained by establishment of new plants from seed during wet years. Can be seeded in areas receiving at least 11" of annual precipitation.	Little information available. Root system is finely divided and branched, and mostly in the upper 8 inches of soil. The roots can extend to about 40 inches in coarse-textured soils, but our soils are medium to fine-textured.	97% germination rate under ideal conditions, but needs moisture for seedling survival and mature plant growth. High seed production; viability to 10 years.Tolerates competition with competitive grasses; can become dominant when protected from grazing; can form pure stands on wetter sites.	8 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 4 collections and 4 collectable populations scouted by 2018 seed crew.	Grazed by livestock and wildlife. Tolerates relatively heavy grazing, but is frequently over grazed because it is highly palatable throughout the year.
Giant sacaton ***Sporobolus wrightii*** Poaceae	Perennial warm season bunchgrass, 3-8'. Widespread in S NM on swales, playas, hard-packed alkaline soil. On Salty Bottomland and Salt Flats ESD lists.	High salinity tolerance. Useful for revegetation of saline soils. Primarily grows on heavier lowland or wetland soils, tolerant of highly alkaline and saline soils and poorly drained soils and seasonally flooded areas.	Drought-resistant once established, but needs occasional flooding for seedling growth. Declines in vigor and size when groundwater below ~5 m.	Helps stabilize watershed structures, streambanks, and floodplain areas. Deep rooted.	Seed reproduction; low germination and estalishment rates at high temps. Seedlings require occasional flooding, but in dry conditions similar to *Bouteloua curtipendula* . Lacks specializeddispersal mechanisms but previous dominance of millions of acres of SW floodplain habitatsuggests high potential for spread in wet areas. Don't graze for the first year.	6 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 1 collectable population scouted by 2018 seed crew.	
Cane bluestem ***Bothriochloa barbinodis*** 	Perennial warm season bunchgrass, 2-4'. Widespread in S NM, including arid plains, drainage ways. On Salt Flats ESD list.	Little information available re: alkalinity/fine-textures but occurrence on alkaline clays and loams, clay loams and bottomlandssuggests tolerance. Low to moderate salinity tolerance. Can grow on a variety of soil types and textures, but growth may be best on calcareous, deep loams, or sandy loams.	High to very high drought tolerance if supplemented by occasional heavy precipitation, ideally 12-16' annually. Seedlings need moisture (USFS FEIS).	Can be used for erosion control on rangelands, road cuts - areas with exposed soil . Produces dense, fibrous roots that extend 1-4 feet deep.	High germination in field and lab studies. Postgermination moisture important. Variable seed producer; tillering also occurs. May produce seed in its first year.	17 records in the Chihuahuan Basins & Playas Level IV Ecoregion; no collections or collectable populations scouted by 2018 seed crew. Lookalikes: *B. wrightii* , *B. alta* , and *B. springieldii* . Beware of cultivars.	Valuable forage species for cattle sheep, and wildlife. Susceptible to grazing pressure; indicator of good range condition.
Vine mesquite ***Hopia obtusa*** *(Panicum obtusum)* Poaceae	Perennial warm season rhizomatous/stoloniferous grass. Widespread in S NM, including on heavy soils of swales, playas, flats, and low spots. On Salt Flats and Salty Bottomland ESD lists.	High salinity tolerance (8-12dS/m). No information on the pH range but its occurrence on Salt Flats and Salty Bottomland ESD lists, two of our soil series lists, and its abundance on and adjacent to a playa at the Jornada LTER suggests alkalinity tolerance. Many soil textures; most abundant on sandy to sandy loam soils. Frequent in periodically dry depressions, riparian ditches, lowland pastures.	Low drought tolerance but may not require flooding for growth. Drought susceptibility similar to *Sporobolus flexuosus, Aristida pupurea, Bouteloua eriopoda,* and *Scleropogon brevifolius* .	Good for erosion control; highly rhizomatous and stoloniferous perennial, 20-80 cm tall, from long slender stolons or shallow rhizomes. Rhizomes up to 1 meter.due to its rhizomatous/stoloniferous habit.	Poor-fair germination and seedling establishment but once established, stand maintenance can be good. Readily establishes on silty and clay soils. Alternating temperatures, and chemical seed pretreatments improve germination.	11 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 4 collections and 5 collectable populations scouted by 2018 seed crew.	

