



# Field Scale Assessment of Artificial Topsoil: A Victorian Coal Mine Experience

Anna Birjak<sup>1</sup> (✉), Alena Walmsley<sup>1</sup>, Nicole Anderson<sup>2</sup>, Jon Missen<sup>2</sup>,  
and Mohan Yellishetty<sup>1</sup>

<sup>1</sup> Department of Civil Engineering, Monash University,  
Melbourne, VIC, Australia  
annabirjak@gmail.com

<sup>2</sup> AGL Loy Yang, Loy Yang, VIC, Australia

**Abstract.** The Latrobe Valley is host to several open-cut coal mines which pose an environmental risk if poorly managed. To reduce risks associated with acid mine drainage and fire, progressive rehabilitation of batters is recommended. A lack of topsoil in the Latrobe Valley has led an industrial symbiosis to generate artificial topsoil's (ATS). Based on previous experiments, three ATS were created by combining overburden (OB), brown coal (BC), fly ash (FA) and one of the two waste products from a local paper mill – Effluent Sewage Recovery (ESR) or Enviroshield (ES). The ATS were compared to a local topsoil (TS). The study analyzed the physical and chemical properties of the topsoil's, seed germination and grass establishment. It was found that all ATS had similar properties and were alkaline compared to an acidic TS. The ATS were enriched in salts and found to be sodic to highly sodic and highly saline while TS was non-saline but slightly sodic. The ATS were also low in nitrogen and, due to the high pH of the soil, nutrients such as phosphorus, iron and manganese were not bioavailable. For the duration of the study, germination and grass establishment on ATS was not significant, however, grass was beginning to establish on the TS. As such, it is recommended further investigation be undertaken to determine an appropriate seed mix for the ATS which is tolerant to alkaline and saline soils. Further research is being conducted to determine the source of the alkalinity and salinity in the ATS.

**Keywords:** Artificial soil · Coal mining · Rehabilitation

## 1 Introduction and Background

Located in Central Gippsland, the Latrobe Valley is host to a large brown coal reserve which has been progressively mined since 1921 to serve the State's energy needs [13]. As these mines approach closure and the energy sector transitions to a less carbon intensive network, mine rehabilitation is becoming increasingly important.

Prior to rehabilitation, overburden (OB) dumps containing sulfide minerals, such as pyrite, were exposed to the atmosphere. When sulfide minerals are exposed to oxygen and water, they can react to form sulfuric acid, thereby lowering the pH of the soil leading to the mobilization of metals – a process commonly referred to as acid mine drainage (AMD) [6]. Additionally, the presence of coal in the batters heightens the risk

of fire which could be potentially devastating as evidenced by the 2014 Hazelwood Fires. The fire that broke out at Hazelwood lasted for 45 days generating significant pollution which had adverse effects on the environment and nearby residents [22]. Interestingly, it was observed that rehabilitated sections of the mine did not catch fire. As such, progressive rehabilitation of batters which utilized OB in the process is recommended to mitigate the risks associated with AMD and the potential for a fire to ignite.

The progressive rehabilitation of batters involves:

- The infill of batters with OB to achieve a desired profile
- Application of topsoil
- Application of a seed mix to promote vegetation.

Currently, there is an insufficient supply of topsoil available in the Latrobe Valley to effectively rehabilitate mining affected land. To address this, an industrial symbiosis combining paper mill waste products and mining waste products has been proposed to create three artificial topsoil's (ATS) for the purpose of slope rehabilitation.

The ATS was created using OB, fly ash (FA), brown coal (BC) and one of the two waste products from a local paper mill - Effluent Sewage Recovery (ESR) or Envirosield (ES). Laboratory based studies have been conducted to determine the optimum ratio of components (Table 1). The purpose of this study is to analyze the physical and chemical properties of the ATS compared to a local topsoil (TS) on the field scale. The success of the ATS will be defined by the successful germination of seeds and establishment of grass.

**Table 1.** The ratios of overburden (OB), fly ash (FA), effluent sewage recovery (ESR), Envirosield (ES) and brown coal (C) in different ATS mixes.

