A Novel Approach to Dry Stacking and Land Rehabilitation Using Ciba® RHEOMAX™ ETD Technology

S. Adkins *Ciba Specialty Chemicals, UK*

I.J. Flanagan *Ciba Specialty Chemicals, UK*

J. Lamperd *Ciba Specialty Chemicals, Australia*

S. Rose *Ciba Specialty Chemicals, UK*

ABSTRACT

After thickening most mineral tailings are transported as slurry to a designated storage area, usually a slimes dam, tailings pond or impoundment area. In some cases tailings are used as mine backfill or in the rehabilitation of a surface mine. Recent advances in tailings management have focussed on thickening the tailings prior to deposition. This approach is typically referred to as "thickened tailings" or "sloped deposition". These systems rely on thickened slurry being deposited in relatively thin layers on a sloped bed to allow consolidation via both gravity drainage and solar drying.

Over the past decade significant advances have been made in the technology associated with thickening dilute slurries, thickeners have become more efficient and flocculants more effective and the production of high density pastes is now possible with the developments in the mechanical systems that can both produce and pump high density material, these advances have aided the development of thickened tailings making the whole process more affordable.

Ciba Specialty Chemicals has developed a range of rheology modifiers, which could play an important role in this type of tailings management process. These products are added at a controlled dose, in line into the thickened slurry at a point determined through laboratory work and plant trials, but usually close to the discharge pipe or launder. The products modify the surface properties of the tailings producing a high yield stress material with controllable stacking and rapid water release and recovery. The application known as Ciba® RHEOMAX™ ETD technology has been investigated on a range of mineral ore types in South Africa, South and North America, Australia and Europe at both laboratory and plant operational scale, amongst the benefits recorded were.

- *Maximisation of existing disposal areas.*
- *Improved and rapid recovery of water or liquor.*
- *Enhanced co-disposal of coarse and fine material.*
- *No reworking of disposal areas.*
- *Faster trafficable surfaces.*
- *Better land rehabilitation and re-vegetation introduction.*

1 INTRODUCTION

Currently Ciba® RHEOMAX™ products are used to extend the period of time that a disposal site can be used, by reducing the area required for tailings storage through a controlled increase in stacking angle.

The use of Ciba® RHEOMAX™ products creates a homogeneous structure whereby solids of disparate particle size are distributed evenly, rather than segregating. This allows viable co-disposal of coarse and fine materials, which in turn has been shown to improve the permeability of the tailings to water and facilitate rapid recovery of water or liquor (Kaiser et al., 2006).

In order to quantify the aforementioned effects the impact of Ciba® RHEOMAX™ products on substrate capping has been determined. Vegetative rehabilitation trials have also been developed in order to determine the effect of the additives on seed germination and plant vigour.

2 EXPERIMENTAL

2.1 Effect of Capping on Water Infiltration

In the absence of Ciba® additives the surface of the tailings heap is prone to capping. Substrate capping or sealing occurs when aggregate breakdown results in the formation of reduced sized pores within the surface layer. Fine particulate material migrates within the surface layers, further blocking the pores immediately below the surface, forming an impermeable layer termed the 'washed out zone'. The processes involved are similar to those identified in the formation of surface caps in soils. These mechanisms have been studied in some detail (McIntyre, 1958). The consequences of capping within tailings substrates are similar to those reported for agricultural soils, namely decreased infiltration, increased runoff of rainfall and applied irrigation resulting in poor germination and subsequent plant growth (Baver et al., 1972; Bradford et al., 1987). Synthetic polymers are known to improve soil aggregate stability (Bavenik, 1994) and reduce soil sealing (Shainberg and Levy, 1994). These polymers have been used commercially for many years to improve seed germination and crop viability. Ciba® RHEOMAX™ products generate a similar effect in that fine and colloidal particles are bound/immobilised within the Ciba® RHEOMAX™ aggregated structure and therefore have reduced availability to participate in the substrate capping processes. This can lead to a significant increase in water permeability at the substrate surface and enhanced and improved vegetative rehabilitation, without the need to rework the substrate surface.

2.1.1 Method

A bi-modal particle size slurry, consisting of kaolinite and quartz, was prepared (the quartz being –500µm and +90µm).

Duplicate treated and untreated tests were conducted, wherein 300g/t rheology modifier was added to the treated slurry samples and conditioned via low shear mixing.

The resultant slurries were transferred into pre-weighed porosity 1 sintered glass crucibles and allowed to free drain. These were placed under timer-controlled lights for several days to simulate natural drying conditions. Ambient temperature was controlled to between 19 and 22ºC and drying profiles were generated.

After 21 hours each test was irrigated with 50g of water. At 45 hours any surface water remaining was removed from the slurry and the weight recorded. At 69 hours the slurry was re-wet for a second time with 50g of water. At predetermined intervals the samples were weighed to obtain a percolation profile.

