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Growth of rye grass and clover in artificial topsoils: a case study

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Abstract

The Latrobe Valley region of eastern Victoria houses three major mines which burns lignite for power generation and is referred to as the power house of Victoria. These mines are looking for sustainable ways to manage their waste and achieve successful mine rehabilitation. One of the problems to be addressed for attaining successful mine rehabilitation is the scarcity of topsoils for vegetation cover. The possible solution for overcoming this problem is the use of artificial topsoils (ATS) developed using waste streams, i.e. overburden, interseam brown coal, ash from the onsite powerplant and nearby paper industry waste i.e. effluent sewage recovery (ESR). Field lysimeter experiments with ATS proved that there is no leachate toxicity but the plant available nutrients were relatively low. Hence, clear understanding of ATS as a substrate for vegetation should be examined before applying it in the field. In a recent study, we tested the growth of ryegrass, clover and ryegrass + clover mixture in ATS with and without addition of nitrogen-phosphorous-potassium fertilizer (NPK) in a greenhouse experiment compared to control, i.e. overburden, overburden + ash, natural topsoil. The results after 12 weeks indicate that the height of ryegrass in ATS with NPK is 2.7 cm higher than the height of ryegrass in natural topsoil and is 16 and 17 cm higher than the growth of ryegrass in overburden and overburden + ash mixture respectively. The height of clover in ATS with NPK is 1 cm higher than the clover grown in natural topsoil and around 5 cm more than the height of clover in overburden and overburden + ash mixture. The germination in ATS was slightly delayed as compared to natural topsoil due to higher exchangeable sodium percent in soil, but the presence of NPK in ATS later aided in survival and growth of grass and clover. The initial results from these experiments show that ATS with addition of NPK can be a potential solution in mine rehabilitation and can be used as a substrate for revegetation.

Keywords: *mine rehabilitation, artificial topsoil, growth*

1 Introduction

Revegetation of land after mining is considered to be one of the cost-effective ways of improving post-mining land use (Wu et al. 2019). The ecological restoration of the mines as the coal mining industry expands represents a major challenge to these industries. In Latrobe Valley region of eastern Victoria (Australia), brown coal mines at AGL, Loy Yang (Figure 1) progressively land rehabilitate of mines and one of the major problems associated with rehabilitation of the land after mining operations is the scarcity of the topsoil.

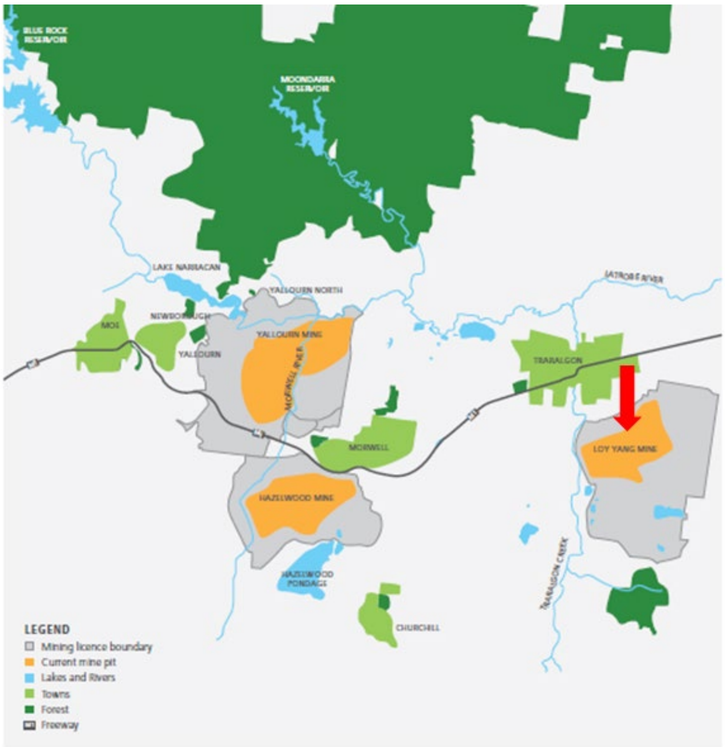


Figure 1 Map of the Latrobe Valley showing the study location (adapted from Hazelwood Mine Fire Inquiry Report 2016)

The shortfall of natural topsoils calls for a need to develop alternate solutions for development of topsoil. A lot of research has been undertaken in amending the abandoned mine sites' with different fertilisers and soil enhancers for improving their soil properties and growth of different species of plants (Beesley et al. 2011; Bleeker et al. 2002; Pardo et al. 2014). Previous research studies have proven that the use of ash, a byproduct of coal combustion of coal, as a soil enhancer increases the water holding capacity of the soil and increases yield of plants (Jala & Goyal 2006; Park et al. 2014).

