

THE EFFECT OF ORGANIC MULCHES ON CRUSTING, INFILTRATION AND SALINITY IN THE REVEGETATION OF A SALINE-SODIC COAL MINE SPOIL FROM CENTRAL QUEENSLAND, AUSTRALIA¹

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Abstract. Dumping of saline-sodic clay spoil materials at the surface during open-cut coal mining in central Queensland, Australia, poses significant challenges for revegetation, particularly where suitable capping media are not available. Infiltration is low and surface crusting can be severe, limiting seedling emergence and the entry of water into the soil profile and subsequent leaching of salts from the root-zone. High salinities in themselves further limit the availability of water to plants.

We examined the role of two different organic mulch amendments (sawdust and straw), either surface-applied or incorporated, in improving plant establishment on a saline-sodic spoil under the sub-tropical climate in central Queensland. Laboratory studies indicated that application of a surface mulch cover improved infiltration, increased surface soil moisture, and reduced surface crust strength. However, under field conditions downward migration of salts out of the root-zone was limited, with consequent negative impacts on overall revegetation success. Recommendations are made on revegetation strategies for saline-sodic spoils in the region.

Additional keywords: reclamation, salinity, crusting, straw, sawdust.

Introduction

Pre-stripping operations employed at many open-cut coal mines in central Queensland result in Tertiary clay spoil materials being deposited on the surface of areas to be revegetated. These spoils can be highly sodic and moderately to extremely saline, forming surface seals that limit infiltration and reduce plant-available soil moisture, and strong crusts on drying that can impede seedling emergence. The materials are also deficient in many nutrients, particularly nitrogen and phosphorus. Experience has shown that without some form of amendment, these spoils pose severe problems for plant establishment and growth (Bell et al., 1991, Philp, 1992, Harwood et al., 1999).

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Application of salvaged topsoil at depths of 30 cm appears to afford a successful long-term solution for these materials (Grigg and Catchpole, 1999). However, for a number of reasons reserves of a suitable topsoil material may not always be available. Amelioration with gypsum has been shown to decrease dispersion, improve hydraulic conductivity and reduce crust strength with drying (Bell et al., 1992), but under field conditions the displaced sodium in the soil solution increases measured electrical conductivity, exacerbating the problems of high salinity for plant growth and survival (Philp, 1992). Conversely, Philp (1992) reported encouraging preliminary results from straw mulch treatments on plant establishment, suggesting that organic mulches may provide a successful alternative amendment.

This paper presents the findings of several laboratory and field-based trials undertaken by the Centre for Mined Land Rehabilitation into the use of organic mulches on a saline-sodic Tertiary spoil from the Goonyella Riverside mine in central Queensland. The broad aim of the research was to evaluate the effectiveness of two organic amendments (sawdust and straw) in improving the growth environment for successful revegetation.

Methods

Study site and media characterization

Tertiary clay spoil material was sourced from an out-of-pit dump at the Goonyella Riverside open-cut coal mine in central Queensland (21.51°S, 148.58°E). The mine experiences a sub-humid climate with approximately 600 mm annual average rainfall, more than 70 % of which falls over the summer (November to April). This period coincides with thunderstorm and sporadic cyclonic activity that can produce localised rainfalls of very high intensities. However, around 60 % of rainfall occurs in falls of 10 mm or less in any one day (Willcocks, 1993), and most of this is lost through evaporation. Evaporation exceeds rainfall in every month and annually by a factor of three. Mean monthly maximum/minimum temperatures range from 34/21 °C in January to 23/7 °C in July.

Typical physical and chemical characteristics of the spoil are listed in Table 1. Clay content is relatively high, and the clay types are reactive in the presence of sodium, the element that dominates the exchange sites in this material. Salinity is very high due to abundant chloride salts. Organic matter content is low, as are the major plant nutrients. The spoil therefore presents an extremely hostile environment for plant establishment and survival. Natural revegetation in the absence of amendment is sparse and dominated by salt-tolerant species.

Table 1. Selected physical and chemical characteristics of surface (0-10 cm) saline-sodic spoil material from Goonyella Riverside mine.

Parameter	Extractant	
Clay* (%)		27
Silt (%)		22
Sand (%)		51
Gravimetric water content (-1.5 MPa)		0.16
Gravimetric water content (-0.01 MPa)		0.31
pH	1:5 H ₂ O	8.95
EC (mS/cm)	1:5 H ₂ O	1.4
ESP (%)	1M NH ₄ OAc	43
Ca (meq/100g)	1M NH ₄ OAc	4.4
CEC (meq/100g)	1M NH ₄ OAc	33.88
Cl (mg/kg)	1:5 H ₂ O	4850
Org.C (%)	K ₂ Cr ₂ O ₇ /H ₂ SO ₄	0.2
N (%)	Combustion	0.02
P (mg/kg)	0.5M NaHCO ₃	2.2

* physical properties from Sheridan *et al.* (2000). Sand 0.02-2 mm, silt 0.002-0.02 mm, clay <0.002 mm.

