

Assessment of herbaceous vegetation species composition growing around an opencast coal mine area

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Abstract

Coal mining involves the removal of natural vegetation, heavy excavation; combustion and ignition accompanied by a release of coal dust to the atmosphere that drastically reduce the ecosystem services. A study was conducted to assess of veld grasses around a coal mine in Emalahleni in Mpumalanga. Six 100 m line transects were established on rehabilitated site and natural veld in KleinKopie coal mine. Plant identification, leaf and tiller counting, and biomass harvesting were conducted on each of five 0.5 m² sampling quadrats placed at intervals of 20 m along the transect. Nineteen (19) grass species, some forbs and sedges were recorded and *Eragrostis curvula* (31.5%) was the most abundant on the natural veld, followed by *Cynodon dactylon* (28.36%) and *Panicum maximum* (22.25%) on the rehabilitated. On the natural veld, *Aristida conjesta* had higher tiller production (17 tillers per plant) while *E. curvula* averaged 11 tillers per plant on the rehabilitated site. On the rehabilitated site, *U. mosambicensis* produced averaged 94 leaves per plant than all other species on both sites. Basal cover, species diversity and richness did not differ ($p > 0.05$) between rehabilitated site and natural veld. Rehabilitated site had a generally higher biomass production of 10 kg DM ha⁻¹ than natural veld. *E. curvula* and *C. dactylon* had higher contribution to the total biomass production on both sites. However, their biomass production was insignificantly different ($p > 0.05$) from that of *Urochloa mozambicensis* and *P. maximum* on rehabilitated site and *Heteropogon contortus* on natural site. Our results indicated that *E. curvula* and *C. dactylon* are highly persistent and productive hence they are ideal for mine rehabilitation.

1. Introduction

South Africa's economy is largely dependent on fossil fuel as a major energy source for electricity that is commonly generated by burning the coal. In addition, South Africa also plays a significant role in the global coal market. Most of the mines in South Africa are concentrated in Mpumalanga Province with most of them around Emalahleni (Witbank) and Middleburg. However, coal mining has negative effects consequences on the environment and land use. Since opencast coal mining is associated with stripping and removal of the topsoil with organic matter and vegetation cover mined areas are usually characterized by poor soil structure (Mushia et al. 2016). This leads to serious negative impacts on the ecology of the land under coal mining. The land deteriorates further if there is no comprehensive rehabilitation practice aimed at re-establishment and reclamation of the mined land back to its original state (Truter et al. 2009). Furthermore, one of the most problematic occurrences is the exposure of the coal to air and water which reacts resulting in spontaneous combustion, ignition and coal oxidation (Pone et al. 2007). The leachate that comes out of the tailings that emanate during coal mining is usually characterized by low pH level, escalating the large volume of acid mine drainage. Acid mine drainage has been reported to have a potential to contaminate groundwater and surface water (Munnik 2010).

Rangeland degradation around coal mining areas of Mpumalanga Province remains a critical issue. Various plant species have been suggested for phytoremediation of the mined areas. For a rapid and successful rehabilitation program herbaceous species, as opposed to trees, have been promoted

because of their rapid growth rate, high biomass production and good stabilization of degraded soils (Xia et al. 1999; Gilbert, 2000; Loch, 2000; Ye et al. 2000). Grasses are well adapted when growing in their favorable environmental conditions, however, once their specific environmental conditions are disturbed either through natural or anthropogenic activities such as mining, their relative abundance, diversity and fitness is compromised (Mansour et al. 2013). The disturbance adversely affects agricultural production particularly rangelands. Over a period, the agricultural land available is either directly or indirectly affected leading to a reduction in productivity of the area.

Despite the loss of agricultural land, surface coal mining also leads to more complicated environmental problems such as air, water pollution, destruction of the soil structure and massive biodiversity loss (McCarthy and Pretorius 2009). Consequently, when soil structure, texture and most importantly soil nutrient composition are disturbed, the concentration of suitable plant nutrients gradually decreases (Kundu and Ghose 2012). As a result, rehabilitation of mined areas turns to be slow due to poor soil structure and low soil nutrient content to support plant growth and development. Furthermore, the effect on soil chemical, physical properties and nutrient loss is exacerbated by prolonged period of the stockpiles (Favas et al. 2011).

Mushia et al. (2016) compared stockpiles with different ages of between 10 and 20 years and found high plant height, fresh and dry biomass on the 10-year-old stockpile. Stockpiling, therefore, leads to ecological changes in the mined areas thus affecting species composition in terms of abundance, diversity and fitness even after rehabilitation has been completed. This study was conducted to assess growth performance of veld grasses growing around a coal mine. It was, therefore, hypothesized that there is variation in tolerance to elemental contaminants among grasses growing around opencast mine areas and this would result in differences in species abundance, diversity and fitness.