	OB	FA	ESR	ES	C
Mix A	1	0.6	<b>0.2</b>	–	0.1
Mix B	1	0.6	<b>0.3</b>	–	0.1
Mix C	1	0.6	–	<b>0.2</b>	0.1

## 2 Materials and Methods

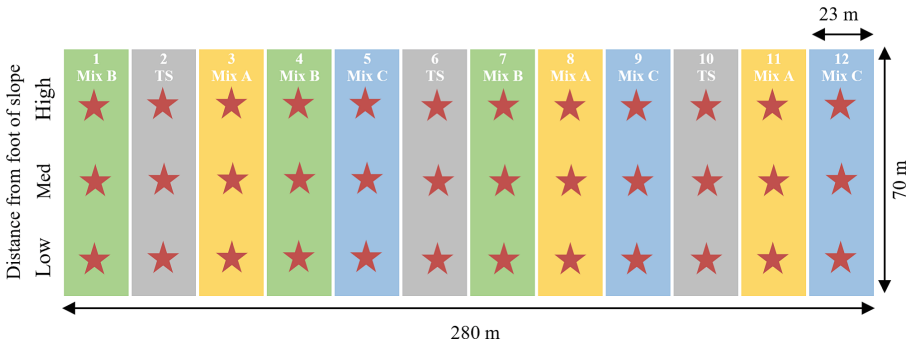
### 2.1 Site Description

The study was conducted between February 2018 and April 2018 at Loy Yang A, an open-cut coal mine located 12 km east of Morwell in the Latrobe Valley, Victoria (−38.23, 146.55; 56 m above sea level).

The area receives 745.2 mm of rainfall annually with spring being the wettest season [4]. During winter and, to a lesser extent spring, frost is common in the area which could have negative implications for seed germination [3].

### 2.2 Experimental Design

A batter located on the west side of the mine was cut down, filled with OB and compacted to create a 20° slope dipping to the east. The experiment was carried out on a section of the slope that was 280 × 70 m. The slope was split into 12 subplots, each 23 m wide. The 3 ATS and TS were applied to the slope in a randomized design (Fig. 1).



**Fig. 1.** Configuration that the topsoils were applied to the slope where red stars represent the location at which samples were taken

The ATS were mixed together on site using a row turner. The ATS and TS were then stockpiled at the foot of the slope. Dozers were used to push the soil from the foot of the slope up. This resulted in the soils being thicker at the foot of the slope compared to the top of the slope.

All subplots were sown with an identical pasture mix consisting of six different grass and legume species as specified in Table 2. At the time of sowing, fertilizer was applied at a rate of 270 kg/ha with a Nitrogen:Phosphorus:Potassium ratio of 11:15:14.

**Table 2.** Application rate, pH and salinity tolerance of the pasture mixed utilized in the field trial [1].

Plant species and variety	Application rate (kg/ha)	pH tolerance	Salinity tolerance, EC <sub>e</sub> (ds/m)
Kingsgate perennial ryegrass	30	5.1–8.4	2.25–4.5
Riverina sub clover	6	6–7.3	0–1.10
Collamon sub clover	6	6–7.3	0–1.10
Uplands cocksfoot	4	5.5–7.5	2.25–4.5
Yarck 11 cocksfoot	4	5.5–7.5	2.25–4.5
Nomad white clover	2	6–7.5	0–1.10

### 2.3 Soil Monitoring

Monitoring occurred on a bimonthly basis with a total of two monitoring events undertaken. The first monitoring event occurred on the 28th of February, 2018 and the second on the 10th of April, 2018. Three samples were taken per subplot. Samples were taken in the middle of the subplot with distance from the foot of the slope varying from low (15 m) to medium (35 m) to high (55 m) (Fig. 1). Monitoring involved the sampling of soils followed by the analysis of their physical and chemical properties.

To measure the bulk density of the soil, samples were taken using a solid steel ring with a known volume of 100 cm<sup>3</sup>. The weight of the samples was recorded, this is known as the wet weight. The soil was then dried in a conventional oven for 48 h at 105 °C. Following drying, the weight of the soil was recorded, this is referred to as the dry weight. Bulk density was then determined by dividing the dry weight of the soil by the volume of the steel ring used to collect the sample.

Soil samples were taken using a hand auger and targeted the top 100 mm of topsoil. The chemical properties of the soil were analyzed by Environmental Analysis Laboratory at Southern Cross University, using standard soil analytical methods. Major soil macro- and micronutrients were analyzed, as was pH and conductivity.