The use of organic wastes, such as composted sewage sludge for improving and restoring soil properties, have proven to be useful in treating the contaminated soil (Pena et al. 2015).The brown coal is proven to be useful in agricultural application due to the presence of humus substance (Patti et al. 2014; Saha et al. 2018, 2019). However, the focus on using the concept of artificial topsoils (ATS) formed by mixing different wastes, integrating the principles of industrial symbiosis, and ecology to improve the properties of post-mining soil has not been studied extensively to date. This could be one potential solution for overcoming the shortfall of topsoils for revegetation in Victorian brown coal mines. To understand the use of the ATS in mine rehabilitation process, it is important to study the germination and establishment of certain species of plants and compare the growth with the natural topsoils.

This study investigated the growth of ryegrass (*Lolium Perenne L.)*, clover *(Trifolium repens)* and a ryegrass and clover mixture in artificial topsoils (ATS) formed using overburden (OB) and interseam brown coal from Loy Yang mine, ash from coal powerplant's ash pond, and effluent sewage recovery (ESR) from Australian Paper's Maryvale plants waste stream.

2 Materials and methods

2.1 Substrates and artificial topsoils used in the study

The overburden and interseam coal used in this study were collected from AGL's Loy Yang mine in Victoria. The leached ash was collected from the ash pond of the adjoining coal-fired powerplant at Loy Yang and the ESR, was collected from the Gippsland soil solutions, which is the composted sewage sludge from Australian

Paper's Maryvale operations. The overburden was collected from the 150–200 mm depth from different points of the overburden dump at Loy Yang mine. The natural topsoil for the experiments was sourced from the land adjacent to Loy Yang mines, which is not mined. To determine the different proportions of substrate to create an artificial topsoil, initially acid base accounting (ABA) of the overburden and ash was performed according to the protocol prescribed by (Sobek et al. 1978) to obtain the neutral optimised ratio of overburden and ash. ABA can be predicted by quantitatively determining the total amount of acidity and the alkalinity that can be produced. The neutralisation potential of ash was calculated as 2.1 t/1000 t and the maximum potential acidity of overburden was 1.24 t/1000 t. Based on these results the optimum neutral ratio of overburden and ash (OB: Ash) was determined as 1:0.6 and this ratio is used as base material (BM) throughout the study for preparation of artificial soil mixtures. To this BM, 15% of ESR and 5% brown coal were added to create the artificial topsoil. The optimum percentage of compost and brown coal that is required to create an ATS was determined by our previous field lysimeter leachate study, where different percentage of compost and brown coal were tested for excess metal leaching and soil nutrients study. The Table 1 shows the different treatments used in the greenhouse pot experiment.

Table 1 Different treatments used in this study

Treatments	OB (%)	OB:Ash (1:0.6) (%)	Brown coal (%)	ESR (%)	Topsoil (%)	NPK (g)
OB (control)	100	–	–	–	–	–
BM (control)		100	–	–	–	–
T1	–	80	5	15	–	–
T2	–	80	5	15	–	1
TS	–	–	–	–	100	–

OB = overburden, OB: Ash = overburden and ash, BM = base material, ESR = effluent sewage recovery, NPK = nitrogen-phosphorous-potassium

2.2 Characterisation of substrates

All the bulk substrates were air-dried, mixed thoroughly, lightly crushed and sieved using < 2 mm mesh screen and the soil analyses were performed at a NATA accredited laboratory (EAL, Southern Cross University, Australia). The substrates were characterised for pH and electrical conductivity (EC) in 1:5 water suspension, and analysed for total concentration of nitrogen and total concentration of carbon (LECO IR analysis), extractable phosphorus (Bray 1 method), exchangeable potassium (Morgan 1 method), exchangeable sodium percent (ESP) and effective cation exchange capacity (ECEC). The characteristics of the different substrates used in this study are shown in Table 2.