2.1.2 Results

The results of the experiment described above were statistically analysed using STATEASE Design Expert software. Mathematical modelling was used to generate the graph shown in Figure 1.

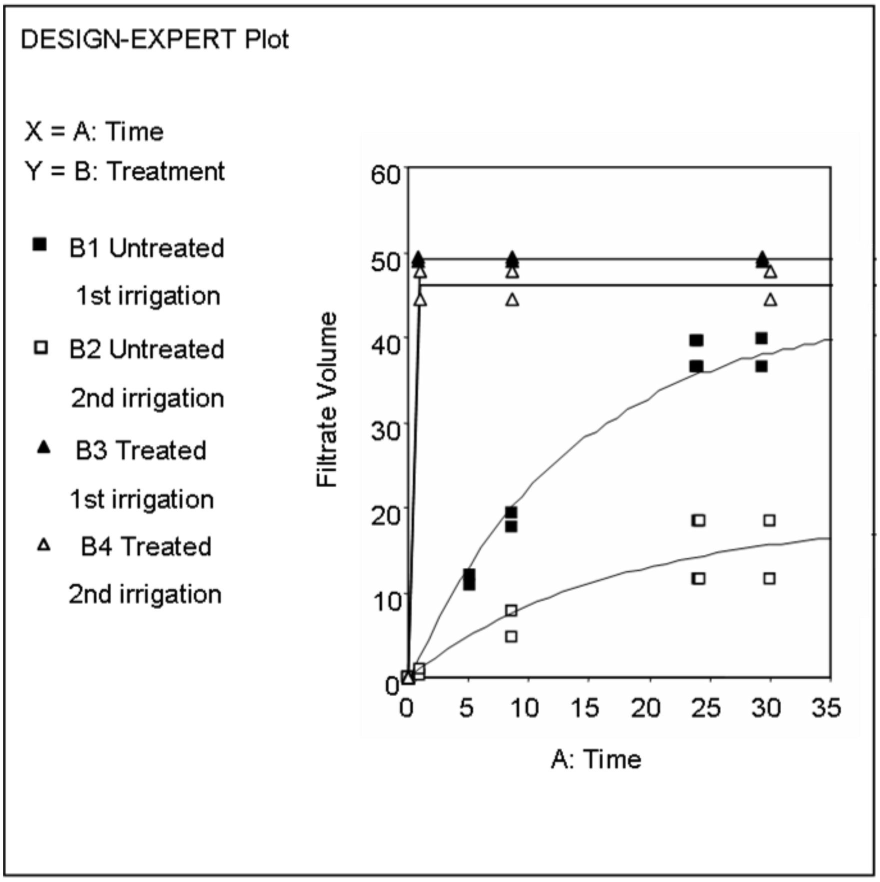

Figure 1 Effect of Ciba®ᵛRHEOMAX™ on slurry capping

Both treated and untreated slurries samples display an asymptotic relationship between filtrate volume (infiltration) and time. In the case of the untreated samples (shown by the square data symbols in Figure 1) the rate of infiltration, initially poor, deteriorates by more than 60%, between the first and second irrigation, this is indicative of progressive capping.

Treatment of the test slurry with Ciba® RHEOMAX™ 9060 generated a medium with a high level of hydraulic conductivity. This is illustrated by the rapid free drainage associated with the treated slurries, wherein >98% of the applied irrigation readily infiltrates through the substrate. Although there is a slight reduction in the rate of infiltration between the first and second irrigations, the hydraulic conductivity of the treated substrate remained significantly greater that the untreated media. This is due to both the immobilisation of the fines and the increased structuring within the Ciba® RHEOMAX™ treated tailings.

2.2 Vegetative Rehabilitation with a Kaolinite Based Substrate

2.2.1 Method

Tailings disposal was simulated on a laboratory scale. Individual storage areas were created consisting of 30 cm diameter steel rings mounted on top of concrete slabs. The rings were not fixed to the concrete in order to facilitate free drainage of tailings liquors. The tailings slurry under test was applied to the storage ring using a 120 cm long, 4 cm diameter pipe, mounted on the upper edge of the storage ring (14 cm above the concrete base) overhanging the lip of the ring by 5 cm, as shown in Figure 2.