## 3 Results and Discussion

The properties of each topsoil were compared based upon the distance from the foot of the slope at which the sample was taken e.g. Mix B at a low distance compared to a Mix B at a medium distance from the foot of the slope (Fig. 1). This analysis was undertaken to determine if there were any significant lateral variation across the slope as the result of leaching. A similar approach was taken to determine if there was variation between subplots of the same mix e.g. Mix B on subplot 1 as opposed to on Mix B on subplot 4 (Fig. 1). Overall, the lateral variation was deemed insignificant and the properties of soils were analyzed based purely upon the mixture. It is assumed that this will change with time as leaching depletes the top of the profile of cations while it enriches the bottom layers of soil.

### 3.1 Texture and Bulk Density

Soil texture indicates the relative proportions of silt, clay and sand in the soil. Texture is indicative of various chemical properties such as cation exchange capacity (CEC). The results of the study show that the ATS formed clay loams while the TS formed a loam. These two textures are very similar with loams containing more silt and clay loams containing more clay. The implications of a higher clay content are an increased buffering capacity and increased CEC.

Bulk density (BD) affects the infiltration rate of water, root penetration and the ability for a soil to store water or air. The critical values at which BD restricts root penetration in loams and clay loams is 1.6 g/cm<sup>3</sup> [11]. Despite compaction applied by the dozers during spreading, the BD of all topsoil's was less than 1.6 g/cm<sup>3</sup>. Thus, indicating there should be no negative impacts of BD in relation to root penetration.

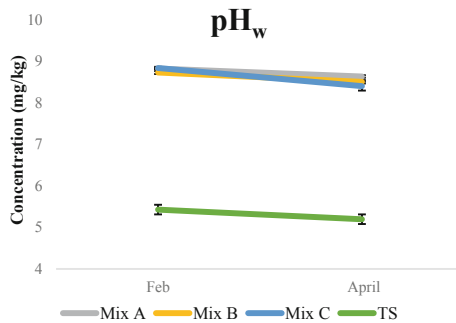
The variation in BD over time relates to the stability and homogeneity of the soils. The BD of the TS was consistent over time while that of the ATS varied but appeared to converge at around  $1.07 \text{ g/cm}^3$ . This BD would provide optimal conditions for plant growth in a clayey soil [10].

### 3.2 PH

pH is one of the most important chemical properties of soil. pH influences nutrient availability, the solubility and reactivity of heavy metals and plays an important role in microbial activity and plant growth [5, 20].

Australian soils vary widely in pH dependent upon their regional setting and factors such as rainfall, leaching and subsurface lithology [5]. However, pH can be characterized on a more local scale with the Latrobe Valley being considered to host moderately to strongly acidic soils [25]. This local characterization of soil is likely to remain true on site as OB used to fill in the slope is characterized as being acidic [23].

The results from this study show the  $\text{pH}_w$  of the ATS varied from 8.4–8.8 while the  $\text{pH}_w$  of TS varied from 5.2–5.4 (Fig. 2). Based upon column leachate studies, the pH of the ATS was not anticipated to be so alkaline. The most alkaline component of the ATS was the FA with a  $\text{pH}_w$  of around 9 which should have been counteracted by the acidity of the OB and BC which had  $\text{pH}_w$  of around 5.5 and 4.0, respectively.



**Fig. 2.** Average concentration of pH for each topsoil as determined using a 1:5 water method.

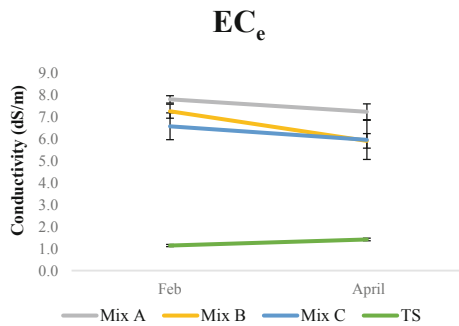
Interestingly, the pH was observed to decrease for all soils between the two sampling events in February and April. This was unexpected as the soils were assumed to have a high buffering capacity due to the high CEC and high concentrations of organic matter (OM) within the soils. The rate of change was greatest in Mix C followed by Mix A, Mix B and, lastly, the TS. The decrease in pH is coupled with a decrease in OM. The reduction in OM is likely related to micro-organisms which breakdown OM and, in the process, create acid thereby lowering the pH of soils [27].