Table 2 Characterisation of substrates used in the study

Parameter	Overburden	Ash	Brown coal	ESR
pH	5.65	9.19	3.90	8.05
EC (dS/m)	0.17	0.65	0.78	1.45
Total nitrogen (%)	0.02	0.02	0.53	0.86
Total carbon (%)	0.21	2.31	57.50	23.30
Extractable phosphorous (mg/kg)	1.8	0.8	2.2	0.3
Exchangeable potassium (mg/kg)	11	79	5.4	159
ESP (%)	19	22.5	25.9	9.6
ECEC (cmol/kg)	7.52	13.27	45.09	15.14

EC = electrical conductivity, ESP = exchangeable sodium percent, ECEC = effective cation exchange capacity, ESR = effluent sewage recovery

2.3 Greenhouse pot experiment

The greenhouse used in this study is made up of a roof of twin walled polycarbonate and walls are 100% UV resistant measuring 2.4 x 4.8 m which allows 90% light transmission. This greenhouse was placed at AGL Loy

Yang with the temperature ranging from 5^0C at night to 25-30^0C during the day and subjected to natural diurnal light cycles. The year-long lysimeter study was carried out in the field ambient condition, to understand the risk of leachate toxicity and soil nutrients present in ATS created using varying ratio of wastes. The results from this experiment helped in determining the suitable ratio of wastes that can be used to form artificial topsoil. The same proportion of waste was used to form ATS in this greenhouse pot experiments to understand the germination and establishment of ryegrass (*Lolium Perenne L.)*, white clover *(Trifolium repens)* and mixture of rye grass and clover for 12 weeks.

Soil samples of all treatments were characterised before starting the experiment, in the same way as substrates. 25 seeds of each ryegrass and clover and mixture of ryegrass+ clover were seeded in the pots and replicated five times. To avoid the moisture stress all pots were watered to field capacity prior to planting. After 2 days the pots in the greenhouse were seeded and an equal volume of deionised water was added to each pot every two days and the weights of each pot were measured and recorded to know the water loss. The germination and growth, i.e. mainly height was measured using tape every 2 days for 12 weeks and the observations were made regularly and the growth of grass and clover in ATS developed was compared to the growth of same in natural topsoils, overburden and BM.

3 Results and discussion

3.1 Characteristics of artificial topsoils

The initial characteristics of the ATS used in this study is shown in Table 3. The pH and EC of BM and ATS are higher as compared to the natural topsoil. The natural topsoil is slightly acidic with pH of 5.5 and the surface soil report of Loy Yang by Sargeant & Imhof (2000), published by department of primary industries, Victoria also shows the surface soil pH of two sites in Latrobe region in the range of 5.5- 6.0. The acidity of the soils could be due to higher rainfall and higher leaching in the area. In this study, the artificial topsoil created using various wastes has a pH of 7.64 making it slightly alkaline. The EC of artificial topsoil used in this study is higher as compared to natural topsoil. This is due to the addition of ESR with an EC of 1.45 dS/cm.

Table 3 Characteristics of base material, artificial topsoil, and natural topsoil