Glasshouse trials

Two trials were undertaken in the glasshouse to examine the effects of organic mulch amendments on surface crust strength and rate of drying of the Goonyella Riverside spoil. In each trial, pots of 15 cm diameter were filled with approximately 1.6 kg of raw spoil, or spoil with either incorporated straw or pine sawdust at rates up to 13.1 t/ha for straw and 80 t/ha for

sawdust. Treatments in each trial also included surface applications of mulch to achieve 25, 50, or 75 % projective surface cover. All treatments contained four replicates. Pots were carefully wetted to field capacity with deionized water and allowed to dry. In the crust strength trial, four strength measurements per pot of the developing crust were periodically taken over a 19-day period using a pocket penetrometer. In the drying rate trial, decline in the weight of each pot was monitored for 22 days, and evaporation determined as the percentage of initial water content remaining.

Rainfall simulation trial

The effects of mulch amendments on infiltration and water retention were investigated under controlled conditions using a tilting flume and rainfall simulator. Flume tray inserts, 3 m long and 0.8 m wide, were filled with spoil to a depth of 15 cm and either straw or sawdust applied (at 5 t/ha and 20 t/ha, respectively) to the surface or incorporated into the spoil. A fifth tray contained bare unconsolidated spoil only. Each tray was divided longitudinally in half, resulting in two replicates for each of the five treatments. Three rainfall events at a nominal rate of 100 mm/h for 30 minutes duration were applied to each flume at approximately monthly intervals. The slope on the flume was 5 %. Infiltration during the rainfall event was calculated as the difference between rain applied and recorded runoff. Moisture content was monitored immediately prior to and following the three events under controlled temperature and humidity conditions in the glasshouse using gypsum blocks embedded in the spoil. For each replicate, three gypsum blocks were buried at 5 cm depth, with a further three at a depth of 10 cm.

Field Trial

A 2 ha trial site on the out-of-pit dump was graded to approximately 2 % slope to prevent ponding, and perimeter drains were constructed to divert run-on water. The site was deep ripped to 1 m and cultivated by grader to produce a suitable seedbed. A basal application of single superphosphate (100 kgP/ha) and potassium chloride (75 kgK/ha), together with several micronutrients (Cu, Mn, Zn) to rectify deficiencies, was made.

Due to practical constraints of applying treatments, the site was divided into four blocks containing bare spoil amended with surface-applied mulch, incorporated mulch, gypsum and incorporated mulch, and topsoil with surface-applied mulch. Mulches used were straw (surface-

applied at 2.5, 5, or 10 t/ha, or incorporated at 5, 10, or 20 t/ha) and pine sawdust (surface-applied at 5, 10, or 20 t/ha, or incorporated at 20, 40, or 80 t/ha). In the gypsum block, gypsum was incorporated at 5 or 20 t/ha together with mulches at the two lower rates for each mulch type. The higher gypsum rate of 20 t/ha was calculated to supply sufficient Ca to displace all Na ions to 15 cm depth. Incorporated mulch and gypsum treatments were mixed to a depth of 15 cm using a tractor-mounted rotary hoe. Mulch type and mulch and gypsum rate treatments (including nil mulch controls) were applied to 5 m x 5 m plots, with four replicate plots per treatment combination assigned randomly within each block (total 626 plots). The topsoil was the A horizon of a red earth common on the mine lease ($EC_{1.5}$ approx. 0.3 mS/cm), and was spread to a depth of approximately 15 cm over the spoil.

Plots were hand-sown with either native grasses and trees (combined 12.8 kg/ha) or introduced pasture species (combined 14 kg/ha) in July 1994. Germination and establishment were poor due to very dry conditions, despite attempts at irrigation, and the plots were resown in February 1997 to coincide with more favorable conditions. The plots were lightly scarified with grader tines and the new seed sown among any existing vegetation. Five native grass species (combined 30 kg/ha) and 14 native tree species (mostly *Eucalyptus* and *Acacia*, combined rate 7 kg/ha) were sown.

Soil and spoil samples were collected for analysis prior to plot establishment and from each treatment plot in December 1994 and July 1997, and of plots within bare spoil and topsoil amended blocks with surface-applied straw mulch only in May 1998. All plots in 1994, and selected plots in May 1998, were sampled at 5 cm intervals to 10 cm depth, then at 10 cm intervals to 50 cm depth. At other times, sampling to a maximum depth of 10 cm was undertaken in two 5 cm intervals. Ground cover was visually assessed in an inner 4 m x 4 m area within each plot in February 1996 (all plots) and May 1998 (surface-applied and topsoil blocks only) and assigned to cover classes. Species composition was also recorded. Woody species establishment was insufficient for reliable analysis of treatment effects and data are not presented.

Results

Effect of mulch on crust strength

Exponential reductions in crust strength with increasing rates of incorporated mulch (Figure 1) were observed from two to more than 13 days. Straw mulch was more effective than sawdust, as indicated by the lower rates required to achieve a given crust strength, and in the steepness of the curve. Surface-applied straw mulch significantly reduced crusting compared to the same rate of incorporated straw, but the pattern was weaker for sawdust.