Although the ATS are still alkaline, the reduction in pH will be beneficial as it now approaches the upper tolerance limit of species within the pasture mix. However, the bioavailability of macro- and micronutrients such as phosphorus, iron and manganese

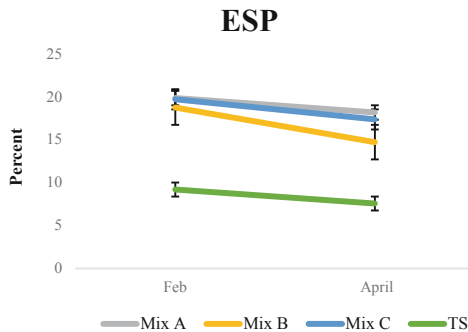
which are required for healthy growth will be reduced given the alkalinity of the ATS. Finally, pH is intrinsically linked to sodium concentration with a pH greater than 8.5 indicating significant quantities of exchangeable sodium present which generates sodic soils and negatively affects soil structure [17]. This is further discussed below.

### 3.3 Salinity and Sodicity

Salinity and sodicity relate to the measurements of soluble salts present in the soil where salinity focuses on the whole salt while sodicity relates specifically to the sodium cation. Salinity and sodicity are important to predict the behavior of the soil in relation to flocculation and dispersion [17]. Soils with high concentrations of sodium will promote the generation of sodic soils leading to dispersion. Sodic soils are defined by an Exchangeable Sodium Percentage (ESP) greater that 6% where ESP is the concentration of sodium cations divided by the concentration of all cations pre-sent. Dispersion of soils due to high ESP can be counteracted if the EC of the soil is high and the soil will flocculate (Figs. 3 and 4).



**Fig. 3.** Average EC<sub>e</sub> for each topsoil determined using the measured EC<sub>w</sub> and conversion rates for clay loam and loams of 8.6 and 9.5.



**Fig. 4.** Percent of exchangeable sodium cations relative to other cations in the topsoil.

As expected, salinity and sodicity vary greatly across Australia. Northcote & Skene (1972) mapped soil morphology across the continent and defined 25 different salt-affected soil classes. Northcote & Skene (1972) estimated that 193 to 257M ha was affected by sodicity while 39M ha was affected by salinity. This study formed the backbone of Australia's evolving study of salt affected soils with many follow up studies focusing on the impacts of salt affected soils on agricultural land [19, 21]. In addition, a more recent study has estimated the quantity of sodic and saline land in Australia to be 340M and 66M ha, respectively [20].

The Latrobe Valley occurs within a saline province which is defined as an area where salinity has been identified but not necessarily mapped [26]. Additionally, the area has been characterized as having sodosols which are soils with a strong change in sodicity between topsoil and subsoil with subsoils being sodic to highly sodic [24]. On site, subsoils will consist of OB which has been characterized as been low in salinity but having a variable ESP. As such, it is expected that soils will display sodosol properties [23].

The results from this study characterize the ATS as moderately to highly saline and sodic to highly sodic while the TS was non saline but sodic (Figs. 6 and 7).

Although issues with salinity were anticipated, column studies predicted ESP levels less than 5% [15]. It is assumed that the high ESP levels of this study are a due to the heterogeneity of FA and OB. The EC was relatively consistent between February and April (Fig. 6) while ESP was seen to decrease for all soils (Fig. 7). This could indicate leaching of sodium ions prior to the April sampling event. Currently, the high levels of salt within the soil will likely restrict plant growth with the exception of some saline tolerant species such as Perennial Ryegrass.

### 3.4 Nutrients

Nutrients are essential for plant growth and metabolism. Dependent on the quantity required for healthy plant growth, nutrients can be split in to macro- and micronutrients. Although nutrients are necessary, some nutrients, such as iron, become toxic as when in excess.

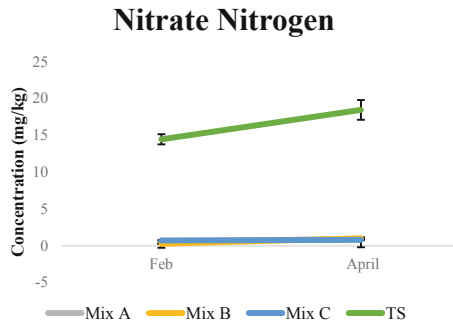
This study focusses on the following nutrients:

- Macronutrients: Nitrogen, Phosphorus, Potassium, Calcium and Magnesium
- Micronutrients: Manganese, Iron and Boron.

