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INVESTIGATION OF SEED BOMBS FOR MILITARY LANDS

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INVESTIGATION OF SEED BOMBS FOR MILITARY LANDS

1. Purpose.

a. This Public Works Technical Bulletin (PWTB) reports on the studies performed to investigate the germination potential of grass species for revegetation, using seed bombs as a viable method for disturbed areas of ranges and other military lands where rapid revegetation is critical for military land management. The studies conducted quantitative analysis to compare the germination counts and biomass of germinated seeds for four seed-bomb formulas, allowing evaluation of each formula’s success. Utilization of this optimized revegetation method will reduce land management expenses under sub-optimal field conditions.

b. All PWTBs are available electronically at the National Institute of Building Sciences’ Whole Building Design Guide webpage, which is accessible through this link:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability.

a. This PWTB applies to engineering activities at all U.S. Army facilities, at any site where revegetation is a concern.

3. References.

a. Army Regulation (AR) 200-1, “Environmental Protection and Enhancement,” 13 December 2007.

b. Executive Order (EO) 13112, “Invasive Species,” 03 February 1999.

c. EO 13423, “Strengthening Federal Environmental, Energy, and Transportation Management,” 26 January 2007.

d. EO 13514, “Federal Leadership in Environmental, Energy, and Economic Performance,” 05 October 2009.

e. Other references are listed in Appendix C.

4. Discussion.

a. AR 200-1, as revised in December 2007, contains policy for environmental protection and enhancement, implementation of pollution prevention, conservation of natural resources, sustainable practices, compliance with environmental laws, and restoration of previously damaged or contaminated sites. AR 200-1 also contains policy for the assessment of the environmental effects of Army actions and training and requires planning for environmental impacts from their actions with an emphasis on good stewardship of land resources.

b. EO 13514 expands on the energy reduction and environmental performance requirements for Federal agencies that were identified in EO 13423. The goals for EO 13514 are to establish an integrated strategy toward sustainability of Federal lands which includes reduction of water use, water runoff, and solid waste as related to both land management and landscaping.

c. An inexpensive and non-invasive method for vegetation establishment was identified by investigations at two laboratories of the U.S. Army Engineering Research and Development Center laboratories – Construction Engineering Research Laboratory (ERDC-CERL) and the Cold Regions Research Laboratory (ERDC-CRREL). The investigations focused on developing optimal materials and formula ratios to produce seed bombs. Additional investigations are underway for best practices of delivery of seed bombs and other variables involved.

d. Appendix A contains an introduction explaining the significance of seed bombs as a method to revegetate disturbed lands when traditional seeding methods cannot be employed effectively.

e. Appendix B contains the methods and results from the studies that compared seed-bomb germination in laboratory growth chambers.

f. Appendix C contains a list of the references cited in the previous appendices.

g. Appendix D is a list of acronyms and abbreviations along with their spellouts.

5. Points of Contact.

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APPENDIX A:

INTRODUCTION

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Sustainability of Training Lands

The U.S. Army is dedicated to the sustainability of its training lands and adheres to legislation and directives for environmental standards for government and civilian projects, as documented in AR 200-1. Additionally, EO 13514 requires the federal government to establish an integrated strategy toward sustainability. The use of native plants fits within the intent of EO 13514 and AR 200-1.

When native plants are used within their native range, it can result in a decrease of supplemental water used on landscaped areas and a decrease in erosion and sediment in natural areas. Disturbance from military impacts and field maneuvers can negatively impact vegetation cover and create landscapes that are particularly vulnerable to erosion if they are not routinely maintained. These disturbed lands need to be managed to reduce the environmental impacts.

In general, the first approach to reduce erosion and sedimentation is to establish vegetative cover. On military lands, however, degraded lands are sometimes inaccessible to traditional methods of seeding and erosion control. This inaccessibility can be because the degraded areas (a) are physically difficult to access, (b) are off-limits due to unexploded ordinances, (c) have diverse and sometimes extreme terrain, and/or (d) are degraded to the degree where conditions are not optimal to establish new vegetation. As a result, reseeding techniques can be a crucial link to the restoration of military training lands.