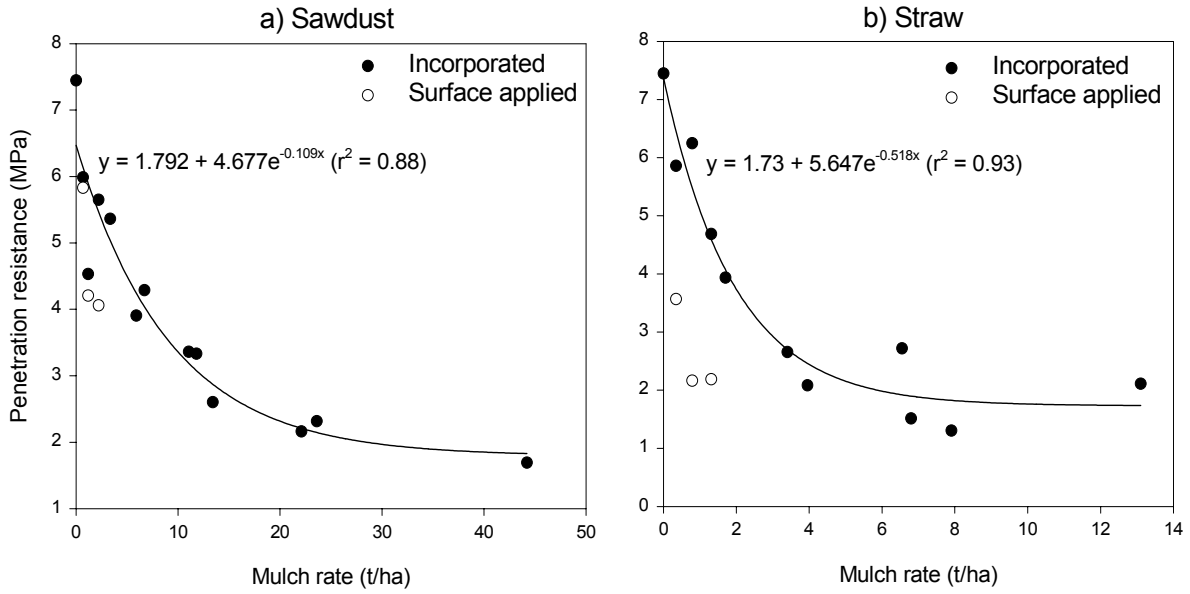


Figure 1. Effect on crust strength after 11 days drying of saline-sodic spoil treated with a) sawdust and b) straw mulches either incorporated or surface-applied. Regression lines for incorporated mulch treatments (including nil mulch) are shown.

Compared to bare spoil, organic mulch amendments delayed the development of a surface crust in the first five days after wetting when seedlings may be emerging, and reduced the final crust strength (Figure 2). Higher rates of mulch maintained relatively lower crust strengths for longer periods.

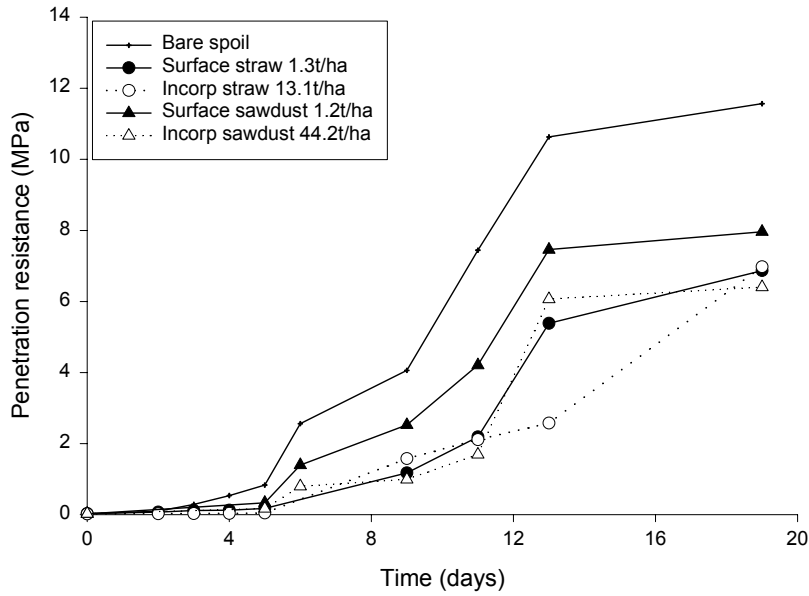


Figure 2. Effect of selected organic mulch amendments on the development of surface crusts with drying of a saline-sodic spoil.

Effect of mulch on rate of drying

Consistent with the development of surface crusts, mulch treatment slowed the rate of drying compared to bare spoil (Figure 3). For sawdust mulch, low rates of surface-applied mulch and incorporated mulch regardless of application rate delayed the rate of drying in the initial 10 days after wetting but moisture content was not significantly different from bare spoil thereafter. Sawdust applied to the surface at the highest rate (20 t/ha) was the most effective in reducing evaporation.