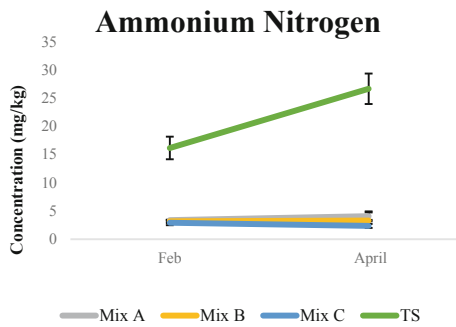
#### Nitrogen

Nitrogen is a major component of chlorophyll and amino acids and is therefore essential for plant growth [29]. Plants are only able to access nitrogen from soil in its mineralized forms of ammonium or nitrate. Both ammonium and nitrate levels of the ATS were significantly lower than the TS (Figs. 5 and 6). This was unexpected as the only component of the ATS that was deprived in both ammonia and nitrate was the OB with all other parts being high in either one of or both sources of nitrogen. Despite the application of fertilizer, there was little variation in the concentration of mineralized nitrogen in the ATS between February and April. It is assumed that ammonium applied to the ATS reacted with the alkaline soils and formed ammonia gas which vaporized.

Given the acidity of the TS, this process did not occur and the levels of mineralized nitrogen increased. It is assumed this trend will continue in the TS as clovers began to establish. Clovers are part of the legume species which are known to facilitate symbiotic bacteria such as *Rhizobium* which fix nitrogen from the atmosphere into its mineral forms leading to increased levels of bioavailable nitrogen [16].



**Fig. 5.** Average concentration of Nitrate Nitrogen for each topsoil.



**Fig. 6.** Average concentration of Ammonium Nitrogen for each topsoil.

## Phosphorus

Phosphorus is important to plants as it enables cell division, tissue development and energy conversion [9]. Similar to nitrogen, it was observed that the concentration of phosphorus in the ATS was significantly less than TS. Based upon column studies, it was expected that the ATS would have phosphorus at levels at least 10 times higher than what was detected in the field [15]. As pH controls phosphorus bioavailability, it is assumed the extremely low levels of phosphorus are related to the alkaline pH of the ATS.

The levels of phosphorus in the ATS were seen to double and triple between February and April while the levels in the TS decreased slightly (Fig. 7). The increase in phosphorus levels in the ATS is related to a decrease in pH coupled with the application of fertilizer which promoted the availability of phosphorus in the soil.



While, the slight decrease in phosphorus levels in the TS has been attributed to the germination and grass establishment which would consume phosphorus.

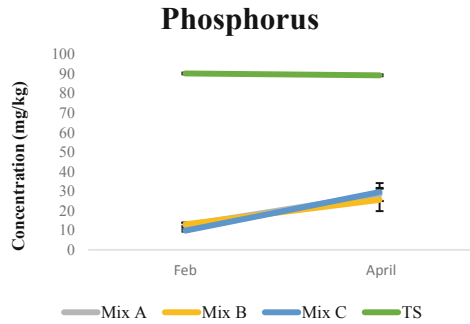


Fig. 7. Average concentration of Phosphorus for each topsoil.

**Potassium**

Potassium plays a vital role in plants by regulating CO<sub>2</sub> uptake and triggering the activation of enzymes [30]. Although the ATS were enriched in cations relative to the TS, the levels of potassium in the soils were comparable with the exception of Mix C which was significantly lower than the other topsoil’s (Fig. 8). The variation between the ATS can be attributed to the nutrient source. Mix A and B utilized ESR which had a much higher potassium concentration relative to the ES used in Mix C. Despite this, all soils present levels of potassium which would enable plant growth. However, potassium levels must not be looked at alone as uptake of potassium will be prevented if other cations, specifically sodium, are in excess [8]. As such, the sodicity of the ATS must be addressed to ensure potassium uptake is sufficient.

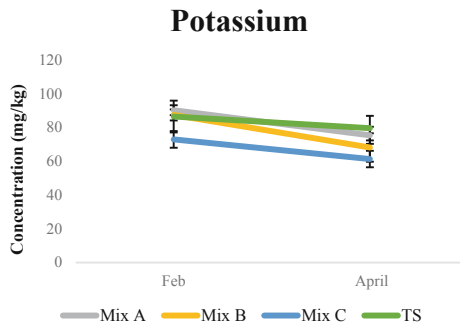
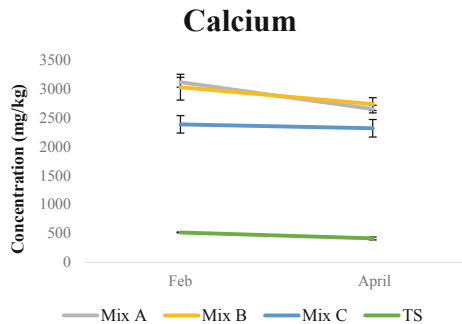


Fig. 8. Average concentration of Potassium for each topsoil.