Seed Bomb Alternative

Investigations by ERDC-CERL and ERDC-CRREL identified an inexpensive and non-invasive method for establishing vegetation using seed bombing. This non-traditional method was investigated for its effectiveness as an accurate and economical seeding intervention strategy because it may be easily adopted by land managers as a best management practice (BMP) for revegetation efforts.

This particularly unique and innovative seed-bomb technique was developed by a grassroots movement to revegetate neglected landscapes. Participants within this movement call themselves “Guerilla Gardeners.” By nature, the neglected spaces that they targeted are often enclosed, private, and bare spaces within urban areas; thus, these gardeners were challenged to develop methods of no-till planting from afar. A popular technique known as seed bombs, green-aids, or seedballs introduced the seeds within tightly packed projectiles compromised of seeds and growing medium within a casing.

The historical record shows that seed bombs were first devised in the mid 1970s independently in both New York City and rural Japan. In New York City, Liz Christy and her team (Green Guerillas) began transforming urban land by dispersing seeds with green-aids. In a strikingly different context in Japan, Masanobu Fukuoka was studying methods for no-till rice farming. He employed pellets of clay infused with rice seeds. Fukuoka developed a method he called “Natural Farming” and explained that his pellets protected the seeds from wind and predators. The pellets allowed seeds to be sown without disturbing the soil, preventing weeds from overtaking the field (Fukuoka 1978). Both Liz Christy in an urban environment and Masanobu Fukuoka in an agricultural context had developed a similar method of delivering seed material to areas remotely, applying techniques that afforded protection to the seeds and greatly increased their germination and survival rates.

The application of seed bombs may be relatively new, but the concept of remote seed dispersal is not new to living organisms within the Plant Kingdom (kingdom Plantae). While wind often has been a key element of plant reproduction, there are various pathways that plants utilize to disperse seed. Three theories account for the driving force in the different types of dispersal methods (Howe and Smallwood 1982).

(1) *Escape hypothesis* – speculates that species can only survive out of the shadow of their parent plant and must develop systems to avoid competing with the parent plant for light and nutrients.

(2) *Colonization hypothesis* – stipulates that organisms had the capacity to anticipate habitat changes and the seed dispersal allowed them to find suitable microhabitat in

locations other than near the parent plant thus optimizing species survival.

(3) *Directed dispersal hypothesis* – concludes that plant and animal species co-evolved or behaved synergistically to catalyze seed dispersal into optimal environments.

The directed dispersal relationship has been observed in ecosystems throughout the world, as many plants rely on animals or some functions of animals for seed dispersal, although these relationships are specialized and by no means the norm. Because the production and delivery of a seed bomb involves the intentional seed dispersal by animals (in this case, humans), it most closely resembles the direct dispersal pattern.

The use of seed bombs has the potential to reduce the need for direct soil-to-seed contact while providing protection from predators and the elements. Some benefits to using seed bombs is that their use is not dependent on regular seeding times and they can be utilized whenever it is convenient, such as during short periods available to a land manager for field operations. Seed bombs also are not dependant on one particular human pathway—they could be dispersed by land managers, or by those originally responsible for the land disturbance (e.g., soldiers in-training). The seed bomb may prove to be both a portable and potent armament easily carried by military personnel.

In remote, disturbed areas, conventional human-initiated seed dispersal methods generally focus on the use of broadcast seeding or “air seeding.” These methods, however, are prone to disruption by high winds, have poor seed-to-soil contact because the seed is sitting open on the soil, vulnerable to predation and washing away by rain. A seed bomb solves these issues by providing seeds with a hospitable environment.