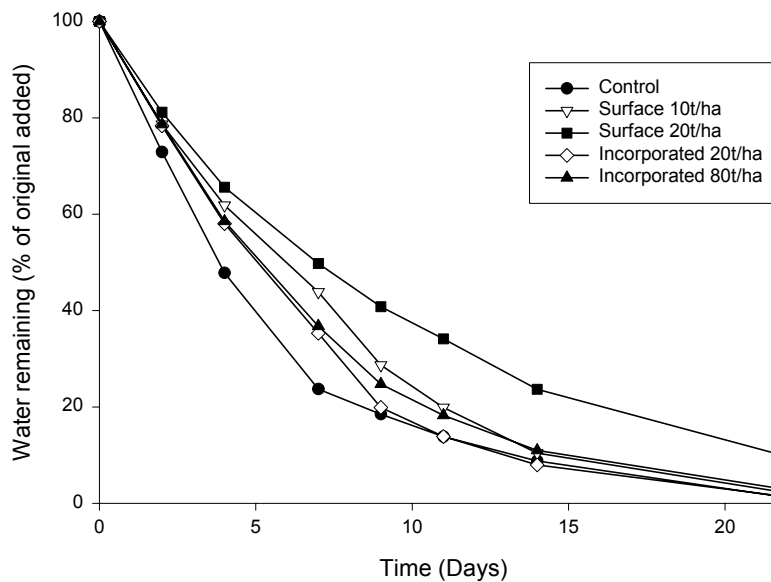


Figure 3. Effect of surface-applied and incorporated sawdust mulch on rates of drying of a sodic-saline spoil from Goonyella Riverside mine.

Effect of mulch under simulated rainfall

The simulated rainfall experiment demonstrated consistently poor infiltration in bare unamended spoil, with more than 90 % of incident rainfall lost as runoff after less than five minutes for each rainfall event (Figure 4). This resulted in a declining moisture content with time despite repeated rain events, eventually falling below wilting point (Figure 5).

Sawdust incorporated into the spoil provided an initial improvement in infiltration relative to bare spoil, but this deteriorated with subsequent rain events as the sawdust particles at or close to the surface were removed or buried. By the third rainfall event, this treatment was almost identical in infiltration characteristics to bare unamended spoil (Figure 4) and progressive drying to below wilting point similarly occurred (Figure 5).

In contrast, incorporated straw mulch displayed the highest rates of infiltration. Surface cover in this treatment was more than 90 %, and the strands of straw were observed to act as stable sub-surface flow paths that permitted penetration of incident rainfall into the profile (Figure 5). However, infiltration patterns were comparatively erratic between rain events (Figure 4), attributed to differential flows into and through the spoil. Substantial through-flow from the base of the flume was measured in this treatment and a potential hazard of field application may be the eventual development of tunnel erosion. A comparatively low rate of drying over time was also demonstrated and the spoil was able to remain at moisture levels close to field capacity for much of the duration of monitoring (Figure 5).

Surface application of both straw and sawdust produced infiltration and spoil moisture contents intermediate to the unamended spoil and incorporated straw treatment. The straw formed an almost complete surface cover, while surface-applied sawdust tended to accumulate and form small terraces, retaining runoff in surface pools. These pools, together with the accumulated sawdust, provided physical protection from raindrop impact and the improvement in infiltration over consecutive rainfall events (Figure 4) may be due to the progressive development of these terraces. Improvements in spoil moisture due to mulch treatments appeared to be cumulative, suggesting inhibition or delayed development of a surface crust, which assisted infiltration of rainfall in subsequent events.

Effect of mulch under field conditions

The field trial was conducted over a series of very dry, although not unusually dry, years. Total annual rainfall to May of each year varied from 265 mm to 435 mm, representing from 44 to 73 % (average 58 %) of the long-term annual average. In each year, 30 – 53 % of the annual total was received in one month (January or February).

Vegetation data collected in May 1998 indicated that both surface-applied mulches, and particularly straw, improved vegetation cover but only at the highest application rates (Figure 6). Surface salinity within spoil plots treated with 10 t/ha of surface-applied straw in May 1998 was lower than for unamended spoil, consistent with the vegetation results (Figure 7). Examination of the salt profile with depth (Figure 8) shows that while the treatment may periodically reduce surface salinity sufficiently to enhance the chances of successful establishment, it has been insufficient to affect salinity at depth or to halt capillary rise of salts over time. Surface salinities on topsoil were lower than for spoil, reflecting lower salinity at establishment, but capillary rise was again apparent although less so for the higher rates of mulch application (Figure 7). Generally, high salinity levels across the site were reflected in the type of vegetation present (Table 2), which was dominated by halophytes or species such as *Chloris gayana*, which has physiological adaptations to elevated salinity (Harwood, 1998).