2. Materials and Methods

2.1 Site description

The study was conducted at Klein-kopje Colliery (26°23'S, 29°21'E; altitude 1570 m) located approximately 20 km south of Emalahleni in Mpumalanga Province of South Africa. Summer average temperature ranges between 12°C to 29°C with winter average temperatures of between 3°C to 20°C. This area is a summer rainfall region, and it receives an average annual rainfall of about 696 mm. The soil characteristics of the study site were a sandy clay loam characterized by 67.8% sand, 11.5% clay, 12.9% loam and with a pH of 5.3. The natural veld was predominantly grassland with some patches of forbs as well as sedge plant species. On the rehabilitated area several grass species, *Eragrostis teff*, *Themeda triandra*, *Digitaria eriantha*, *Panicum maximum*, *Chloris gayana*, *Melinis repens* and *Cynodon dactylon*, were planted during the rehabilitation program (Mentis, 1999). The rehabilitated site was initially fertilized and irrigated with treated mine water but later converted into a naturalized pasture that is fully dependent on natural rainfall.

2.2 Data collection

2.2.1 Assessment of herbaceous vegetation

Vegetation assessment was conducted during the growing season in February and March 2016. Three transect lines each 100 m long were established at natural and rehabilitated and were inter-spaced by 100 m from each other. Along each transect, five 0.5 m² sampling quadrats were placed at intervals of 20 m. Plants in each quadrat were identified and their representative tiller and leaf numbers were counted. Total biomass was determined by harvesting all the herbage followed by separation by species and oven drying at 65°C to a constant weight.

2.2.2 Basal cover

Basal cover for each site was recorded using a measuring tape to measure the tuft size (minimum and maximum diameter) of each of identified living plant species per quadrat. The inter-tuft distance from the tuft of a living plant to the nearest tuft of another living plant was also measured. Basal cover was calculated using the formula developed by Hardy and Tinton (2007).

$$BC = 19.8 + 0.39 (D) - 11.87 (\log_e D) + 0.64 (d) + 2.93 (\log_e d) \quad (1)$$

Where *BC* denotes Basal Cover, *D* the distance (cm) of the tuft of living plant to the nearest living plant, *d* was the mean basal diameter of the tuft of the living plant.

2.2.3 Shannon – Wiener Index

A Shannon – Wiener index formula (diversity, richness) was applied to calculate species diversity per site. The grass species were classified into, grass species were classified into their ecological value such as Decreaser species (these are the most desirable species commonly found in a properly managed rangeland), Increaser I species (less wanted species that increase in abundance with light grazing), Increaser II species (this group of grasses is noticed to increase in yield with over/heavy grazing), Invader species (none native grasses that grow and out-compete native species). The grass species were also categorized into life forms that is, annuals and perennials. Forbs and sedges were recorded. The equation that was used to calculate the species diversity is as follows:

$$H' = -\sum_{i=1} (q_i/Q) \log(q_i/Q) \quad (\text{Shannon and Weiner, 1963}) \quad (2)$$

Where *H'* is the Shannon-Weiner diversity index, *q_i* is the number of individuals of each *ith* species, *Q* is the total number of the individual species for each site. Grass species evenness was measured by Pielou's equation, where evenness (*E*) is represented as follows:

$$E = H' / \ln S \quad (\text{Pielou, 1966}) \quad (3)$$

Where *H'* is the Shannon-Wiener diversity index and *S* is the number of species recorded per site.

Table 1
Chemical composition of treated mine water used for
irrigation of sites under rehabilitation.

Element	Concentration
Electrical Conductivity (mS.m ⁻¹)	557.00
pH	7.8
Cations	
Sodium (400) (mg/l)	38.80
Potassium (400) (mg/l)	17.57
Calcium (200) (mg/l)	645.64
Magnesium (100) (mg/l)	282.05
Boron (1.5) (mg/l)	0.10
Anions	
Fluoride (1.5) (mg/l)	1.83
Nitrite (4.0) (mg/l)	0.41
Nitrate (44.0) (mg/l)	24.73
Chloride (250) (mg/l)	10.82
Sulphate (500) (mg/l)	2833.22
Phosphate (mg/l)	16.26
Carbonate (20.0) (mg/l)	0.00
Bicarbonate (mg/l)	70.76
Alkalinity (mg/l)	58.00

Figures within brackets are the recommended maximum values for human use in mg/l.