## Calcium

Calcium is utilized by plant to build and give structure to cell walls [28]. As expected, given cations were enriched in ATS relative to TS, levels of calcium within the ATS were significantly higher compared to the TS (Fig. 9). Levels of calcium were relatively consistent between February and April with the exception of Mix A. The concentration of Mix A was seen to decrease by 15%. However, as calcium isn't considered leachable, this has been attributed to the heterogeneity of calcium within the soil.



**Fig. 9.** Average concentration of Calcium for each topsoil.

Calcium is not considered toxic to plants so the high levels present in the ATS should not prohibit grass establishment [12]. The levels of calcium present in the ATS and TS should be sufficient to enable germination and grass establishment. However, it is important to note that the uptake of calcium maybe reduced by the high levels of sodium in the ATS [12].

## Magnesium

Magnesium is essential to plant survival as it is utilized to produce chlorophyll [7]. As the ATS were enriched in cations relative to the TS it follows that the concentration of magnesium was also significantly higher in the ATS compared to TS (Fig. 10). Although the level of magnesium in the ATS is high, this won't necessarily correspond with efficient uptake. Cation competition, specifically with calcium and sodium, is likely to limit the ability for plants to uptake magnesium [7].

The concentration of magnesium in the ATS reduced between sampling events while the concentration within the TS remained constant. It is assumed the reduction in the ATS relates to the base components of each mix. Although all the concentration of magnesium decreased for all ATS the effects were much more noticeable for Mix A and B. As such, it assumed the reduction in magnesium is related to the use of ESR as a source of nutrients compared to ES.

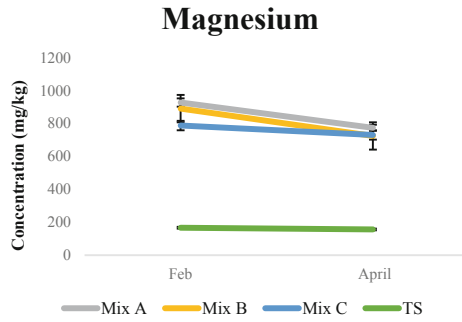


Fig. 10. Average concentration of Calcium for each topsoil.

### Manganese

Manganese supports photosynthesis and is essential for growth however, when in excess, manganese can become toxic [14]. The bioavailability of manganese is controlled by pH. At high pH manganese availability is reduced while at low pH manganese availability can become toxic [14]. High OM and low nitrogen will also reduce the availability of manganese.

In the field trial, bioavailable manganese was seen to be significantly lower in the ATS compared to the TS (Fig. 11). With the exception of Mix A, the concentration of manganese was seen to increase between sampling events. As such, it is assumed this difference relates to pH with a decrease in pH increasing the bioavailability of manganese. However, this effect was negligible for Mix B and C based on the low initial concentration of manganese. As such, further reductions in pH coupled with increases in nitrogen would promote manganese concentration in ATS to sufficient levels.

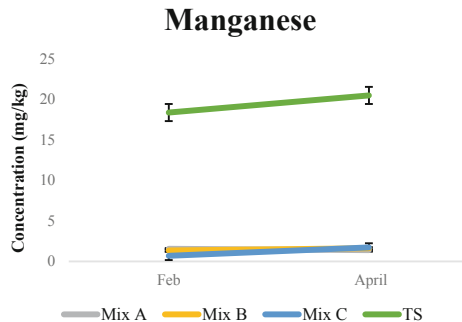
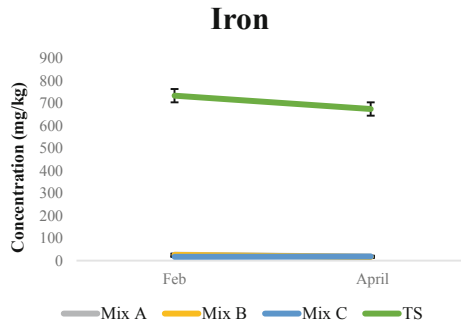


Fig. 11. Average concentration of Manganese for each topsoil.