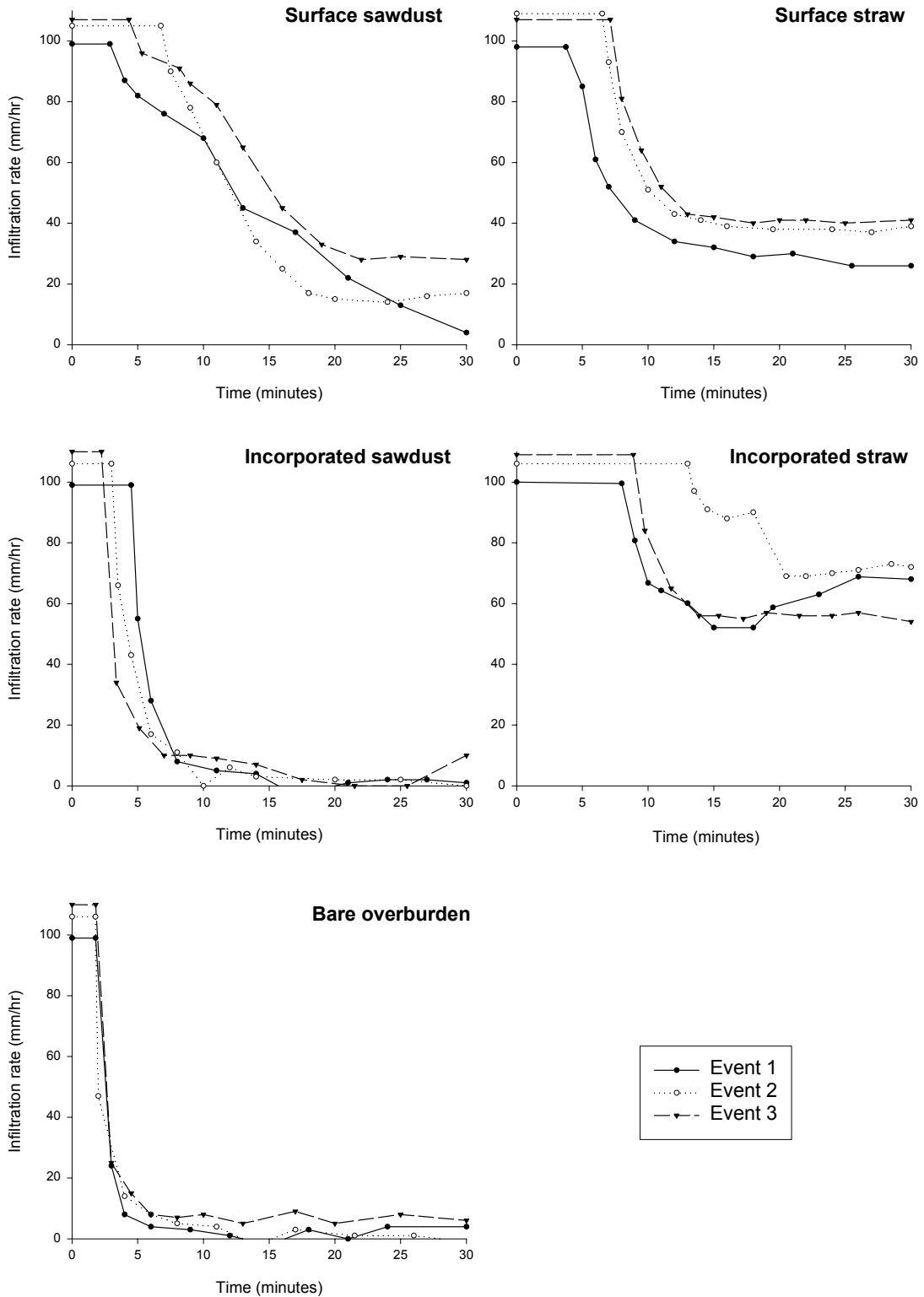


Figure 4. Infiltration under three consecutive simulated rainfall events (nominal 100 mm/hr, 30 minutes) and drying episodes into a saline-sodic spoil unamended or treated with two different organic mulches.