Dust Mitigation and Ecological Attributes for Researched Species: Novel Species (p. 4 of 4)							
Feather fingergrass ***Chloris virgata*** Poaceae	Annual, warm-season grass, +/- tufted, weak stems, shallow roots, to 31". Widespread in S NM; no association with playa.	Alkali tolerant halophyte adapted to both saline and alkaline soils; occurs on highly alkaline soils (pH >10) with no growth impact documented at pH 8.74. Optimal germination from pH 6.4-8. Occurs on sandy-silty soils, washes, roadsides, agricultural fields, and other disturbed areas in the Southwest.	Drought-tolerant (CABI, Ying et al. 2018). In a watering experiment, it was found that CHVI4 still reproduced during drought conditions. However, seed size decreased with increased water stress while germination rates and seedling rates increased with water availability (Ying et al. 2018).	Annual with short roots, so soil stabilization might not be it's strongest suit. However, on disturbed soils it can form dense stands after summer rains (SEINet).	Little information on germination. Germinates in 1-3 days in the laboratory, and in alkaline and saline conditions. High spread; aggressive weed outside of its native range due to prolific seed production and dispersal by wind and water.	31 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 0 collections and 0 collectable populations scouted by 2018 seed crew.	Inconsistent assignment to native status (native in USDA Plants, SEINet, CABI, alien Cox 2001,. Gleason & Cronquist 1991, Allred & Ivey 2012.
Whorled dropseed ***Sporobolus coromandelianus*** Poaceae	Ann. or short-lived per. warm season bunchgrass, 7-35 cm tall. Rare in S NM. Grows on sandy plains, clay flats, and disturbed ground.	Frequently on saline clay or alkaline inland soils; disturbed areas and clay flats.	Little information online; assume some drought tolerance due to occurrecne in Chihuahuan DesertLevel III Ecoregion. As Faculative Upland (FACU) species in the arid west, it usually grows in non-wetlands but may occur in wetlands (USDA Plants).	An annual or short-lived perennial, can form pure stands and "the primary use of whorled dropseed is to stabilize saline and/or alkaline soil conditions."	Little information on germination. Fast growing with high reproductive potential, mature seed is sticky and can disperse rapidly. Invasive and weedy outside of its native range, effective competitor due to alleopathic effects however can self-inhibit leading to growth reduction in the center of stands.	8 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 0 collections and 0 collectable populations scouted by 2018 seed crew.	
Mound saltbush ***Atriplex obovata*** *Chenopodiaceae*	Sub-shrub, 2-8 dm. Common in bootheel of NM, including salt-desert scrub, fine textured soils. Genus on Salty Btmlnds, Salt Flats ESD lists.	Adapted to fine-textured soils, tolerates strognly saline, alkaline, and sodic soils.	Documented high drought tolerance.	Useful for stabilizing disturbed sites due to tolerance of alkaline and saline soils that few other species can grow on. Invades disturbed margins of new highways.	Optimal germination with sprign sowing after 3.5+ months of over-ripening. Grows rapidly. Most sucessful of seven studied chenopod shrubs;>80% survival after 6 years with out without irrigation.	31 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 2 collections and 0 collectable populations scouted by 2018 seed crew.	Dioecious. Can hybridize with A. canescens in Mexico.
Armed saltbush ***Atriplex acanthocarpa*** Chenopodiaceae	Shrub, 3-10dm. Infrequent in S NM; locally common on alkaline soils, playas. Genus on Salty Btmlnds, Salt Flats ESD lists.	Adapted to alkaline soil. High salt tolerance. Used in restoration with high salinities with complex alkaline and saline problems.	Prefers well-drained, dry sites; susceptible to cotton root rot at wetter sites. Less tolerant to drought than *Atriplex canescens* .	No information. *Atriplex* in general are useful for reclamation and stabilization of disturbed areas due to their ability to grow in difficult soil conditions.	Difficult to grow from seed because it has particular conditions under which it will germinate (USDA Plant Guide).	14 records in the Chihuahuan Basins & Playas Level IV Ecoregion; 0 collections and 0 collectable populations scouted by 2018 seed crew.	Diecious.Can hybridize with A. canescens in Mexico.Provides shelter for birds and small animals, also nutritious browse for cattle and deer (USDA Plant Guide).