In training area revegetation efforts, the use of seed bombs carries the potential to revegetate impact inaccessible sites as well as areas where more common seeding techniques have previously not succeeded. An impact area, for instance, may be inaccessible to a hydroseeding operation because of site access or water supply issues. Drill seeding is impossible in impact areas because of safety concerns. In non-impact training areas of high topographic relief, access and feasibility limitations also limit the use of the more conventional drill seeding technique.

As previously explained, seed bombs have often been discussed as a guerilla gardening technique and an “alternative” agricultural method. However, little research has been conducted on an optimal seed-bomb formula. Research at the University of Texas examined seed bombs as a method for prairie restoration (Kemp et al. 1998). In that case, the seed bombs were not effective because a lack of precipitation did not allow the seed bombs to break down and promote germination. Additional observational literature revealed low-germination rates and seed-bomb matrices that either did not break down at all or broke down too soon, resulting in poor germination or death due to seedlings drying out.

The lack of investigation in the formula for seed carrying and growth media prompted ERDC-CERL’s design study to investigate potential formulas for successful seed bombs. ERDC-CERL wanted to develop a seed bomb that would provide seeds protection from predation while still breaking down at an optimal rate, to promote seed germination and seedling establishment without risk of drying out. The study conducted at ERDC-CERL and ERDC-CRREL focused on the ratios of clay, compost, and sand necessary for the most functional seed bomb – one that: is not vulnerable to predators, is permeable to moisture, scars the seeds effectively, and provides a nutrient rich environment for maximized seed germination and plant establishment.

APPENDIX B

PRODUCTION AND TESTING METHODS

Seed Bomb Production

Drawing from current literature, The University of Texas Study, and Fukuoka's approach, five (5) seed bomb formulas were investigated. Using guidelines from the literature, ratios for clay, compost, and sand (clay:compost:sand) were chosen to determine the influences of each parameter on seed bomb success (Table B-1).

Table B-1. Ratios of components for each seed-bomb formula, before seeds.

Formula	Ratios (clay: compost: sand)	Amt (L) of each component needed for a 2.5-kg dry mix, before seeds		
		Clay	Compost	Sand
1	1:3:0	1.12	3.36	0.00
2	5:3:0	2.50	1.50	0.00
3	3:1:1	1.97	0.67	0.67
4	5:1:0	3.15	0.63	0.00
5	2:2:1	1.37	1.37	0.69

While clay was used in all formulas, ratios were varied to determine whether clay promoted or inhibited germination (Formula 2), and if clay slowed breakdown due to the stronger clay bonds (Formula 3 and 4). The compost content was evaluated for high levels of compost with Formulas 1 and 2, medium levels in Formula 5, and low levels both with and without sand in Formulas 3 and 4. Sand was added in Formula 3 and 5 as it was believed that it could provide scarification of the seed coat and promote faster breakdown of the seed bomb.

All materials were obtained locally, to reflect the context of what might happen if an installation needed the capability to produce seed bombs with locally sourced and non-standardized materials. Materials for the matrix included screened garden compost (sourced locally from the Urbana Recycling Center), montmorillonite clay (Kio pond flocculent), and sand (red play sand). To avoid potential issues with pathogens in the initial growth chamber evaluations, the sand and clay were autoclaved and air dried. Compost was not sterilized but was air dried and rescreened to less than 1/4" particle size. The clay, compost, and sand were weighed separately (Figure B-1) and mixed using a hand drill with paint mixer attachment in 5-gallon buckets. Table B-1 describes the mixture ratios and Table B-2 describes the weights of component materials.

Grass species Switchgrass (*Panicum virgatum*), Big Bluestem (*Andropogon gerardii*), Buffalograss (*Bouteloua dactyloides*), and Little Bluestem (*Schizachyrium scoparium*) were chosen for their common use, availability, wide distribution, and inclusion in seed mixes used on many military lands. Varietals were selected and grouped based on percentage pure live seed, percentage germination, and percentage dormancy (Table B-2). Viability controls were run in the growth chamber for each varietal during this evaluation (Figure B-1). Controls were prepared in petri dishes with germination paper and 100-seed counts, then placed in the growth chamber at the same time as the seed bombs.