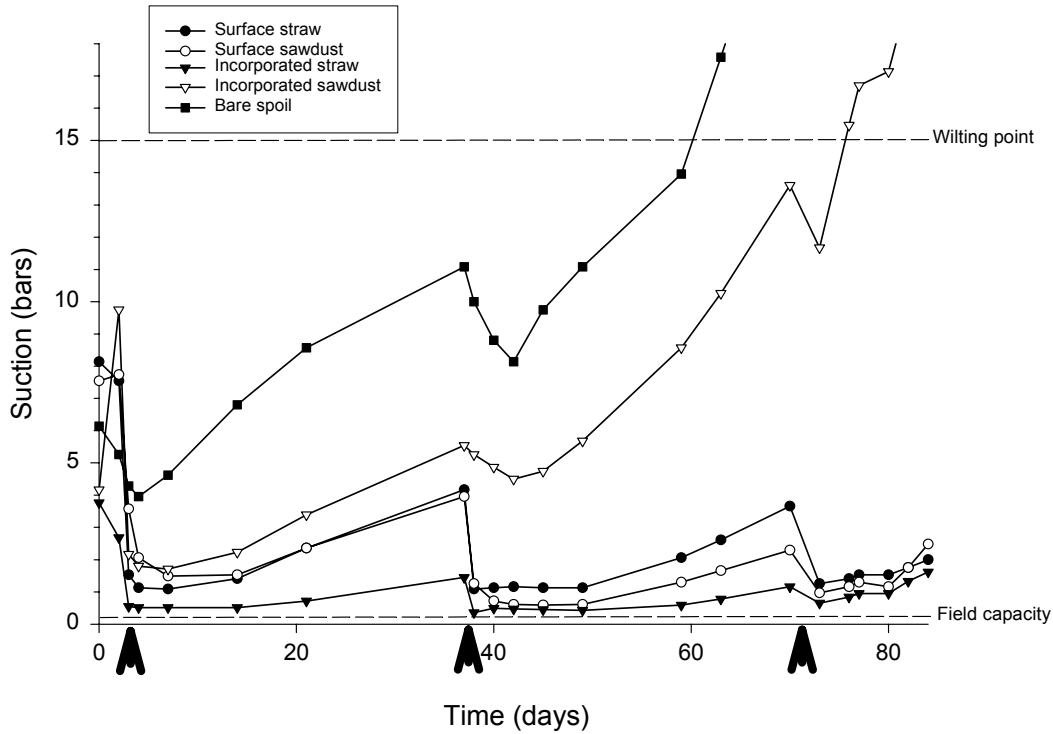


Figure 5: Moisture content (average of readings at 5 cm and 10 cm) over repeated simulated rainfall events (100 mm/h, 30 minutes) and subsequent drying episodes of bare spoil and spoil amended with two organic mulches. Rainfall events are indicated by arrows.

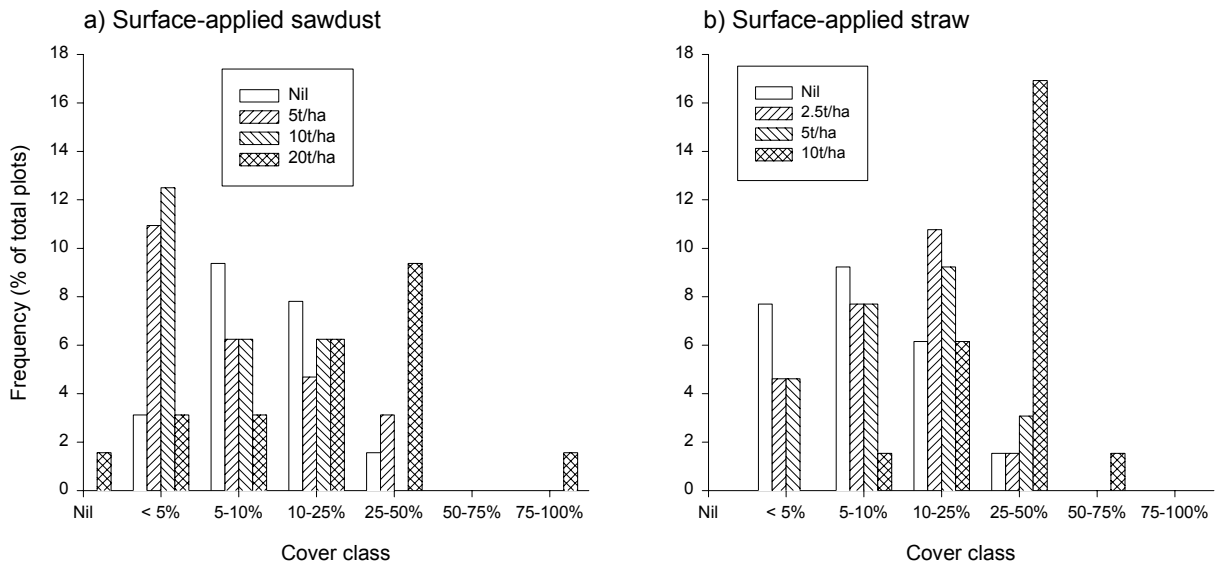


Figure 6. Effect of mulch type and rate of application on ground cover on a saline-sodic spoil sown with native species (May 1998).