Appendix B: Information sources for each researched species, in alphabetical order by species.

Atriplex acanthocarpa

SEINet. *Atriplex acanthocarpa. http://swbiodiversity.org/seinet/taxa/index.php?taxon=125*

USDA Plant Guide. Armed Saltbush *Atriplex acanthocarpa.* https://plants.usda.gov/plantguide/pdf/pg_atac.pdf

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Sanderson, S. C., & Stutz, H. C. 2001. Chromosome races of fourwing saltbush (Atriplex canescens), Chenopodiaceae. USDA Forest Service Proceedings RMRS-P-21.https://www.fs.fed.us/rm/pubs/rmrs_p021/rmrs_p021_075_088.pdf

Atriplex canescens

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USDA-NRCS. Ecological Site Characteristics: Salty Bottomland (R042XC033NM). https://esis.sc.egov.usda.gov/ESDReport/fsReport.aspx?approved=yes&rptLevel=all&id=R042XC033NM

USDA-NRCS Plant Fact Sheet. Fourwing saltbush, Atriplex canescens. https://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/idpmcfs11638.pdf

USDA-NRCS Plant Guide. Fourwing saltbush, *Atriplex canescens* . https://plants.usda.gov/plantguide/pdf/pg_atca2.pdf

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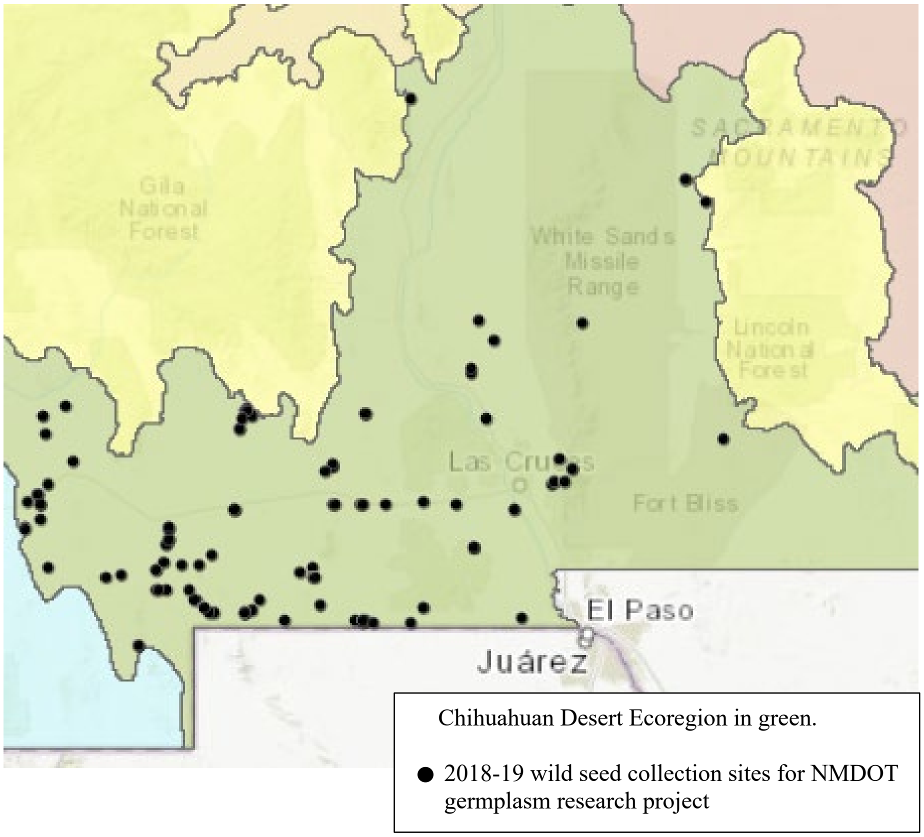
Appendix C. Map of 2018-19 Seed Collection Sites



