In Situ Seed Germination for Rehabilitation of Waste Fly Ash

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INTRODUCTION

The coal-fired power station at Port Augusta in South Australia generates 600,000 tonnes of fly-ash waste each year.

Establishment of a vegetative cover on fly-ash lagoons would stabilise the surface against erosion and considerably improve its microclimate and aesthetics. Plants were required to tolerate the saline and alkaline medium, as well as the hot dry climate and prevailing strong winds at the site. Direct seeding was considered to be an efficient method for revegetating the large areas involved, but little information was available on the germination success of plants sown directly into fly ash, although several reports had demonstrated the feasibility of growing plants on fly ash or fly-ash-amended soils (Holliday et al., 1958; Meecham and Bell, 1977; Rees and Sidrak,1956).

Initial screening of seeds for germination and growth on fly ash, or on fly-ash/soil mixtures and overlays was performed in glasshouse pot trials (Pillman and Jusaitis, 1991). The most promising species were subsequently tested in field trials on the fly-ash lagoons at Port Augusta. Germination and early growth in glasshouse pot trials were much improved if a 3- to 4-cm layer of sandy topsoil was spread over the fly-ash surface as an overlay, and seed was sown into this layer. Early attempts at establishing plants from seed using this technique in situ were hampered by severe winds which eroded a large proportion of the surface layers and seed within a month of sowing. This paper describes the results of field trials designed to screen a range of plant species for their ability to germinate and grow on fly ash, and discusses techniques for surface amelioration to optimise germination, establishment, and growth of plants following direct seeding.

MATERIALS AND METHODS

Most seeds were collected from volunteer species which grew around the edges of fly-ash lagoons or in salt flats at Port Augusta, and from species growing on and around the overburden heaps at Leigh Creek where the parent coal was mined. Plants growing in these areas already showed tolerance to the arid climate and soils containing salt or black coal, and were expected to have a better-than-average chance of germinating and surviving on ash. *Medicago* spp. were purchased from a commercial seed supplier.

A field trial site on relatively fresh fly ash (2 years old) was prepared by deep ripping, leaving the surface in an uneven condition to encourage seed lodgement, and to provide early wind protection for seedlings. The following surface amelioration treatments were randomly assigned to 8 × 1 m plots (separated by 2-m buffer zones) within each of three replicates:

1) Untreated fly ash (control).
2) Approximately 70% of fly-ash surface covered by rocks (50 to 150 mm diameter).
3) Organic mulch (chipped tree prunings) spread 30 to 50 mm deep over fly ash.
4) Hydromulch (an aqueous suspension of pulped, recycled paper) sprayed in a

thin layer over the fly-ash surface.

5) Niche (250 mm high × 500 mm wide mound running the length of the plot with a 100 mm deep furrow at its apex containing the seed), seed covered with hydromulch.

6) Niche (as for 5), seed covered with fine gravel.

7) Local sandy topsoil spread 50 to 100 mm thick over fly ash and stabilised with woven erosion control fabric (Oystershade).

8) Local sandy topsoil spread 50 to 100 mm thick over fly ash and stabilised with hydromulch.

9) Compost plus mulch treatment (an organic compost developed from water filtration sludge was spread to a depth of 100 mm before being rotary-hoed into the upper 150 mm of ash. A further 100 mm layer of compost was spread over this and covered with a 20- to 30-mm deep layer of coarse pine splinters to reduce wind erosion).

A seed mixture of 16 plant species (in the proportions shown in Table 1) was sown without any pretreatment. The number of each species to germinate in a randomly selected 1 × 1 m quadrant was recorded at regular intervals.

RESULTS

The germination performance of the 16 plant species on pure fly ash and on amelioration treatments is shown in Table 1. Only *Minuria cunninghamii* failed to germinate at all across the site. The dominant species across all treatments were *Atriplex lindleyi, Enchylaena tomentosa, Mesembryanthemum nodiflorum* and *Nitraria billardieri*, each with over 300 seedlings surviving a year after sowing (Table 1). *Nitraria billardieri* and *Scaevola collaris* were slow to germinate, with germinants still appearing over a year after sowing. *Mesembryanthemum* spp., *A. holocarpa, E. tomentosa, Medicago* spp. and *N. billardieri* were all observed to germinate on pure fly ash, although only *M. aitonis* and *N. billardieri* still survived on this medium when assessed 12 months after sowing.

The majority of sown species germinated and survived for over a year on sand plus fabric, sand plus hydromulch and compost plus mulch (Table 2). Over 18% of species germinated on pure fly ash, but only 2% survived for 12 months on this medium. The proportion of species surviving after a year was less in all treatments than the maximum proportion to have germinated during the course of the year. This reduction was proportionately less in treatments 7 to 9, where a layer of sand or compost enabled plant roots to become established before coming into contact with fly ash. Similarly, plant numbers per unit area were maximised in overlay treatments, with the most dense growth being observed in sand plus fabric and compost plus mulch treatments.

DISCUSSION

Fly ash reduced not only germination rate and percentage, but also growth and survival of plant species tested in this trial.

Table 1. Seed germination and plant survival on fly ash and amelioration treatments over all replicates.