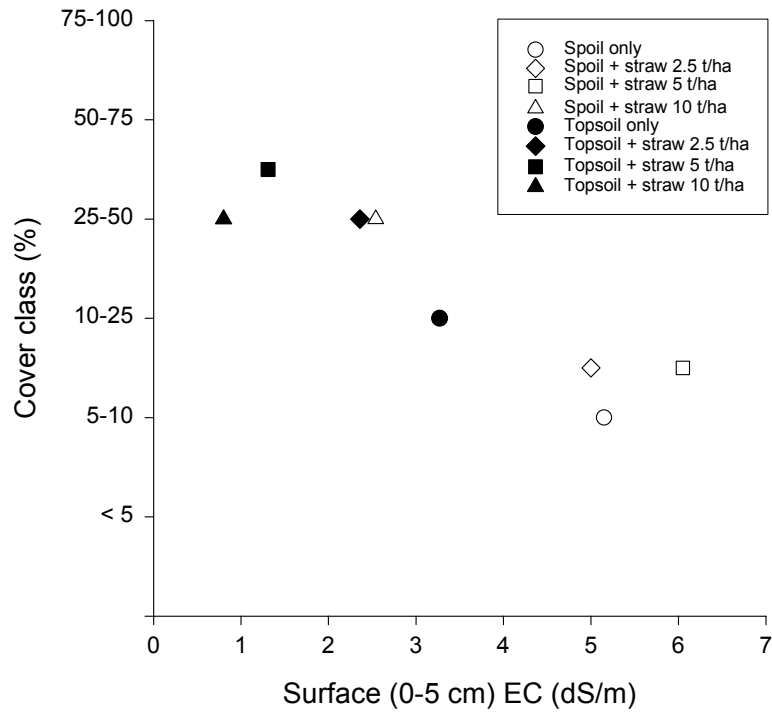


Figure 7. Effect of surface amendment and mulch application rate on median vegetation cover for plots sown with native species (May 1998).

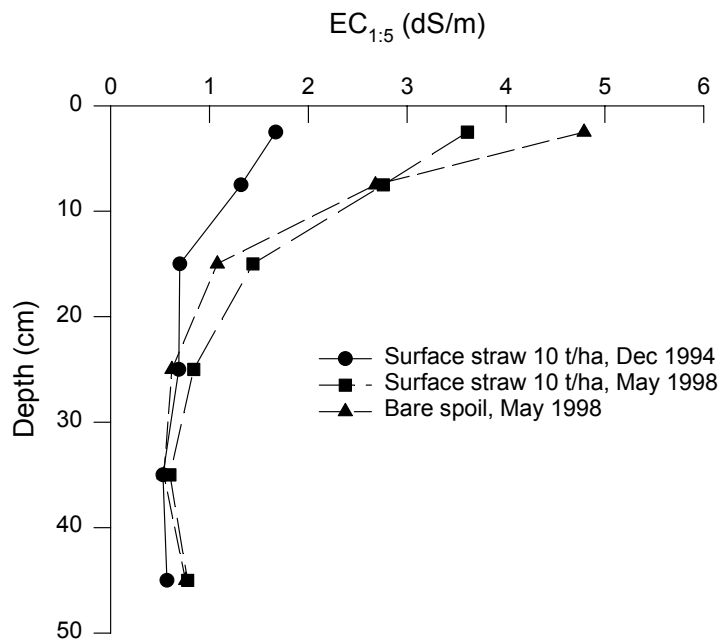


Figure 8. Comparison of salinity profiles over time in a saline-sodic spoil either untreated or amended with a surface application of straw mulch.

Table 2. Species recorded in the ground layer of either spoil or replaced topsoil amended with surface-applied mulches (February 1996).

Species	Common name	Frequency (%)	
		Spoil	Topsoil
<i>Atriplex</i> sp.	Annual saltbush	35	12
<i>Salsola kali</i>	Salsola	21	42
<i>Chloris gayana</i> cv. Katembora	Rhodes grass	18	17
<i>Enchylaena tomentosa</i>	Ruby saltbush	4	10
<i>Cenchrus ciliaris</i> cv. Biloela	Buffel grass	7	4
<i>Heteropogon contortus</i>	Black speargrass	5	3
Other species		9	13

Data on other treatments are limited, but samples collected in July 1997 indicated a significant reduction in surface (0-5 cm) salinity (2.2 dS/m vs. 3.6 dS/m Control) in plots treated with very high rates of incorporated straw and sawdust (20 and 80 t/ha, respectively). Conversely, surface salinity was unaffected by gypsum application or gypsum-mulch combinations (data not shown).

Discussion

In laboratory-based studies, improvements in growth conditions of the saline-sodic spoil from Goonyella Riverside mine resulting from organic mulch amendments were clearly demonstrated, and are in accord with other similar studies on saline-sodic bentonite spoil (Smith et al., 1985, Belden et al., 1990). Infiltration was increased and the rate of drying reduced, thereby enhancing moisture availability for plant establishment and growth. The rainfall simulation trial showed that mulch amendment increased infiltration in several ways: by retarding runoff once rainfall commenced (Figure 4), so increasing the opportunity for downward movement into the profile; by protecting the surface from raindrop impact and presumably subsequent breakdown in surface structure leading to seal formation (Agassi et al., 1981); and in the case of straw mulch, by providing stable pathways for direct entry to sub-surface levels. The drying and crust strength trials indicated that, in periods between rainfall

events, mulch additions lessened crust formation by delays in moisture loss via evaporation, and physical disruption of the crusting layer. Lower crust strength enhanced infiltration in later rainfall events in a positive feedback effect. Greater effectiveness of straw compared to sawdust at the same rates of application was considered to be due to the relatively larger particle size and greater volume per unit weight of straw, conferring lower spoil densities when incorporated and greater surface protection from rainsplash and drying when surface-applied. Incorporating the mulch (at the same rate of application) decreased spoil moisture status by not only reducing surface protection and water retention capabilities, but also by reducing the protection against evaporation. Hence, the benefits of 20 t/ha of incorporated sawdust in the rainfall simulation trial were short-lived (Figures 4, 5).