Appendix D. Wild seed collection – species and quantities

species	code	common name	clean seed weight (#)
Aristida purpurea	ARPU	purple three awn	0.304
Atriplex canescens	ATCA	fourwing saltbush	43.89
Atriplex canescens	ATCA-HEXA	hexaploid	2.07
Atriplex obovata	ATOB	mound saltbush	13.32
Baileya multiradiata	BAMU	desert marigold	1.939
Bouteloua aristidoides	BOAR	needle grama	0.328
Bouteloua curtipendula	BOCU	sideoats grama	13.57
Bothriochloa barbinodis	BOTBAR	cane bluestem	0.733
Bouteloua barbata	BOUBAR	sixweeks grama	0.792
Chloris virgata	CHVI	feather fingergrass	0.397
Digitaria californica	DICA	Arizona cottontop	0.612
Hoffmannseggia glauca	HOGL	Indian rushpea	0.233
Hopia obtusa	HOOB	vine mesquite	0.890
Machaeranthera tanacetifolia	MATA	tansyleaf aster	0.121
Scleropogon brevifolius	SCBR	burro grass	0.315
Setaria leucopila	SELE	streambed bristlegrass	0.263
Sporobolus airoides	SPAI	alkali sacaton	10.437
Sporobolus flexulosus	SPFL	mesa dropseed	0.264
Sporobolus wrightii	SPWR	big sacaton	5.851
Thelesperma megapotamicum	THME	cota	0.500
Verbesina encelioides	VEEN	golden crownbeard	0.673
Xanthisma gracile	XAGR	slender goldenweed	0.16
		TOTAL	97.664

Appendix E. Destinations of seed remaining following experimental seeding

Destination : NM DOT Restoration

species	common name	lbs
Atriplex canescens	fourwing saltbush	32
Atriplex canescens	fourwing saltbush	9
Baileya multiradiata	desert marigold	4
Bouteloua aristidoides	needle grama	8
Bouteloua curtipendula	sideoats grama	6
Elymus elymoides	squirreltail	6
Machaeranthera tanacetifolia	tansyleaf aster (commercial)	4
Sporobolus airoides	alkali sacaton	6
	TOTAL	75

Destination : NMSU Faist Lab + grower

species	common name	lbs
Bouteloua aristidoides	needle grama	0.02
Bothriochloa barbinodis	cane bluestem	0.20
Chloris virgata	feather fingergrass	0.02
Digitaria californica	Arizona cottontop	0.002
Machaeranthera tanacetifolia	tansyleaf aster	0.02
Verbesina encelioides	golden crownbeard	0.2
Atriplex obovata	mound saltbush	4
Bouteloua curtipendula	sideoats grama	3
Sporobolus airoides	alkali sacaton	4
Sporobolus wrightii	big sacaton (local source)	3
	TOTAL	14