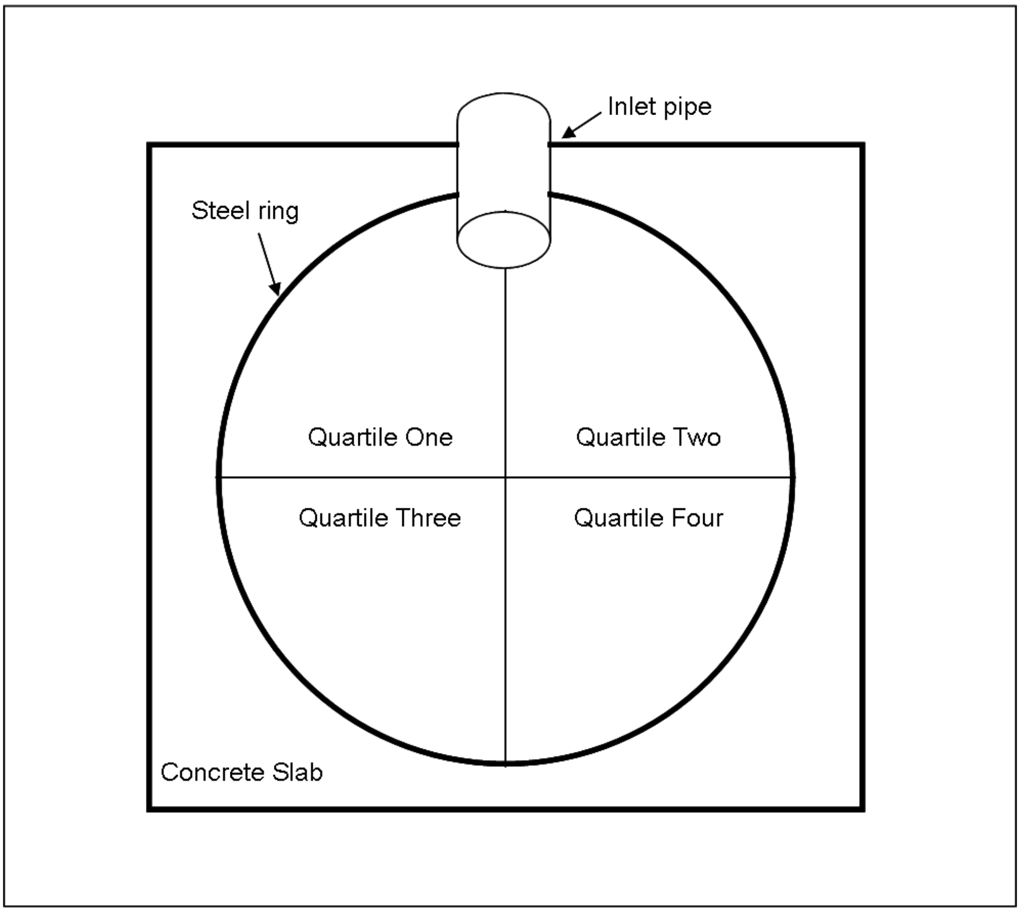

Figure 2 Laboratory scale tailings management equipment

The kaolinite and quartz slurry used in Section 2.1.was treated using Ciba® RHEOMAX™ 9060.

Tailings were applied into the storage area on a daily basis (2 litres of tailings slurry/day) to allow accumulation of a dewatered, stacked substrate. The storage rings were placed on a growing table under artificial illumination throughout the trial period. The rings were subjected to controlled lighting for a period of 10 hours per day. Ambient temperature was controlled to between 19 and 22ºC.

Perennial rye grass (*Lolium perenne* L.) seed was added to the final addition of slurry at a rate of 33g/l, a relatively high rate to give a significant distribution of seed over the substrate surface, in order to stimulate the maximum degree of re-vegetation.

From this point on, the rings were irrigated with 500g of water every other day, spread evenly across the surface. The growth and vigour of the grass was determined periodically after germination using a visual assessment rating where 100 indicates lush vigorous growth and 0 indicates minimal germination. Separate assessments were made for the four quartiles indicated in Figure 2. The vegetative biomass was cropped at the end of the study and the wet weight of the organic matter was determined.

2.2.2 Results

As previously the results of the biological trial were statistically analysed using STATEASE Design Expert software. Mathematical modelling was used to generate the graphs shown in the following section.

The growth data were fitted to a quadratic model including linear, quadratic and interaction terms. The data were transformed prior to analysis using a log 10 transformation as is the common practice for biological growth data, which tend to be asymptotic. Only statistically significant terms were included in the model and an overall fit was very good, the adjusted R-squared for the model was 0.9829. No outliers were observed. The most important trends observed within the model can be summarised graphically and are shown in Figures 3-5.

The vigour of the plants from Quartile One is shown in Figure 3. As the vigour data is expressed in log form as plant vigour approaches a maximum of 100% (i.e. strong vigour) the plotted results tend towards a value of 2.

The first significant plant growth was observed 8 days after sowing.