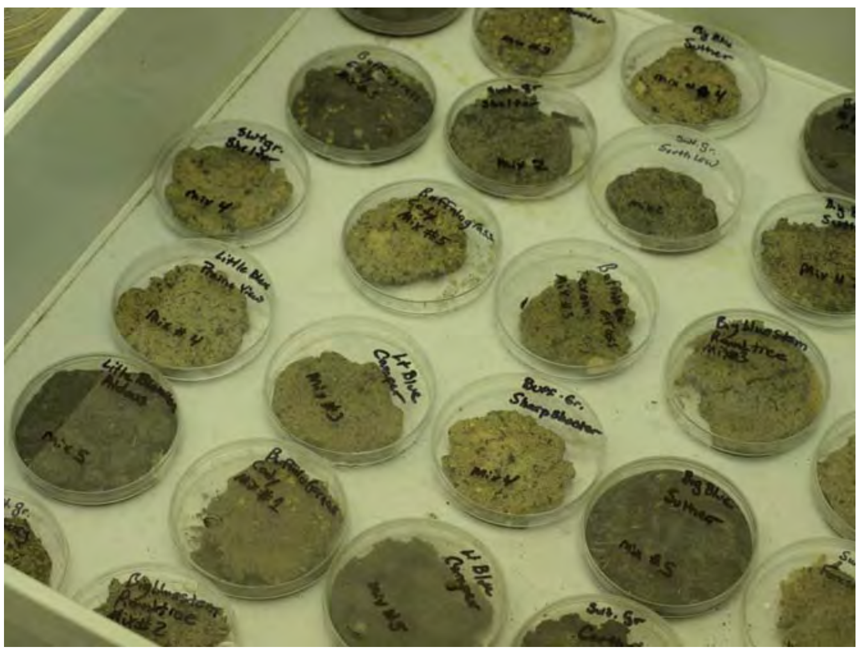

Figure B-1. Formed seed bombs labeled in petri dishes.

Table B-2. Groupings by cultivar based on percentages of pure live seed (PLS), germination, and dormancy.

Variety	PLS (%)	Germination (%)	Dormant (%)
Niagra	96	51	45
Roundtree	93	85	8
Suther	90	25	65
Aldous	94	54	40
Camper	95	86	9
Prairie View	96	5	91
Blackwell	88	15	73
Carthage	94	51	43
Forestburg	95	41	54
Southlow	96	6	90
Shawnee	92	88	4
Shelter	94	94	0
Cody	96	45	51
Sharpshooter	98	57	41
Sharps Improved	96	60	36
Sharps Improved II	97	73	24

The seed bombs were hand-crafted at CERL using the following method. Seeds for each varietal were individually counted into nine 100-seed lots. These lots were then used to determine the average weight of a 100-count; each 100-count seed lot would be used for one seed bomb. Batches of assumed 100-counts were weighed out for the study. The seed bombs were replicated six times for each varietal and for each formula. A known weight for each formula (Table B-3) was used with a seed lot added and mixed into the dry matrix.

Table B-3. Dry mixes before addition of water and seeds.

Formula	**Component**								
	Clay		**Compost**		**Sand**		**Bucket**	**Total**	
	Vol (L)	**Wt (g)**	**Vol (L)**	**Wt (g)**	**Vol (L)**	**Wt (g)**	**Wt (g)**	**Vol (L)**	**Wt (g)**
1	1.12	695.0	3.36	1621.5	0	0	938.5	4.48	2316.5
2	2.50	1714.0	1.50	763.5	0	0	938.0	4.00	2477.5
3	1.97	1303.5	0.66	328.0	0.66	780	968.0	3.29	2411.5
4	3.15	2023.0	0.63	562.0	0	0	809.5	3.78	2585.0
5	1.37	887.5	1.37	719.5	0.69	714	808.0	3.43	2321.0