Appendix F. Final planting design NMDOT germplasm project

Site	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Plot 13	Plot 14	Plot 15	Plot 16
Rafter 1	new shrub	new grass 2	local grass 1	DOT grass 1	local shrub	DOT forb	local grass 2	mixed new 1	DOT shrub	new grass 1	local forb	new forb	mixed DOT	DOT grass 2	mixed new 2	mixed local
	ATOB	ELEL	SPAI	SPAI	ATCA	BAMU	BOCU	BOAR, ELEL, MATA, ATOB	ATCA	BOAR	BAMU	MATA	SPAI, BOCU, BAMU, ATCA	BOCU	*16 species	SPAI, BOCU, BAMU, ATCA
Rafter 6	new forb	mixed local	local grass 1	new grass 1	mixed new 2	DOT forb	new shrub	mixed DOT	new grass 2	local grass 2	DOT shrub	DOT grass 1	DOT grass 2	local shrub	local forb	mixed new
	MATA	SPAI, BOCU, BAMU, ATCA	SPAI	BOAR	*16 species	BAMU	ATOB	SPAI, BOCU, BAMU, ATCA	ELEL	BOCU	ATCA	SPAI	BOCU	ATCA	BAMU	BOAR, ELEL, MATA, ATOB
Kerr	DOT shrub	DOT forb	mixed local	local shrub	new grass 2	new grass 1	mixed new 2	local grass 2	local grass 1	new forb	local forb	mixed new	new shrub	DOT grass 1	DOT grass 2	mixed DOT
	ATCA	BAMU	SPAI, BOCU, BAMU, ATCA	ATCA	ELEL	BOAR	*16 species	BOCU	SPAI	MATA	BAMU	BOAR, ELEL, MATA, ATOB	ATOB	SPAI	BOCU	SPAI, BOCU, BAMU, ATCA
DOT 1	DOT shrub	mixed new 2	local shrub	new grass 2	mixed DOT	DOT forb	new forb	new shrub	DOT grass 1	mixed local	local forb	new grass 1	DOT grass 2	mixed new	local grass 1	local grass 2
	ATCA	*16 species	ATCA	ELEL	SPAI, BOCU, BAMU, ATCA	BAMU	MATA	ATOB	SPAI	SPAI, BOCU, BAMU, ATCA	BAMU	BOAR	BOCU	BOAR, ELEL, MATA, ATOB	SPAI	BOCU
DOT 2	new grass 1	mixed new 2	local shrub	mixed DOT	DOT grass 1	new shrub	DOT forb	new forb	new grass 2	local grass 2	DOT shrub	mixed new	local grass 1	local forb	mixed local	DOT grass 2
	BOAR	*16 species	ATCA	SPAI, BOCU, BAMU, ATCA	SPAI	ATOB	BAMU	MATA	ELEL	BOCU	ATCA	BOAR, ELEL, MATA, ATOB	SPAI	BAMU	SPAI, BOCU, BAMU, ATCA	BOCU

Appendix G. Seeding rates by species by treatment. Plots seeded at a rate of 10.28#/acre.