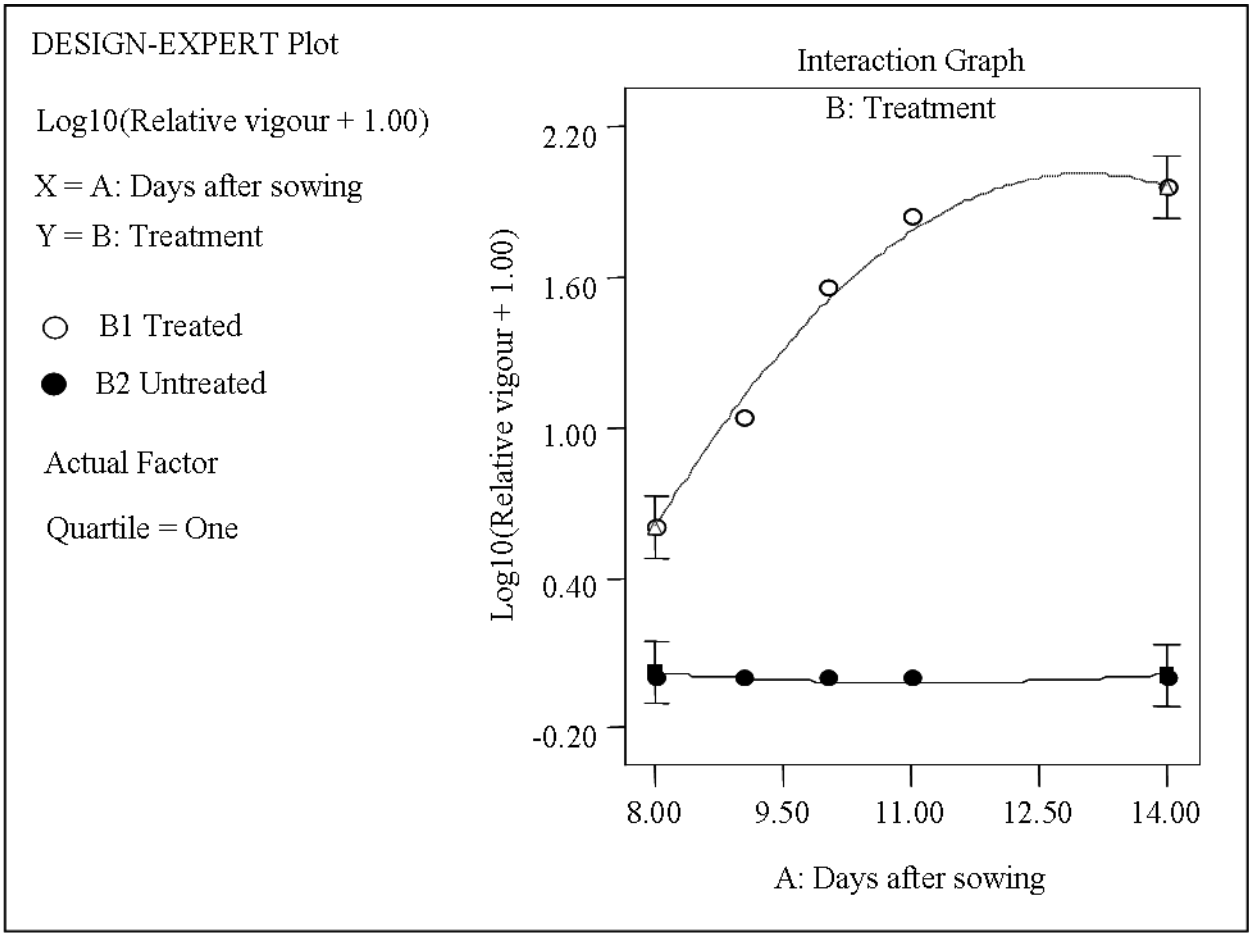

Figure 3 Growth versus time plot – Quartile One

Figure 3 shows the individual data points are in good agreement with the model at all the measured levels. Growth in the treated substrate within Quartile One was strong and approached maximum vigour towards the end of the trial: as compared to the poor growth in the untreated substrate. Growth was weak in the untreated substrate particularly close to the outlet in Quartiles One and Two where only very limited germination was noted. Surface capping was noted to be extremely severe in the untreated substrate in this area. Some germination and limited plant growth was evident in the third and fourth quartiles of the untreated substrate. This can be explained in part by the distribution of the grass seed in the untreated substrate heap; where the seeds preferentially re-distributed along with the finer particulates in the lower quartiles, as can be seen from the data shown in Figure 4.

The graph for the upper quartiles are almost identical, hence the data for Quartile Two is not shown. Similarly, the same was true of the lower quartiles the results for Quartile Four are not presented.