After uniform seed distribution was achieved, water was added in small increments to avoid over-saturation. When the mix reached a dough-like consistency, it was hand-rolled and pressed into a patty shape of roughly 1/4-in. thickness, and placed into a labeled petri dish. The seed bombs were dried at 25 °C in a forced-air oven for approximately 72 hr. Seed bombs were shipped to CRREL for germination, where the growth chamber was set at 18 °C with light intensity of 800 micro moles/m^2/s and 50% humidity. Petri dishes were checked daily and watered when needed. The experiment was run twice with each run containing three replicates for each variety and seed bomb formula.

Data Collection and Results

Data was collected by determining how many of the 100 seeds had germinated in each petri dish at 14-day and 28-day benchmarks. Germination times were statistically analyzed for each varietal as well as relative to each seed bomb formula. Overall germination results are presented in Table B-4, with the percentage of seed germination at the 14-day and 28-day benchmarks shown for each formula.

Preliminary results showed that the seed bombs were germinating successfully, indicating that they could be used successfully to revegetate difficult areas.

Table B-4. Overall germination results, with the percentage of seed germination at the 14-day and 28-day benchmarks shown for each formula (germination categories shown per the statistical analysis as statistically different; 14-day LSD 4.0 and 28-day LSD 3.9).

Formula #	**14-day Benchmark**	**Germination Category (significant difference)**	**28-day Benchmark**	**Germination Category (significant difference)**
1	35.5	a	48.3	ab
2	30.8	b	45.3	b
3	19.9	c	34.6	d
4	34.3	ab	51.1	a
5	23.1	c	40.5	c
LSD @ 0.05	**4.0**		**3.9**	

From the results at the 14-day benchmark, Formula 1 ranked first in percentage of seeds germinated, with 35.5% germination at a ratio of 1:3:0. Formula 4 ranked second, with 34.3% germination at a ratio of 5:1:0. Formula 2 was third (30.8%; ratio 5:3:0), Formula 5 fourth (23.1%; ratio 2:2:1), and Formula 3 fifth (19.9%; ratio 3:1:1).

An assessment of the total percentage germination after 28 days showed some differences in seed germination per formula. Formula 4 ranked first with 51.1%, Formula 1 second (48.3% germination), Formula 2 third (45.3%), Formula 5 fourth (40.5%), and Formula 3 fifth (34.6%).

However, since the germination rates for both Formula 1 and Formula 4 were not significantly different from each other, both at the 14-day benchmark and the 28-day benchmark, they can both be identified to contain an optimal ratio for a seed-bomb mechanism of rapid revegetation.

Figure B-2 shows the germination rates graphically presented, subdivided by all species and varietals. An analysis of individual varietal performance subdivided by species as recorded per seed bomb formula is presented in Table B-5 (Switchgrass), Table B-6 (Big Bluestem), Table B-7 (Buffalograss), and Table B-8 (Little Bluestem).