2.2.4 Statistical analysis

For quantitative field data, a completely randomized design (CRD) was used in the analysis of variance. Each of the two sites had 3 replicates. The outline of the model used for analysis was: $Y_{ij(k)} = \mu + \alpha_j + \epsilon_{ij(k)}$

Where $Y_{ij(k)}$ = Response variables (Species composition, biomass basal cover, tiller and leaf numbers).

μ = Overall mean.

α_{ij} = The effect of the j^{th} treatment on i^{th} site.

$E_{ij(k)}$ = Random error.

Biomass production, basal cover, tiller and leaf numbers and different sites were analyzed at 95% confidence level ($p \leq 0.05$) using t-test and one way ANOVA. General Linear Model (GLM) using p-diff. procedure of Statistical Analyses Systems of (SAS Institution, 2003) was conducted for mean separation at ($p \leq 0.05$) on herbaceous species composition.

3. Results and Discussion

3.1 Herbaceous species abundance

The mean values for herbaceous species composition recorded in both rehabilitated and natural sites are presented in Table 2. This study recorded a total number of about 19 different grass species, some forbs and sedges from both sites. *Eragrostis curvula* was the most abundant species (31.50%) recorded on the natural veld and it was higher by 12% relative to that which was recorded on the rehabilitation site. *E. curvular* was the most abundant species than all recorded plant species on both sites. On the rehabilitated site *Cynodon dactylon* and *Panicum maximum* were significantly more abundant than all recorded species on the rehabilitated site. There was also higher comparative to those that were recorded on the natural veld. All the other recorded species on both sites were less abundant ranging between 0.80–15.10% (Table 2).

Generally, there were more Increaser IIb species as opposed to Decreaser species on both sites. However, the herbaceous vegetation comprised of 47% Increaser IIb species, 20% Increaser IIc species, 13% Increaser IIa species, 20% Decreaser species and there were no Increaser I species recorded on the rehabilitated. On the natural veld 6% were Increaser I species, 25% Increaser IIa, 31% Increaser IIb, 25% Increaser IIc and 13% Decreaser species. In general, perennial species were more prevalent on both sites relative to the abundance of annual species. Out of 15 species recorded on the rehabilitated, 80% were perennial species and 20% were annual species. On the natural veld 75% were perennial and 25% were annual species. The results show that perennial species were more abundant on the rehabilitated site that on the natural site whereas, annual plants were prevalent on the natural veld.

Diversity index combines both the species richness and abundance. There were differences in Shannan - Wiener diversity index between the natural veld and the rehabilitated site and the indexes were 0.84 and 0.82 respectively. More species diversity was observed on the natural veld relative to the rehabilitated site. Both sites had low species evenness, and this was due low diversity component (Rutherford and Powrie, 2013) (Table 2).

Table 2
Mean abundance (%) of herbaceous species composition at Kleinkopje colliery.

FREQUENCY (%)				
Species name	Life forms	Ecological status	Natural site	Rehabilitated site
<i>Aristida adscensionis</i>	Perennial	Increaser IIb	1.45 ^a	3.04 ^a
<i>Aristida congesta</i>	Annual	Increaser IIc	4.65 ^a	1.35 ^a
<i>Cynodon dactylon</i>	Perennial	Increaser IIc	15.10 ^b	28.36 ^b
<i>Diheteropogon. amplexans</i>	Perennial	Decreaser	2.85 ^a	1.85 ^a
<i>Eragrostis curvula</i>	Perennial	Increaser IIa	31.50 ^b	9.20 ^a
<i>Eragrostis lehmanniana</i>	Perennial	Increaser IIa	5.86 ^a	3.90 ^a
<i>Eragrostis plana</i>	Perennial	Increaser IIb	0.80 ^a	0.80 ^a
<i>Forbs</i>	Annual	Increaser IIb	2.70 ^a	6.20 ^a
<i>Heteropogon contortus</i>	Perennial	Increaser IIa	1.05 ^a	
<i>Perotis patens</i>	Annual	Increaser IIc	3.64 ^a	
<i>Pogonarthria squarrosa</i>	Perennial	Increaser IIc	1.40 ^a	
<i>Sedges</i>	Annual	Increaser IIb	4.60 ^a	1.50 ^a
<i>Panicum maximum</i>	Perennial	Decreaser	1.50 ^a	22.25 ^{ab}
<i>Eulalia villosa</i>	Perennial	Increaser I	13.80 ^a	
<i>Eragrostis gummiiflua</i>	Perennial	Increaser IIb	4.30 ^a	
<i>Eragrostis chloromelas</i>	Perennial	Increaser IIa	3.80 ^a	
<i>Digitaria eriantha</i>	Perennial	Increaser IIb		3.90 ^a
<i>Chloris gayana</i>	Perennial	Decreaser		5.20 ^a
<i>Urochloa mosambicensis</i>	Perennial	Increaser IIb		2.55 ^a
<i>Paspalum notatum</i>	Perennial	Increaser IIc		6.40 ^a
<i>Melinis repens</i>	Perennial	Increaser IIb		3.50 ^a
Diversity index			0.84	0.16