code	species	common name	type of plot	PLS%	mono rate	mono bulk #	mix rate	mix bulk #
BAMU	*Baileya multiradiata*	desert marigold	DOT forb	83	0.64	0.77	0.129	0.155
SPAI	*Sporobolus airoides*	alkali sacaton	DOT grass 1	91.2	0.64	0.66	0.235	0.242
BOCU	*Bouteloua curtipendula*	sideoats grama	DOT grass 2	93.4	0.64	0.69	0.235	0.252
ATCA	*Atriplex canescens*	fourwing saltbush	DOT shrub	49.9	0.64	1.29	0.045	0.090
MATA	*Machaeranthera tanacetifolia*	tansyleaf aster	New forb (commercial)	65.4	0.64	0.99	0.129	0.198
BOAR	*Bouteloua aristidoides*	needle grama	New grass 1 (commercial)	70.3	0.64	0.92	0.235	0.335
ELEL	*Elymus elymoides*	squirreltail	New grass 1 (commercial)	92.6	0.64	0.69	0.235	0.252
ATOB	*Atriplex obovata*	mound saltbush	New shrub (local)	55.9	0.64	1.15	0.045	0.080
SPAI	*Sporobolus airoides*	alkali sacaton	Local grass 1	85.3	0.64	0.75	0.235	0.275
BOCU	*Bouteloua curtipendula*	sideoats grama	Local grass 2	41.1	0.64	1.56	0.235	0.571
ATCA	*Atriplex canescens*	fourwing saltbush	Local shrub	33.7	0.64	1.91	0.045	0.133
BAMU	*Baileya multiradiata*	desert marigold	Local forb	49.0	0.64	0.32	0.129	0.065
ATCA- HEXA	*Atriplex canescens 6X*	fourwing saltbush 6X	trial shrub	14.8	n/a	n/a	0.045	0.304
SPWR	*Sporobolus wrightii*	big sacaton	trial grass 1	77.6	n/a	n/a	0.047	0.279
BOTBAR	*Bothriochloa barbinodis*	cane bluestem	trial grass 2	42	n/a	n/a	0.047	0.140
BOAR	*Bouteloua aristidoides*	needle grama	trial grass 3	39	n/a	n/a	0.047	0.060
BOUBAR	*Bouteloua barbata*	sixweeks grama	trial grass 4	31.1	n/a	n/a	0.047	0.134
CHVI	*Chloris virgata*	feather fingergrass	trial grass 5	31	n/a	n/a	0.047	0.075
DICA	*Digitaria californica*	Arizona cottontop	trial grass 6	67	n/a	n/a	0.047	0.096
SPFL	*Sporobolus flexulosus*	mesa dropseed	trial grass 7	45	n/a	n/a	0.047	0.052
ARPU	*Aristida purpurea*	purple three awn	trial grass 8	56	n/a	n/a	0.047	0.061
SCBR	*Scleropogon brevifolius*	burro grass	trial grass 9	41	n/a	n/a	0.047	0.063
HOOB	*Hopia obtusa*	vine mesquite	trial grass 10	19.9	n/a	n/a	0.047	0.178
BOTBAR	*Bothriochloa barbinodis*	cane bluestem	trial grass 2	42.0	n/a	n/a	0.047	0.065
HOGL	*Hoffmannseggia glauca*	Indian rushpea	trial forb 1	44.5	n/a	n/a	0.026	0.047
THME	*Thelesperma megapotamicum*	cota	trial forb 2	82	n/a	n/a	0.026	0.055
VEEN	*Verbesina encelioides*	golden crownbeard	trial forb 3	84.4	n/a	n/a	0.026	0.066
XAGR	*Xanthisma gracile*	slender goldenweed	trial forb 4	36	n/a	n/a	0.026	0.032
MATA	*Machaeranthera tanacetifolia*	tansyleaf aster	trial forb 5	81	n/a	n/a	0.026	0.020
VEEN	*Verbesina encelioides*	golden crownbeard	trial forb 3	84.4	n/a	n/a	0.026	0.004
ATCA-HEXA	*Atriplex canescens*	four wing saltbush 6X	hand seed - shrub	14.8	n/a	n/a	n/a	n/a
MATA	*Machaeranthera tanacetifolia*	tansyleaf aster (commercial source)	hand seed - forb	65.4	n/a	n/a	n/a	n/a
SPWR	*Sporobolus wrightii*	big sacaton (local source)	hand seed- grass	77.6	n/a	n/a	n/a	n/a
ATOB	*Atriplex obovata*	mound saltbush	hand seed - forb	55.9	n/a	n/a	n/a	n/a
SPAI	*Sporobolus airoides*	alkali sacaton	hand seed- grass	91.2	n/a	n/a	n/a	n/a
SELE	*Setaria leucopila*	streambed bristlegrass	hand seed- grass	2.0	n/a	n/a	n/a	n/a

Appendix H. Mean percent cover all quads and plots

Mean percent cover (calculated as the average of all 40 quads - 8 quads in each plot, and one plot in each of 5 sites) for all plant species observed, grouped by treatment. Yellow shading indicates the target species for each treatment that had a mono-species mix. For the ATCA cover for the ATCA.Local.1 treatment, observers considered this cover value was due to a volunteer plant and not a seeded plant. Blank cells indicate the species.