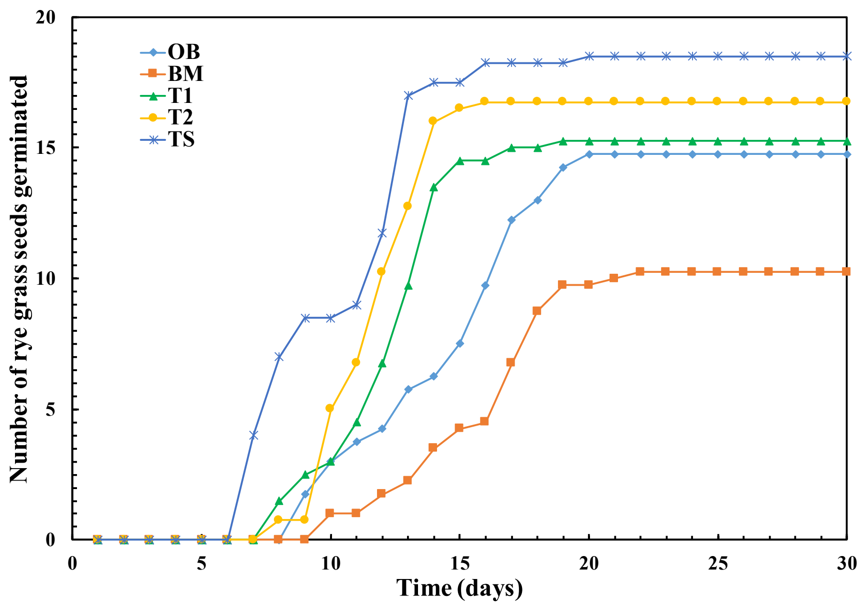
Parameters	Base material	Artificial topsoil (T1)	Natural topsoil (TS)
pH	7.39	7.64	5.5
EC (dS/m)	0.620	0.917	0.132
Total nitrogen (%)	0.03	0.14	0.16
Total carbon (%)	1.74	6.81	2.77
Extractable phosphorous (mg/kg)	1.5	1.5	23
Exchangeable potassium (mg/kg)	32	60	40
ESP (%)	24.4	12.2	4.9
ECEC (cmol/kg)	11.10	28.05	4.64

The total nitrogen present in the ATS is comparable to the nitrogen concentration in natural topsoil. Addition of ESR increased the total nitrogen in ATS as compared to the BM. The concentration of carbon is higher in the ATS compared to natural topsoil due to the addition of ESR which has higher concentration of carbon and also due to addition of brown coal (Patti et al. 2014; Feng et al. 2019). The extractable P was relatively low in ATS and the addition of NPK would help in improving the extractable P in ATS. The exchangeable potassium is higher in ATS as compared to BM and natural topsoil due to compost addition. The addition of compost increased nutrients like N, P, and K in artificial topsoil developed (Lakhdar et al. 2008). The main concern with the ATS is higher ESP - mainly due to the presence of higher sodium content in ash. ATS has relatively lower ESP as compared to the BM (Table 2), mainly due to the addition of compost, which contains higher amount of calcium.

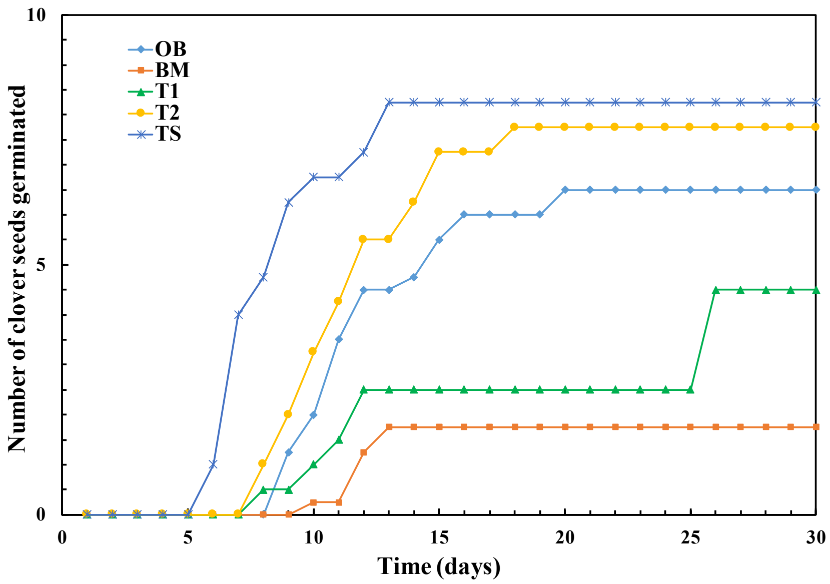
The ECEC is higher in ATS due to the addition of compost. The ECEC is also higher in overburden as compared to the natural topsoil mainly because of the presence of clay in overburden.