In the laboratory trials, research interest was focussed on the ability of mulch amendments to improve water relations, with the implied expectation that removal of salts from the upper profile would follow. Belden et al. (1990), for example, showed that improved water relations as a result of wood residue amendment enabled vegetation establishment and the leaching of soluble salts from the surface 15 cm of a saline-sodic spoil over a four-year period. High salinity constitutes a major limitation for successful revegetation, reducing the level of seedling emergence by slowing germination and thus increasing the time that the growth media must remain moist (Harwood, 1998). It also retards plant growth through osmotic stress and indirectly by lowering nutrient availability. Salinity acts as a direct constraint to revegetation success but also compounds the problem of an adequate moisture supply from rainfall. Results from the field trial showed that surface-applied mulch amendments were able to reduce salinity in the surface 5 cm, at least for periods sufficient to promote vegetation establishment when plants are at greatest risk of osmotic stress (Bewley and Black, 1978). However, salinity at depth was unaffected and indeed capillary rise over time caused a deteriorating growth environment. Clearly, surface mulch application on this spoil type does not promote sufficient infiltration and downward leaching of salts under the climate experienced to overcome upward migration during drying periods. Incorporated mulch will permit water penetration to the depth of incorporation (Smith et al., 1985), but application rates need to be increased accordingly to retain the beneficial effects of mulches on surface structure. In the field trial, significant reductions in salinity only occurred at rates of 20 t/ha for straw and even higher rates of 80 t/ha for sawdust, incorporated to 15 cm depth. However, EC levels under these treatments were such that salt-tolerant plant

species dominated. By contrast, Belden et al. (1990) reported significant reductions in EC only at rates of 90 t/ha and above (up to 135 t/ha), although incorporated to 30 cm depth. Furthermore, the wood residues used were reasonably coarse-textured, comprised of only 35 % sawdust (Smith et al., 1985). Undoubtedly, the dry weather conditions experienced throughout the field trial have affected the utility of mulch amendments since even at the higher rates used, Belden et al. (1990) observed salt rise during a drought period. However, extended dry conditions are not unusual in central Queensland and any sustainable revegetation strategy for these spoil materials must be able to transfer salts deep enough to mitigate against periodic rise. It may also be necessary for some time to elapse between mulch amendment and sowing of vegetation to allow for salt levels to be reduced at the surface sufficiently for less salt-tolerant species to establish. Further research is therefore needed to clarify appropriate mulch rates, depths of application, and 'lag' times prior to sowing.

Under low rainfall conditions, the use of gypsum has limited effect on improving soil structure since dissolution of Ca necessary to replace Na is lowered. Both Russell (1980) and Evans et al. (1980), for example, found no benefit of gypsum application in overcoming crusting tendencies in spoils at other mines in the region, leading them to suggest that crusting was mainly a physical phenomenon involving particle resorting into a crust with high bulk density. However, dispersive tendencies in the saline-sodic spoil from Goonyella Riverside mine were clearly evident in the piping and through-flow observed in the rainfall simulation experiment, and Bell et al. (1992) showed that gypsum applied to this spoil under glasshouse conditions decreased measured dispersed clay by flocculation. The lack of response to gypsum in the field trial described here is therefore not totally unexpected. The absence of a significant increase in salinity that can occur with dry weather and materials of low permeability (Philp, 1992, Schuman and Meining, 1993) suggests that dissolution may have been very low. Voorhees and Uresk (1990) indicated that dissolution of gypsum was accentuated by incorporated mulch due to increased infiltration, but in the field trial only the lower rates of incorporated mulches were tested. Despite the apparent ineffectiveness of gypsum, application may be necessary in conjunction with organic mulch amendments to counter elevated SAR and subsequent deterioration in structure of the leached spoil (Belden et al., 1990).

Conclusions

Straw and sawdust mulches are able to reduce surface crust strength and improve moisture relations of highly saline sodic spoil through increased infiltration and reduced evaporation. However, under the drying conditions experienced on central Queensland coal mines, the effectiveness of surface-applied mulches in removing salts is limited by the poor permeability of the spoil, and establishment of only salt-tolerant species is favoured. Mulches will be most effective where downward salt migration as a result of increased infiltration during rain events is deep enough to mitigate against periodic capillary rise during ensuing dry periods. Incorporated mulches, as opposed to surface-applied mulches, are therefore desirable, provided that application rates are high enough to provide adequate surface cover. Rates of 20 t/ha of straw and 80 t/ha of sawdust are recommended as a minimum, but further research is needed to quantify optimal rates of application and depth of incorporation.

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