### Iron

Iron is used by plants to develop chlorophyll, enzymes and proteins however at high concentrations iron can become toxic [2]. Iron availability is heavily dependent on pH

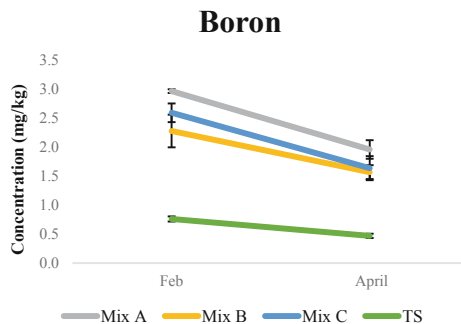
with high pH reducing availability and low pH increasing availability. Again, iron levels in ATS were seen to be very low compared to TS. This is likely due to the high pH of ATS making iron unavailable to plants (Fig. 12). Interestingly, although pH dropped between sampling events an increase in iron concentrations was only observed in Mix C. It's assumed these small changes in concentration are better explained by heterogeneity of the topsoil.



**Fig. 12.** Average concentration of Iron for each topsoil.

## Boron

Boron plays a structural role in plant function and, although it is necessary for plant growth, it can be toxic when in excess [18]. Boron availability is again dependent on pH with boron being most available between pH of 5.5–7.5 or greater than 10.5. As such, boron toxicity can become an issue in alkaline soils. As expected, the concentration of boron in ATS was greater than in the TS (Fig. 13). The concentration was seen to decrease between February and April which corresponds with a decrease in pH. To ensure boron doesn't occur at toxic levels with the ATS, pH must be reduced.



**Fig. 13.** Average concentration of Boron for each topsoil.

## 4 Conclusions

Industrial symbiosis was practiced to address the growing demand for topsoil within the Latrobe Valley. Three ATS were created and compared to a local topsoil. The ATS aimed to prevent AMD and reduce risks associated with fire whilst prompting seed germination and grass establishment. Overall, there was little significant variation between the three ATS. All ATS were alkaline and presented saline and sodic properties. The effect of alkalinity on nutrient availability was ultimately negative as it either made nutrients unavailable or in the case of boron, the availability was in excess leading to potential issue with toxicity. The properties of the TS were very different to the ATS as it was slightly acidic, non-saline and slightly sodic. Nutrients in the TS were sufficiently available and allowed for germination and grass establishment. Although the high alkalinity of the ATS will prevent AMD initially, its inability to establish grass will lead to erosion. If erosion is sufficient, OB will be exposed to the atmosphere which could potentially lead to AMD if left untreated.

Currently, the ATS has been unsuccessful in establishing grass cover. Going forward, it is recommended further monitoring be undertaken over the winter months to establish what effect increased rainfall has on the soils ability to support grass establishment. If the grass is unable to establish, it is recommended that the field trial be resown with an alkaline and saline tolerant seed mix. Additionally, further investigate is recommended to determine the root cause of the high pH and salinity of ATS.

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## References

1. Agriculture Victoria: Salinity and the Growth of Forage Species (2008). <http://agriculture.vic.gov.au/agriculture/farm-management/soil-and-water/salinity/salinity-and-the-growth-of-forage-species>. Accessed 4 Apr 2018
2. Briat, J., Dubos, C., Gaymard, F.: Iron nutrition, biomass production, and plant product quality. *Trends Plant Sci.* **20**(1), 33–40 (2015)
3. Bureau of Meteorology: Annual and monthly potential frost days (2016). [http://www.bom.gov.au/jsp/ncc/climate\\_averages/frost/index.jsp?period=an&thold=lt2deg#maps](http://www.bom.gov.au/jsp/ncc/climate_averages/frost/index.jsp?period=an&thold=lt2deg#maps). Accessed 5 Oct 2017
4. Bureau of Meteorology: Climate statistics for Australian locations (2017). [http://www.bom.gov.au/climate/averages/tables/cw\\_085280\\_All.shtml](http://www.bom.gov.au/climate/averages/tables/cw_085280_All.shtml). Accessed 5 Oct 2017
5. de Caritat, P., Cooper, M., Wilfor, J.: The pH of Australian soils: field results from a national survey. *Soil Res.* **49**(2), 173–182 (2011)
6. Evangelou, V.P., Zhang, Y.L.: A review: pyrite oxidation mechanisms and acid mine drainage prevention. *Crit. Rev. Environ. Sci. Technol.* **25**(2), 141–199 (1995)
7. Farhat, N., Elkhouni, A., Zorrig, W., Smaoui, A., Abdelly, C., Rabhi, M.: Effects of magnesium deficiency on photosynthesis and carbohydrate partitioning. *Acta Physiol. Plant.* **38**(6), 1–10 (2016)