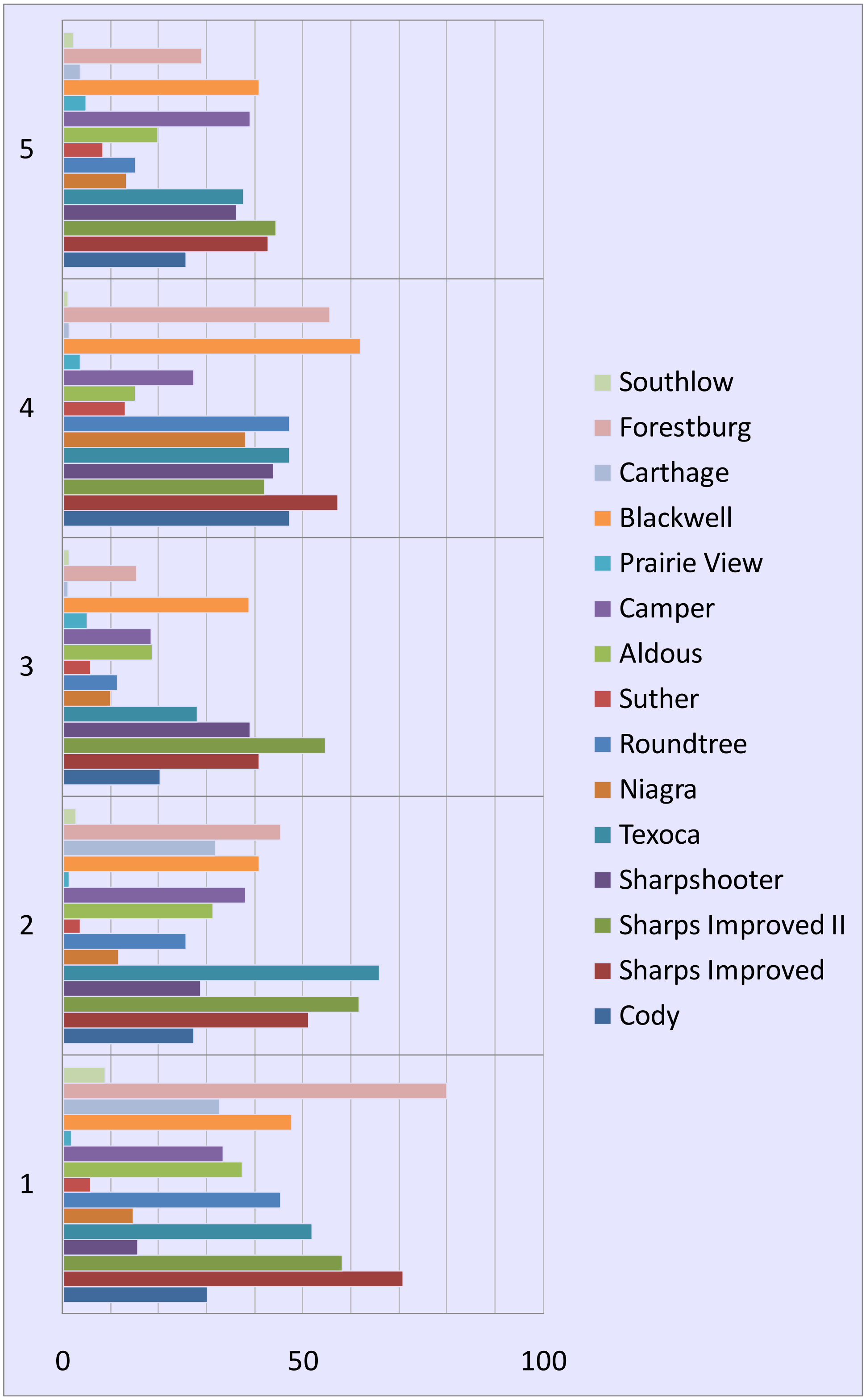

Figure B-2. Formula 1 and Formula 4 consistently show the highest germination and growth.

An initial assessment of overall best-germinating species can be taken from Figure B-2. Looking at Formula 1, the two fastest germinating species were the Switchgrass “Forestburg” and Buffalograss “Sharps Improved I.” In Formula 2, the two fastest germinating species were the Buffalograss “Texacoa” and Buffalograss “Sharps Improved II.” In Formula 3, Buffalograsses “Sharps Improved II” and “Sharps Improved I” germinated fastest. In Formula 4, Switchgrass “Blackwell” and Buffalograss “Sharps Improved I” were fastest (although Switchgrass “Forestburg” was a close third-fastest). In Formula 5, Buffalograsses “Sharps Improved II” and “Sharps Improved I” were the fastest.