3.2 Germination of ryegrass and clover in artificial topsoil

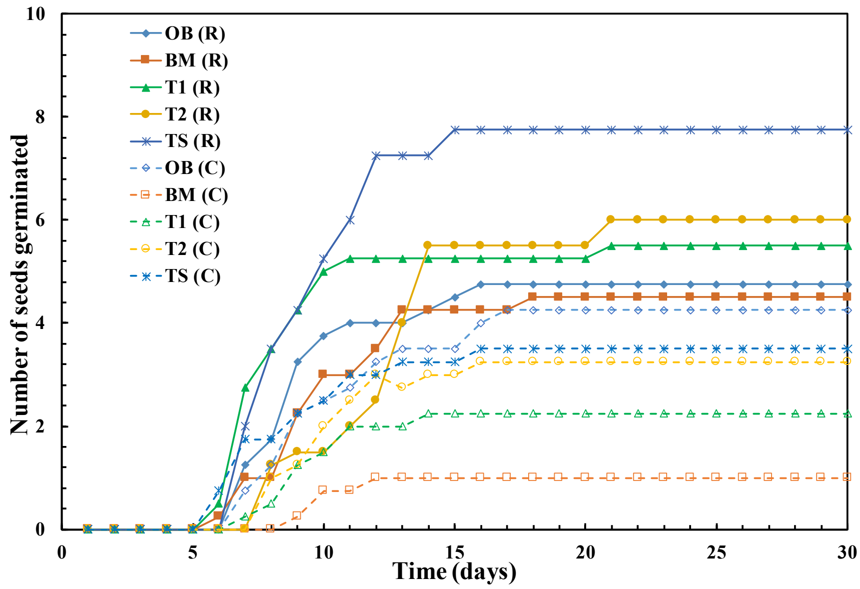
The germination of ryegrass started at 7 days in the natural topsoil, after 8 days in T1 and T2 and after 9 days in OB and BM after sowing seeds. Even though ATS took slightly more time to germinate, after 30 days of experiment the total number of ryegrass seeds germinated in T2 was slightly lower than the seeds germinated in the natural topsoil, whereas seeds germinated in T1 where lower than T2 and higher than OB and BM. Figure 2(a) shows total number of seeds germinated in overburden and BM was much less than the T2 used in the study. The germination percentage of overburden and BM was less than 60%. The germination percentage of T2 was 6% higher to the germination percentage in T1 and was 7% less to the germination percentage in TS. The sodic nature of OB and BM might have caused the clay present in overburden to swell and disperse causing poor germination. The ATS, T2 showed better germination at the end of 30 days because of the application of fertiliser, which helped in increased survival of germinated seeds (Ramteke et al. 2013). The germination of seeds is higher in OB as compared to BM, mainly because of higher sodium content in ash. The number of seeds germinated in T1 is higher than that of BM as the compost contains higher amount of calcium, which could help in reducing the sodic issue of ash and coal and compost addition also helps in providing some of the macro and micronutrients for plant growth (Aggelides & Londra 2000). T2 had quicker and higher germination as compared to T1, mainly because of the nutrients that is available readily with the addition of fertiliser. The growth of ryegrass was much better in the T2 as compared to the overburden and well comparable to the growth in natural topsoil. The clover growth in T2 (Figure 2(b)) was also comparable to the growth in natural topsoil. The clover germination percentage in T2 was 2% less compared to germination percentage in TS. The BM had lowest germination this could be due to the sensitivity of clover towards highly sodic soils. The germination of clover in all treatments were less than 50%. In the information supplied by the Agriculture Victoria (1997), the white clover is sensitive towards higher salinity as compared to the ryegrass. Hence the germination of ryegrass was dominant to clover germination in ryegrass+ clover mixture (Figure 2(c)).



(a)



(b)



(c)

Figure 2 Germination of (a) rye grass (Lolium Perenne); (b) white clover (Trifolium repens); (c) ryegrass (R) - clover (C) mixture in different treatments with time

3.3 Growth of ryegrass and clover in artificial topsoil

The growth of ryegrass, clover and ryegrass + clover mixture is shown in the Figure 3. The height of ryegrass in T2 was 2 cm higher than that of TS. This is mainly due to availability of nutrients with the addition of fertilisers (Liu et al. 2018). Even the growth of ryegrass and clover in T1 is comparable to TS and this shows the potential for ATS to be used as a vegetation cover in mine rehabilitation. The compost in the ATS provides nutrients for plant growth and hence growth is higher as compared to the OB and BM. The OB usually lacks organic matter and nutrients for growth of plants and hence the lower growth of clover and ryegrass. The BM is highly sodic due to the presence of ash and this could also be one of the reasons for poor growth seen in BM. The growth of ryegrass and clover in pots where mixture were sown had slightly reduced growth, which might be attributed to the competency of both in establishing their cover causing limitation in availability of nutrients. The Figure 4 shows the growth of ryegrass and clover in artificial topsoil.