FREQUENCY (%)				
Species name	Life forms	Ecological status	Natural site	Rehabilitated site
Evenness			0.82	0.15

Underscore denotes that the species were not found on that site, Different superscripts denote significantly differences at ($p \leq 0.05$) between mean frequencies.

However, the prevalence of *C. dactylon* in the rehabilitated site might be encouraged by its ability to reduce the accumulation of toxic ions that could be found on the rehabilitated site. Such plants sequester toxic ions into their vacuoles to minimize toxicity level. Our results agree with the findings by Platt (2009) who reported that *C. dactylon* was amongst most prevalent grass species on the rehabilitation site. This demonstrates that the most abundant grasses exhibit tolerance and/or avoidance adaptation mechanism for them to be able to survive under hostile environmental condition such as mined areas where mine coal dust, heavy metal and disturbed soil structure is a huge problem. Our results are also still in agreement with the results by Truter (2009) and Limpitlaw et al. (2005) who reported that these two grass species *i.e.*, *C. dactylon* as the main dominating grass species around the rehabilitated site amongst grass species that were identified in their studies. In our study *P. maximum* appears amongst the most prevalent species on the rehabilitated site. This suggests that this grass would also be ideal for restoration of mined areas unlike *E. curvula* that only colonized the natural veld in abundance.

Observed species composition in both sites had more Increaser II species and Forbs a feature that depicts a mismanaged rangeland (Oluwole and Dube, 2008). Furthermore, Increaser II grass species colonize an area that have been disturbed either through natural or anthropogenic activities. Our results are still consistent with the results reported by Snyman (2004) and Firn (2009), who reported that successful establishment for *E. curvula*, was by exacerbated by disturbances such as selective/light grazing. Therefore, since there were no grazing management practices employed on these two sites, *E. curvula* grows to its full potential and out compete other grass species that were recorded on the natural site. On the rehabilitated site, reduction in the abundance of the plant species recorded in this study including *E. curvula* could be linked to poor adaptation strategies under disturbed areas and possible with elemental contaminants. This leads to failure in re-vegetating mined lands, and this might also be due to poor soil nutrient content or soil compaction around the rehabilitated site (Truter et al. 2000).

Changes in soil nutrient content and introduction or removal of the vegetation on the rehabilitated site might be responsible for differences in species diversity among the two sites with low diversity on the rehabilitated site than the natural veld. Soil properties are important in plant growth and survival and once disturbed vegetation chances from best to worst (Oluwole and Dube, 2008). The presence of salt ions in treated mine water (Table 1) could reduce the uptake of potassium due to the nature of their chemical reaction, therefore this inhibits growth in plants on the rehabilitated site. The results in Table 2 also showed that the natural veld had high species evenness compared to the rehabilitated site. This

could be attributed to elemental contaminants that might affect growth and development of plant species on the rehabilitated site.

The basal cover for the natural and rehabilitated sites ranged from 1.78–20.90 cm²/m² and 4.12–20.09 cm²/m², respectively. Furthermore, this varied greatly with species wherein forbs had a significantly high basal cover area of 20.81 cm²/m² relative to all recorded species on the natural veld. This was followed by *C. dactylon* and *P. maximum* with 20.29 cm²/m² and 18.59 cm²/m² basal cover recorded on the rehabilitated site (Fig. 1). The largest portion of land on the natural veld was covered by forb species and this show that the area more likely to be susceptible to soil erosion due to the short life span of forb species. On the rehabilitated site the observed grasses species covering a large area were *C. dactylon*, *P. maximum*, *A. adcessionis* and sedge species were perennial species which have longer lifespan than annual species. *A. congesta*, *E. plana* *D. amplexens* and *P. squarossa* recorded on the natural veld had the smallest basal cover and therefore this site is more exposed to soil erosion than the rehabilitated site.