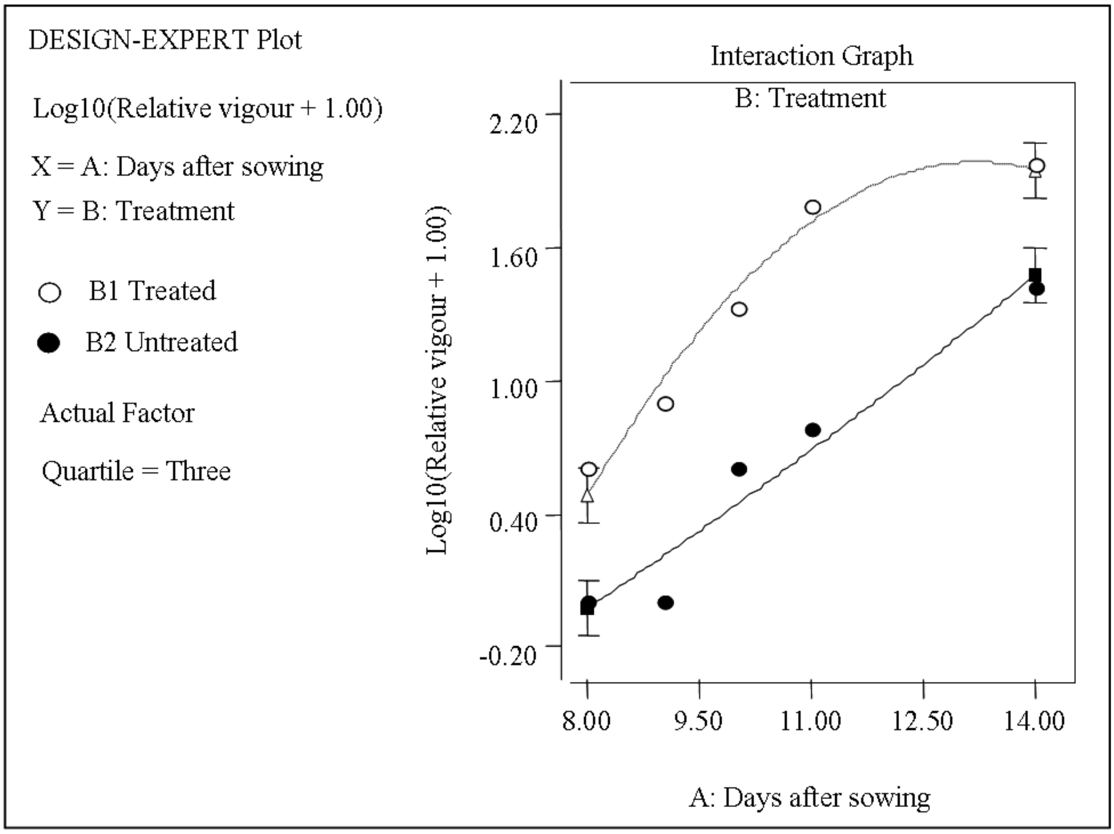

Figure 4 **Growth versus time plot – Quartile Three**

The results towards the end of the study are summarised in Figure 5, which shows that overall the treated substrate gave improved, uniform plant growth over the whole surface of the tailings heap. This is substantiated by the biomass data collected, wherein compared to the untreated system, the treated substrate produced a 157% increase in biomass, see Table 1.