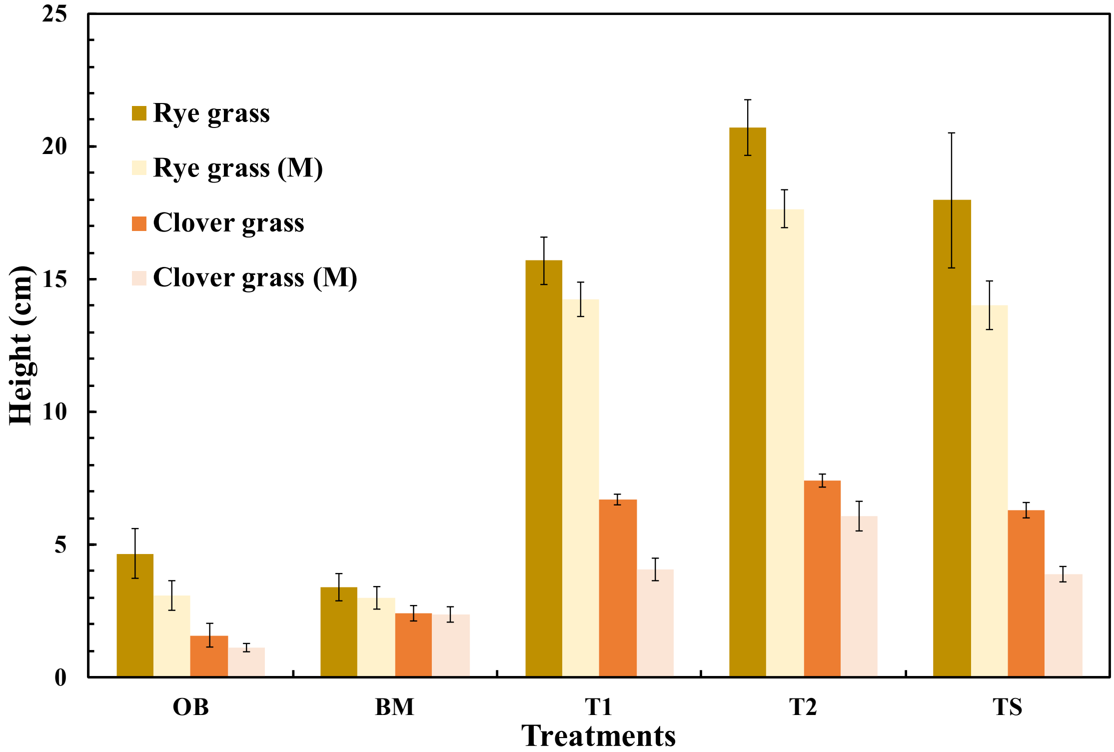


Figure 3 Growth of rye grass (Lolium Perenne), white clover (Trifolium repens), and ryegrass clover mixture (M) in different treatments after 12 weeks

Figure 4 Image showing growth of clover and ryegrass in artificial topsoil

4 Conclusion

The ATS developed from different wastes from coal mine, coal powerplant and the paper industry in this study exhibited improved characteristics compared to that of BM in terms of plant growth, and has suitable pH and EC for the growth of broader range of plant species. The growth of ryegrass in ATS developed is comparable to growth in natural topsoil. The germination of clover was relatively lower in all the treatments due to its sensitivity for weather conditions and for saline soils. The initial observations of the study show ATS as being one possible solution for the scarcity of natural topsoil for mine rehabilitation. Future work involves detailed understanding of the soil metal pool and plant metal uptake in ATS, to determine any environmental hazards that might be present with the use of ATS as vegetative cover for rehabilitation of mined land. Based on the outcome of all these experiment the long-term field trials are planned to be carried out at Loy Yang to understand the viability of use of artificial topsoil in mine rehabilitation.

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