Family	Genus/species	Seed sown (g/m^2)	Germination		Number of plants at 15 months [1]
			Fly ash	Fly ash-soil [2]	
Aizoaceae	*Mesembryanthemum aitonis*	0.03	**	**	5
	M. nodiflorum	0.03	*	**	311
Chenopodiaceae	*Atriplex holocarpa*	0.2	*	**	54
	A. lindleyi	0.6	-	**	300
	A. vesicaria	0.5	-	**	178
	Enchylaena tomentosa	2.5	*	**	355
	Halosarcia halocnemoides	0.2	-	**	16[3]
	H. pergranulata	0.2	-	**	
	Maireana pyramidata	0.4	-	**	2
Compositae	*Minuria cunninghamii*	0.01	-	-	0
Goodeniaceae	*Scaevola collaris*	1.9	-	**	55
Gramineae	*Danthonia caespitosa*	0.02	-	*	0
Leguminosae	*Acacia victoriae*	0.3	-	*	0
	Medicago truncatula 'Parabinga'	0.5	*	*	0
	M. polymorpha 'Serena'	0.5	*	**	39
Zygophyllaceae	*Nitraria billardieri*	0.7	**	**	358

[1]Total number of surviving plants over the whole trial site (all treatments) at termination of the trial.
[2]Fly-ash soil includes any of the fly ash amelioration treatments tested, excluding the control.
[3]Seedlings of *Halosarcia* species were difficult to distinguish to species level and hence data refer to the genera rather than to individual species.
** indicates that seed germinated and plants were alive at 12 months after sowing.
* indicates that seed germinated but seedlings failed to survive to 12 months after sowing.
- dash indicates that no germinants were observed.

Table 2. Proportion of sown species that germinated and survived during the first year on the fly-ash amelioration treatments, and the number of plants (all species) surviving in each treatment at the termination of the trial.

Treatment	Maximum species germinated (%)	Species surviving after 12 months (%)	Number plants/m^2
1. Untreated	18.8 a [1]	2.1 a	0.1 a
2. Rock mulch	22.9 a	12.5 a	1.4 a
3. Organic mulch	39.6 ab	0.0 a	0.0 a
4. Hydromulch	33.3 ab	14.6 a	1.4 a
5. Niche + hydromulch	45.8 abc	12.5 a	1.3 a
6. Niche + gravel	43.8 ab	6.3 a	0.2 a
7. Sand + fabric	75.0 cd	70.8 c	31.8 c
8. Sand + hydromulch	58.3 bd	52.1 bc	9.3 b
9. Compost + mulch	54.2 bd	45.8 b	24.0 bc

[1]Mean separation within columns by Fisher's l.s.d. (P=0.05) calculated on untransformed data (except for number of plants per m^2 which was calculated on Log_{10} transformed data).

Of the surface amelioration treatments, sand or compost overlays were outstanding in terms of maximising the species range for germination and plant survival. Sand-overlay treatments supported germination rates equivalent to those on compost plus mulch but did not sustain the long-term growth rate or dry matter production observed on the latter (Jusaitis and Pillman, unpublished). The compost overlay treatment had the added advantages of extra thickness, partial incorporation with the ash surface, improved physical (aeration and water retention) and nutritional characteristics, and a cover of pine splinters.

Neither organic mulch nor rock mulch significantly improved germination or survival above controls, suggesting that their effects on surface microclimate were insufficiently beneficial to warrant their use in isolation. They may nevertheless prove more successful if applied onto an overlay treatment rather than directly onto ash.

The niche treatments did not significantly enhance germination, growth, or survival above control levels. The niche technique was developed for revegetation of salt-affected areas, and its effectiveness purportedly relies on the reduction of salinity in the germination zone as a result of concentrated leaching. The lack of response to this treatment suggested that fly-ash salinity levels were unlikely to be solely responsible for the poor performance of plants on control plots.

Hydromulch and erosion-control fabric were applied primarily in attempts to protect seed and germination zones from the effects of wind erosion. To that extent they were both successful, since preliminary trials using uncultivated fly ash or sand overlays alone supported no germinants or were severely eroded by wind respectively. Hydromulch was a more effective and longer lasting surface stabiliser than bitumen emulsion seal, which reportedly lasted for only two weeks under strong winds (Junor, 1978). Applied directly to fly ash, however, hydromulch provided no germination advantage over controls.

The benefits of surface stabilisation really become apparent when used in conjunction with overlay treatments. When applied in combination with a sand overlay, significantly more plants were established from seed under erosion control fabric (oystershade) than under hydromulch (Table 2). Field observations established that the wind protection afforded to the sand surface by fabric was superior to that by hydromulch, since the latter was not always applied at consistently uniform thickness, leading to small pockets of erosion (pitting). Although the fabric's structure began to disintegrate after the first year's use, sufficient vegetative cover would have established by that time to reduce future erosive effects of wind. Of the three stabilisation materials applied to overlay treatments (treatments 7 to 9), pine mulch was the most enduring.

By improving the physical characteristics of the growth medium and diluting the effects of salinity and nutrient toxicity, overlays encouraged rapid germination and active winter growth, allowing plants to build up sufficient reserves to survive the summer. While this study found that overlays of sandy soils required stabilisation against wind erosion, work at another windy fly-ash site demonstrated that heavy clay to loam soils containing shales and sandstone rocks made equally effective overlays and could be used without any additional stabilisation (Junor, 1978).

Most plant families tested showed some predilection for germination and growth on fly ash or amelioration treatments. It was not unexpected that the plants showing most promise in this dry, saline environment were from the largely xerophytic and halophytic families Aizoaceae, Chenopodiaceae, and Zygophyllaceae. On the basis of this study, the species most suited for fly-ash revegetation were *Mesembryanthemum aitonis, M. nodiflorum, Atriplex holocarpa, A. lindleyi, A. vesicaria, Enchylaena tomentosa, Halosarcia halocnemoides, H. pergranulata, Scaevola collaris*, and *Nitraria billardieri*. These species all occurred naturally around the Port Augusta power station and were also found as volunteers encroaching onto the edges of ash ponds and surrounding levee banks.

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