The species with the poorest germination rates are as following per formula: Formula 1 - Prairie View and Suther; Formula 2 – Prairie View and Southlow; Formula 3 – Southlow and Carthage; Formula 4 – Southlow and Carthage; and Formula 5 – Southlow and Suther.

As seen, some seeds germinated very well in certain formulas but very poorly in others (e.g., Buffalograss “Texoca”). Likewise, the seeds that germinated well in the optimal growth mediums (Formula 1 and Formula 4) did not germinate as well in the other formulas.

Table B-5. Germination rates for Switchgrass.

Variety	**Germination % (14 days)**	**Group**	**Germination % (28 days)**	**Group**
Blackwell	41.6	a	72.4	a
Carthage	12.9	b	17.9	b
Forestburg	34.1	a	78.5	a
Southlow	2.3	c	3.7	c
LSD @ 0.05	**9.5**		**7.2**	
Formula	**Germination % (14 days)**	**Group**	**Germination % (28 days)**	**Group**
1	42.2	a	57.9	a
2	30.2	b	46.5	b
3	13.5	c	34.4	c
4	29.4	b	41.0	b,c
5	17.5	c	35.7	c
LSD @ 0.05	**10.6**		**8.1**	

Table B-6. Germination rates for Big Bluestem.

Variety	Germination % (14 days)	Group	Germination % (28 days)	Group
Niagra	17.5	b	23.5	b
Roundtree	28.9	a	43.3	a
Suther	7.3	c	12.5	c
LSD @ 0.05	**4.4**		**5.3**	
Formula	**Germination % (14 days)**	**Group**	**Germination % (28 days)**	**Group**
1	21.9	b	28.8	b
2	13.7	c	23	b,c
3	9	c	18.9	c
4	32.8	a	40.6	a
5	12.2	c	21.2	c
LSD @ 0.05	**5.7**		**6.8**	

Table B-7. Germination rates for Buffalograss.

Variety	Germination % (14 days)	Group	Germination % (28 days)	Group
Sharps Improved	52.7	a	66.4	b
Sharps Improved II	52.2	a,b	72.9	a
Texoca	46.2	b	57.5	c
Sharpshooter	32.7	c	50.3	d
Cody	30.1	c	46.3	d
LSD @ 0.05	**6.1**		**7.1**	
Formula	**Germination % (14 days)**	**Group**	**Germination % (28 days)**	**Group**
1	45.4	a	56.5	b,c
2	47	a	60	a,b
3	36.6	b	50	c
4	47.6	a	66.8	a
5	37.3	b	61.3	a,b
LSD @ 0.05	**6.1**		**7.1**	

Table B-8. Germination rates for Little Bluestem.

Variety	Germination % (14 days)	Group	Germination % (28 days)	Group
Aldous	24.4	a	47.8	a
Camper	31.2	a	53.1	a
Prairie View	3.3	b	9.0	b
LSD @ 0.05	**8.2**		**6.5**	
Formula	**Germination % (14 days)**	**Group**	**Germination % (28 days)**	**Group**
1	24.1		40.6	a
2	23.6		39.2	a
3	14.0		27.9	b
4	15.3		38.2	a
5	21.1		37.47	a
LSD @ 0.05	**ns**		**8.4**	

The germination rates per grass variety also show interesting results.

Out of the Switchgrasses species group, the varietals “Blackwell” and “Forestburg” performed best overall (their results were not significantly different from each other). Overall, Switchgrass germination was highest in Formula 1.

Out of the Big Bluestem species group, the varietal “Roundtree” performed the best. This species group germinated best in Formula 4.

For the Buffalograss species group, the two best-performing varietals were “Sharps Improved I” and “Sharps Improved II” (no significant difference between the two). This species performed best in Formula 1, Formula 2, and Formula 4 (no significant difference between formulas).