8. Gourley, C.: Potassium. In: Peverill, K., Sparrow, L., Reuter, D. (eds.) *Soil Analysis: An Interpretation Manual*. CSIRO, Melbourne (1999)
9. Hopkins, B., Ellsworth, J.: Phosphorus availability with alkaline/calcareous soil. In: *Western Nutrient Management Conference*, vol. 6, pp. 88–93 (2005)
10. Hunt, N., Gilkes, R.: *Farm Monitoring Handbook - A practical down-to-earth manual for farmers and other land users*. University of Western Australia: Nedlands WA and Land Management Society: Como WA (1992)
11. Jones, C.: Effect of soil texture on critical bulk densities for root growth. *Soil Sci. Soc. Am. J.* **47**, 1028–1211 (1983)
12. Kirkby, E., Pilbeam, D.: Calcium as a plant nutrient. *Plant, Cell Environ.* **7**(6), 397–405 (1984)
13. Minerals Council of Australia (n.d) Brown Coal - Lignite. [http://www.minerals.org.au/file\\_upload/files/resources/victoria/minerals\\_fact\\_sheets/Minerals\\_-\\_Fact\\_Sheets\\_-\\_Brown\\_Coal\\_-\\_Lignite.pdf](http://www.minerals.org.au/file_upload/files/resources/victoria/minerals_fact_sheets/Minerals_-_Fact_Sheets_-_Brown_Coal_-_Lignite.pdf). Accessed 15 Oct 2017
14. Mulder, E., Gerretsen, F.: Soil manganese in relation to plant growth. *Ind. Eng. Chem.* **4**, 221–277 (1952)
15. Mundodi, L.: *Innovative Way to Mine Rehabilitation through Waste Utilization: A Case Study from Latrobe Valley*. Monash University, Melbourne (2015)
16. Nesheim, L., Boller, N.: Nitrogen fixation by white clover when competing with grasses at moderately low temperatures. *Plant Soil* **133**(1), 47–56 (1991)
17. Northcote, K., Skene, J.: *Australia Soils with Saline and Sodic Properties*. CSIRO, Canberra (1972)
18. Reid, R.: Understanding the Boron transport network in plants. *Plant Soil* **385**(2), 1–13 (2014)
19. Rengasamy, P.: Transient salinity and subsoil constraints to dryland farming in Australian sodic soils: an overview. *Aust. J. Exp. Agric.* **42**(3), 351–361 (2002)
20. Rengasamy, P.: World salinization with emphasis on Australia. *J. Exp. Bot.* **57**(5), 1017–1023 (2006)
21. Rengasamy, P., Olsson, K.: Irrigation and sodicity. *Aust. J. Soil Res.* **31**(9), 821–837 (1993)
22. State Government of Victoria (2014) Hazelwood Mine Fire Inquiry, State Government of Victoria, Victoria
23. Taylor, M., Yellishetty, M., Panther, B.C.: Geotechnical and hydrogeological evaluation of artificial soils to remediate acid mine drainage and improve mine rehabilitation - an australian case study. In: Drebenstedt, C., Singhal, R. (eds.) *Mine Planning and Equipment Selection*. Springer, Cham (2014)
24. Victorian Government: Map of Victorian Sodic Soils (2014). <http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/grains-soil-map-victoria>. Accessed 25 Apr 2018
25. Victorian Government: Surface Soil pH (2015). [http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/vic-soil\\_surface-soil-ph\\_map](http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/vic-soil_surface-soil-ph_map). Accessed 23 Mar 2018
26. Victorian Government: Victoria's Salinity Provinces (2017). [http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/lwm\\_salinity-provinces](http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/lwm_salinity-provinces). Accessed 25 Apr 2018
27. Wershaw, R.: Model for humus in soils and sediments. *Environ. Sci. Technol.* **27**(5), 814–816 (1993)
28. White, J., Broadley, R.: Calcium in plants. *Ann. Bot.* **92**(4), 487–511 (2003)
29. Zhao, D., Reddy, K., Kakani, K., Reddy, V.: Nitrogen deficiency effects on plant growth, leaf photosynthesis, and hyperspectral reflectance properties of sorghum. *Eur. J. Agron.* **22**(4), 391–403 (2005)
30. Zörb, C., Senbayram, M., Peiter, E.: Potassium in agriculture – status and perspectives. *J. Plant Physiol.* **171**(9), 656–669 (2014)