Table 1 **Biomass data**

Untreated	**Treated**
45.5 g	117.0 g

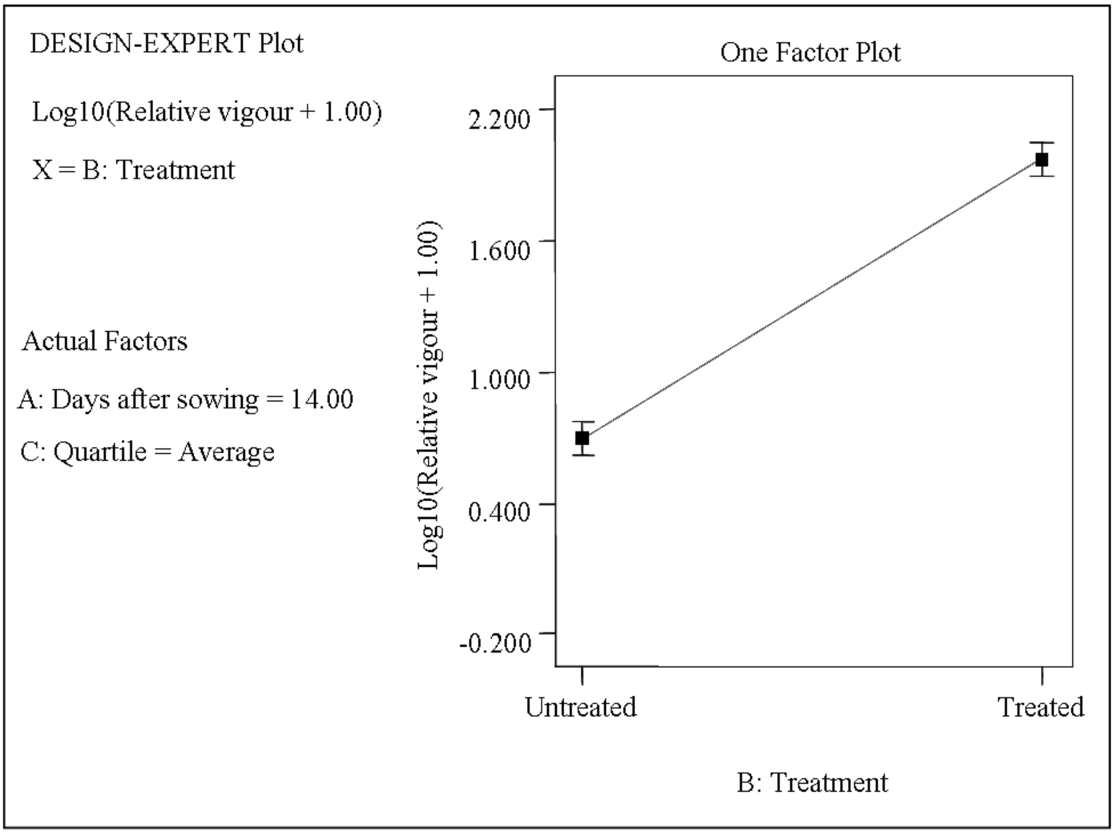

Figure 5 Summary treatment plot

2.3 Vegetative Rehabilitation with a Typical Sand and Gravel Effluent Substrate

2.3.1 Method

The experimental procedure reported in Section 2.2 was repeated, replacing the substrate under test with a typical sand and gravel effluent obtained from a commercial operation. The substrate was treated with Ciba® RHEOMAX™ 9010.

2.3.2 Results

The results of the study were modelled in a similar manner to that reported above. The R-squared was determined and was found to be 0.9866, again indicating a good fit of the data to the model. The trends observed are similar to those seen with the previous substrate and are summarised in Figures 6-9.

Growth and germination was again significantly greater in the treated substrate overall. Some germination and moderate growth was noted in the untreated substrate in the upper quartiles, particularly Quartile Two, as shown in Figure 7. The growth in the untreated substrate within Quartile One was initially relatively strong, however, some die back was noted toward the end of the trial as shown in Figure 6. Comparatively, growth within the treated substrate remained strong throughout the trial period. Visual assessment of the untreated substrate in the upper quartiles indicated that a greater proportion of larger particles were deposited in this area, close to the outlet of the slurry feed pipe. This resulted in reduced capping and improved plant vigour in this area, albeit to the detriment of plant growth within the lower quartiles.