Within the Little Bluestem species group, the two varietals performing best were “Aldous” and “Camper.” All seed bomb formulas except for Formula 3 seemed to be similarly effective for germination at the 28-day benchmark (no significant difference at the 14-day benchmark).

Conclusions

Formula 1 (clay:compost:sand ratio of 1:3:0), and Formula 4 (5:1:0) can both be identified to contain an optimal ratio for a seed bomb rapid-revegetation mechanism. Both of these formulas did not contain any sand (indeed, the formulas that did contain sand did not yield high germination rates). Interestingly, Formula 1 was composed predominantly of compost, while Formula 4 was composed predominantly of clay. From these results, it seems that either a mixture with high clay or high compost content works well for providing a growing medium for seed bombs.

Results suggest that including sand actually inhibits germination. The seed bombs with sand broke down much more rapidly during the germination study, making it impractical to include sand for large-scale use in seed bombs. Ratios of either predominantly clay or predominantly compost did *not* have a strong influence on germination as hypothesized; Formula 1 performed as well as Formula 4.

It was noted however, that Formula 4 yielded a much “harder” and “slimier” seed bomb; additionally, clay was expensive when compared to the screened compost. Within a real-world condition, cost may be a factor in deciding which formula to utilize. Due to the material properties and cost constraints, a land manager may choose Formula 1 for the seed bomb mix.

The three highest-performing grasses (under optimal growth conditions) are: (1) the Switchgrass “Blackwell,” (2) the Switchgrass “Forestburg,” and (3) the Buffalograss “Sharps Improved I.” The varietals of Switchgrass “Southlow” and the Little Bluestem “Prairie View” were the poorest performers overall (closely followed by Big Bluestem “Suther”). However, the performance of species/varietal germination overall varied per formula. In the two formulas with the highest germination percentages (therefore considered optimal for seed germination), the species composition and number of germinated seeds was different from the less-optimal seed-bomb formulas.

This variance in germination per Formula media could be attributed to some type of seed-formula compatibility factor. It should also be noted that although there are three grasses that have been seen as high-performers, it is still worth including lesser-performing grass species/varietals. This inclusion will give an added value benefit of higher biodiversity, which could be optimal to ensure the resilience of the revegetation procedure. The optimal seed bomb would likely contain the high-performing species/varietals, while also including those seeds that either germinated later or less prolifically.

Note also that site-specific conditions and climate zones may still have further effects on the effectiveness of seed bomb formulas and seed combinations. Ideally, a land manager could test out a few seed combinations and/or formulas in small applications on-site to obtain an idea of what works best locally. The control of seed species and varietals, along with the variance of germination between individual species in the seed bomb may also affect the potential of establishing desired species such as Threatened and Endangered Species in critical habitat. Additionally, species that are generally considered difficult to establish may benefit from this application for the same reason.

Regarding installation and application of this seed bomb technique for revegetation of remote disturbed areas, positive results have been observed in the field demonstrations. Labor associated with this technique is high (as seed bombs are thus far hand-crafted), and this cost should be counted when considering the use of seed bombs for revegetation of large areas.

APPENDIX C

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APPENDIX D

ACRONYMS AND ABBREVIATIONS

Term	Spellout
AR	Army Regulation
CECW	Directorate of Civil Works, U. S. Army Corps of Engineers
CEMP	Directorate of Military Programs, U. S. Army Corps of Engineers
CERL	Construction Engineering Research Laboratory
CFR	Code of the Federal Regulations
CONUS	Continental United States
DA	Department of the Army
DPW	Directorate of Public Works
DoD	Department of Defense
EPA	Environmental Protection Agency; also USEPA
ERDC	Engineer Research and Development Center
HQUSACE	Headquarters, U.S. Army Corps of Engineers
OCONUS	outside Continental United States
PDF	portable document file
POC	point of contact
PWTB	Public Works Technical Bulletin
URL	universal resource locator
USACE	U.S. Army Corps of Engineers
WBDG	Whole Building Design Guide
WWW	World Wide Web