	Shrub mono-species mixes			Forb mono-species mixes			C4 Grass mono-species mixes			Grass mono-species mixes			4-species mixes			
Species Code	ATCA.COM.1	ATCA.Local.1	ATOB.Alt.1	BAMU.COM.1	BAMU.Local.1	MATA.Alt.1	SPAI.COM.1	SPAI.Local.1	BOAR.Alt.1	BOCU.COM.1	BOCU.Local.1	ELEL.Alt.1	MIX.COM.4	MIX.Local.4	MIX.Alt.4	MIX.Alt.16
ARAD						0.025	0.250							0.075	0.450	
ASTRAGALUS SP.									0.025							
ATAC									0.008	0.003		0.003				
ATCA		1.625														0.188
ATOB			0.050	0.050		0.025	0.075			0.050	0.050	0.100	0.100	0.075	0.150	
BAMU				0.008	0.005											
BASC										0.003						
BOAR	0.475	0.030	0.328	0.060	0.078	0.075	0.025	0.130	0.028	0.128	0.130	0.053	0.100	0.050	0.153	
BOCU				0.578			0.050					0.025				
BOGR									0.200							
BOIN	0.025	0.008	0.025	0.003	0.100			0.003		0.005	0.003	0.050			0.078	
BOTO			0.030		0.010			0.003	0.075						0.005	
BOUBAR	0.730	0.353	1.060	0.060	1.908	2.450	1.353	1.185	1.155	1.285	0.985	1.535	1.475	2.933	1.878	4.942
BULBOUS		0.003									0.003					
CHVI	0.003	0.003		0.003									0.003			0.006
DAPU					0.010			0.078								
ELEL																
ERCI	0.075	0.005	0.005	0.008	0.075	0.025	0.030	0.038		0.100	0.033	0.013	0.005	0.050	0.018	0.006
ERLE	0.150		0.025		0.075	0.075		0.025	0.103	0.028				0.200	0.003	
EUPHORBIA SP.	0.003			0.003	0.008		0.108	0.080	0.150	0.150	0.025			0.025	0.050	
GUSA									0.050							
HOGL	0.025	0.153	0.003		0.050	0.075	0.025	0.003				0.005	0.003			
KAHI							0.025				0.005					
MALE					0.003											
MATA						0.100										0.063
MENTZELIA SP.				0.003								0.003				
PAHI	0.053		0.078	0.005	0.080	0.108	0.003	0.003	0.455	0.125	0.708	0.005	0.453	0.728	0.205	0.004
PEAN	0.008			0.005						0.003						0.938
PLMU		0.025	0.025													
POOL	0.078	1.155	0.483	0.058	0.530	0.575	1.028	0.085	0.003	0.355	0.380	0.255	0.180	0.568	0.758	0.458
POPI															0.003	
SATR	2.203	0.153	1.655	0.050	0.450	0.550	1.150	0.075	1.075	0.250	0.228	0.228	0.028	0.225	0.253	2.250
SIAB									0.005							
SOEL								0.053								
SPAI				0.003		0.325				0.075					0.028	0.063
SPHAERALCEA SP	0.025						0.003	0.028	0.075							
SPOROBOLUS SP.		0.025														
SPPY	0.055	0.435	1.315	0.213	1.905	0.428	0.228	0.733	0.260	2.900	0.633	0.090	2.578	3.028	1.013	0.600
STPA									0.150							
TALINUM SP.		0.030	0.003	0.005		0.025	0.025									
TILA	0.100										0.025			0.025		0.063
TRTE							0.100	0.025							0.053	
UNKNOWN					0.003				0.008			0.003			0.005	
Totals	**4.005**	**4**	**5.0825**	**1.11**	**5.2875**	**4.86**	**4.475**	**2.5425**	**3.8225**	**5.4575**	**3.205**	**2.365**	**4.9225**	**7.98**	**5.0975**	**9.5793**

Appendix I. Sample plot layout