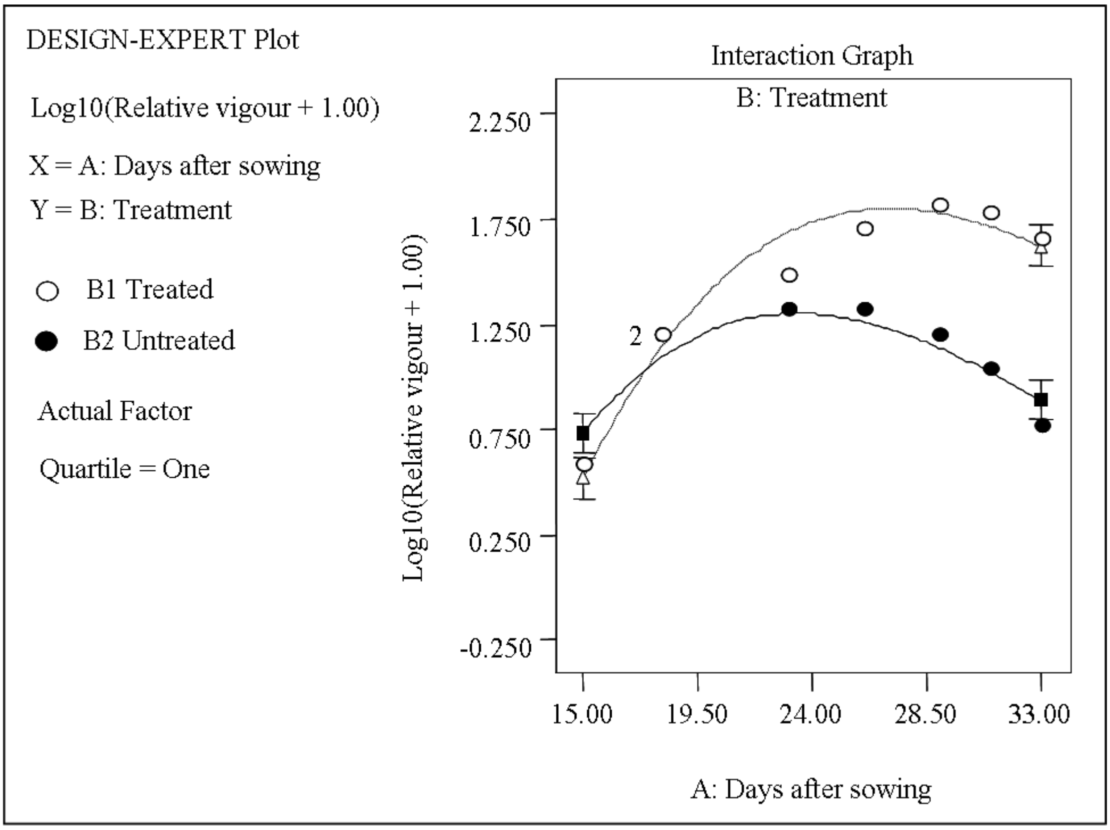

Figure 6 **Growth versus time plot – Quartile One**

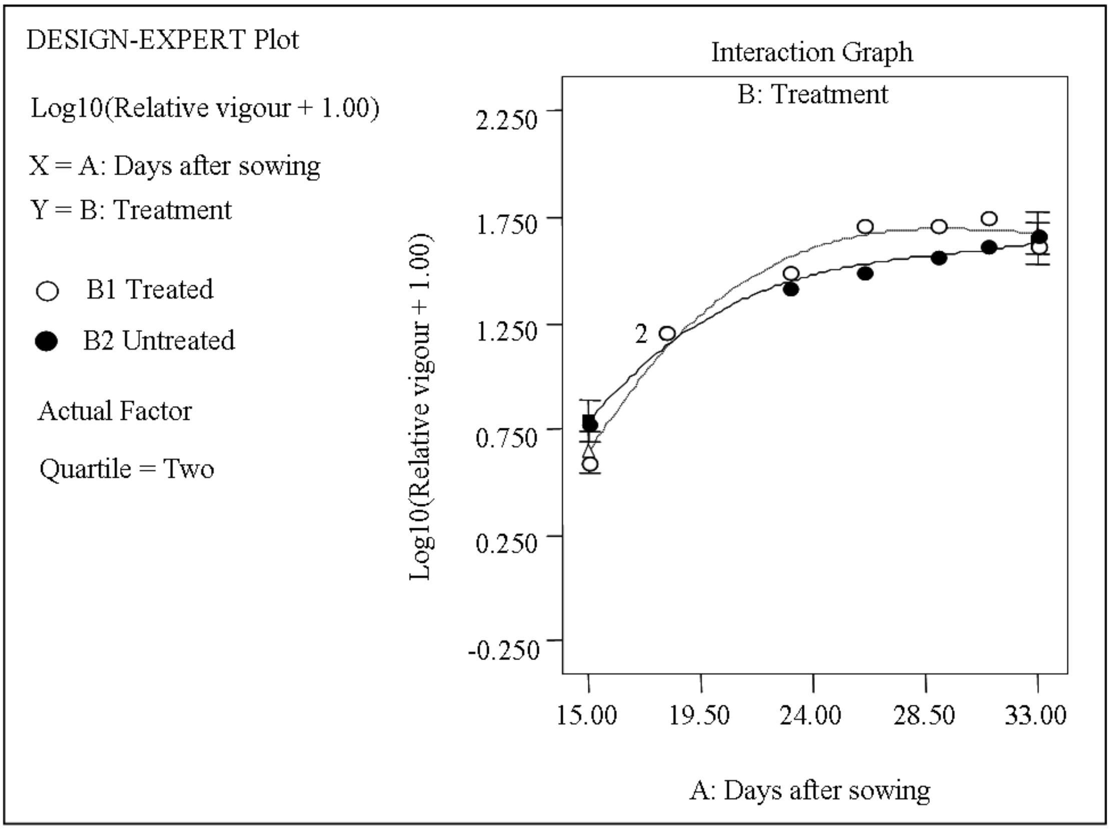

Figure 7 **Growth versus time plot – Quartile Two**

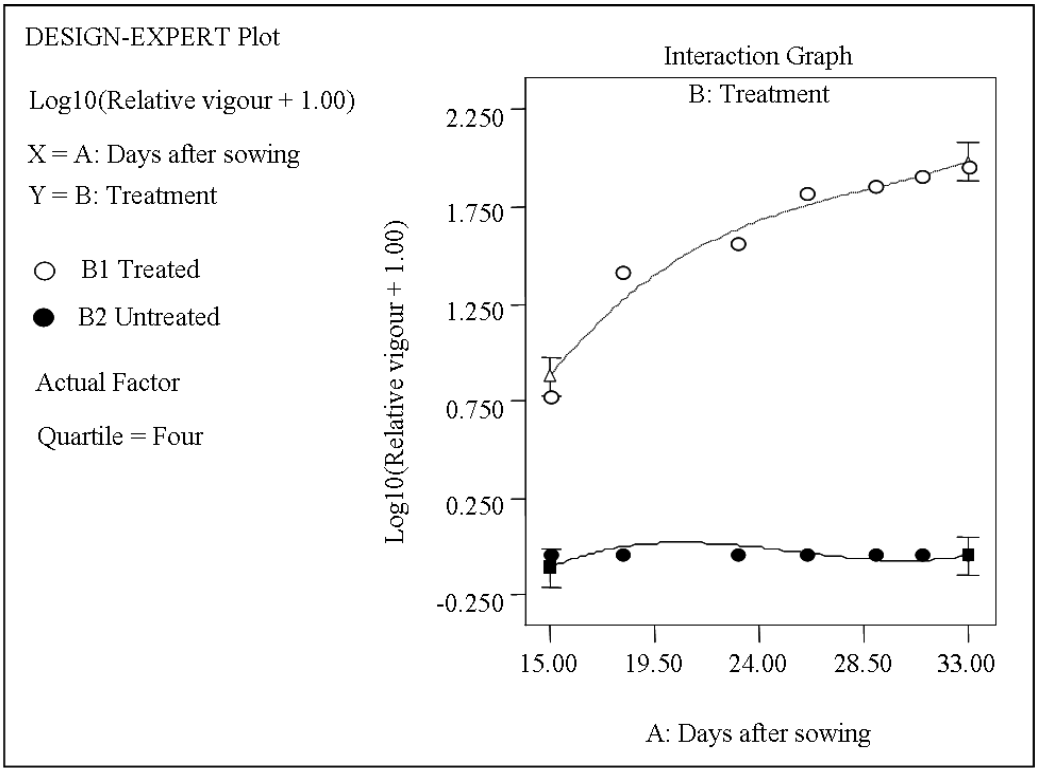

Figure 8 **Growth versus time plot – Quartile Three**

The growth results for the two lower quartiles were comparable; hence the results for Quartile Four are not shown. Growth in the lower quartiles of the untreated substrate was poor as shown in Figure 8.

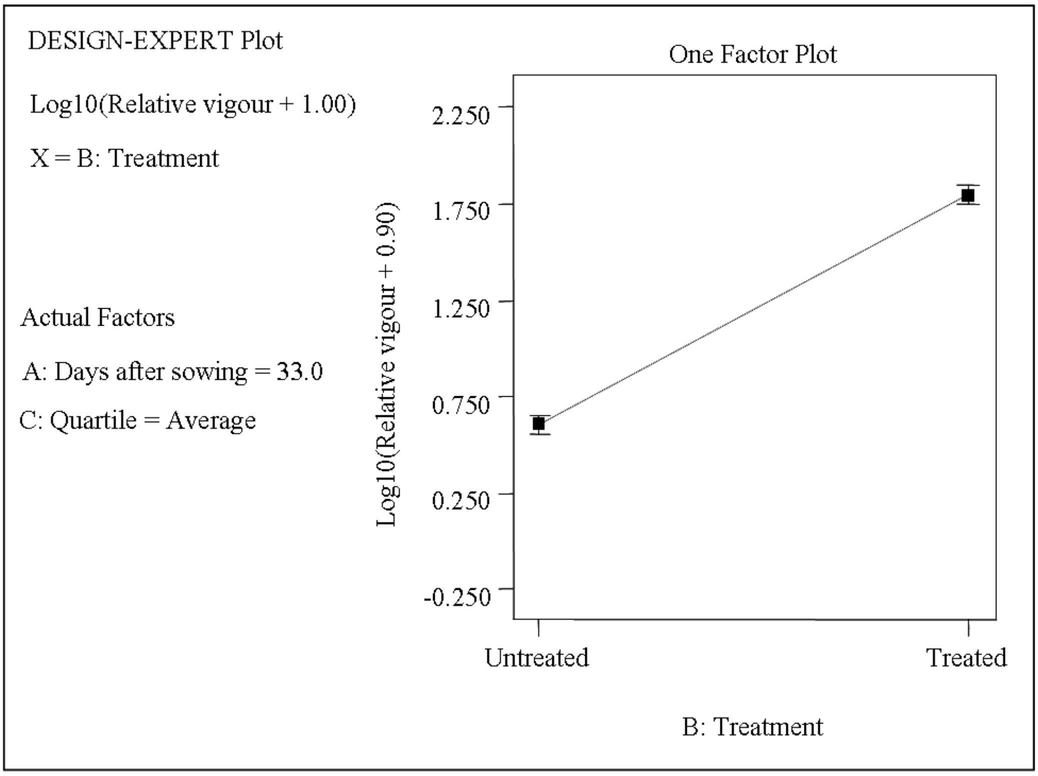

Figure 9 **Summary treatment plot**

Plant growth and vigour was significantly greater at the end of the study in the treated substrate as shown in Figure 9. Again increased growth is evident from the associated biomass data, wherein compared to the untreated system, the treated substrate produced a 107% improvement in biomass, see Table 2.

Table 2 Biomass data

Untreated	Treated
5.9 g	12.2 g

4 CONCLUSIONS

The application work carried out to date indicates that the Ciba® RHEOMAX™ ETD treatment of tailings provides an effective method for the dry stacking of various residues (tailings). These latest investigations demonstrate that the same treatment can generate a deposit that is substantially more amenable to both restoration and re-vegetation than conventional or untreated areas.

This technology already provides the following benefits:

- Rapid clean water release.
- No segregation of coarse tailings and slimes.
- Effective stacking “in cell” or “in situ”.
- Excellent drying properties.
- Faster trafficable surfaces.

The latest findings highlight the additional benefits associated with this technology, namely:

- Viable land rehabilitation.
- Improved re-vegetation.

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