Generally, both these sites were of poor veld condition since they were dominated by forbs on the natural veld and tufted species on the rehabilitated sites. Basal cover of the two sites might have been affected severely by soil disturbance, soil compaction, heavy metals and coal dust within the coal mine. Coal dust released during coal extraction when the coal seam is cut. The major contributing activities in the dispersal of coal dust are blasting, drilling, hauling, shunting and transportation which affect vegetation around the mine. Furthermore, this does not only pollute the air but also areas in the surrounding of the coal mining operation (Avila et al. 2012). Spencer (2001) reported that coal dust significantly increased soil temperatures, reduced pH, and increased concentration of heavy metals in the soil. Therefore, all these have a potential to induce serious negative effects on plant growth, development and recruitment of new seedlings. The presence of heavy metals in the soil cause visible damage to flora and fauna and yet limiting soil use (Avila 2012).

3.2 Tiller and leaf production of grass species growing around a coal mine.

The main tiller producing species was *Aristida congesta* (17 tillers per plant) followed by *E. plana* and *E. villosa* (12 tillers per plant) recorded on the natural site. This was followed by *E. curvula* recorded on the natural veld with 11 tillers per plant (Table 3). Grass species such as *D. amplexens*, *P. notatum*, *M. repens* and the other presented grasses in Table 3 produced low tiller numbers ranging from (2–9 tillers per plant) on both sites, *C. dactylon* the lowest being tiller producer on both sites.

Urochloa mosambicensis produced significantly high leaf numbers (94 leaves per plant) on the rehabilitated site (Table 3) compared to all other species recorded on both sites. However, some plant species that were recorded on the natural veld also demonstrated significant high ($p < 0.05$) leaf numbers. These plant species include *E. plana* (59 leaves per plant), Forbs (56 leaves per plant), *A. congesta* (43 leaves per plant) and *D. amplexens* (41 leaves per plant). The number of leaves of other

herbaceous species that were recorded on both sites were lower ranging between (5–40 leaves per plant) with *A. adscensionis* being the least leaf producing grass species on the rehabilitated site. This clearly showed that this grass has good adaptation strategies even under harsh environmental conditions within the rehabilitated site where soil nutrient composition is low.

Grasses were noticeable for their relatively high tiller/leaf production with an increasing linear relationship in both sites. Among the recorded grass species on the natural veld *C. dactylon* and *E. curvula* leaf production increased linearly in response to increasing tiller numbers ($r^2 > 60$) followed by *E. lehmanniana* ($r^2 > 70$). *D. amplexens* and *A. congesta* were observed to produce a smaller number of leaves on the natural veld (Fig. 2). On the rehabilitated site, *P. maximum* and *D. eriantha* tiller leaf relationship was ($r^2 > 0.79$). While *M. repens* and *E. chloromelas* were ($r^2 \geq 0.50$).

Our results showed that *A. congesta* produced high tillers than all recorded grasses. The difference in phenological cycle following growing season of these grasses influence the growth and establishment of tillers and leaf production per plant (Livela et al. 2013). High relationship values among these grass species are possible because of the morphological characteristics expressed during growth and development (Lemaire et al. 2005). However, this might also be influenced by many factors such as edaphic and soil contamination associated with coal dust generated during mining.

The average dust particle size that can be carried away by wind is reported to be 0.106 mm and the concentration of heavy metals carried along are often determined by the quantity of the dust particles that have settled on the surface (Armbrust 1986). Therefore, when coal dust settles back to the soil and landing on the aerial parts of the plant, it changes the physiology of the plant leading to reduction of leaf size, leaf mass and rate of photosynthesis (Spencer 2001). Therefore, leading to reduced carbon dioxide (CO₂) exchange into and out of the stomatal opening, electron transport rate (ETR). Barre et al. (2015) reported that leaf length is an important part for the survival of the plant within a sward. However, when plants are exposed to coal dust leaf areas is affected and reduced. Therefore, reduction in photosynthesis rate due to reduced light occurrence on the photosynthetic tissues as a result of the shade caused by coal dust on plant leaves. Additionally, plants with hairy leaves are more susceptible to coal dust attachment as compared to those with glabrous leaves. This reduces tiller to leaf production as some plants are more susceptible to toxic elements. Dust induced effects vary greatly amongst plant species (Naddeo and Naddeo 2005).

Table 3
Mean differences in tiller/leaf production per plant

Species name	Number of tillers per plant		Number of leaves per plant	
	Rehabilitated	Natural	Rehabilitated	Natural
<i>A. adscensionisa</i>		8.50 ^{ab}	5.00 ^a	28.50 ^a
<i>A. congesta</i>		17.00 ^a		43.00 ^a
<i>C. dactylon</i>	2.33 ^a	2.50 ^b	12.66 ^a	24.00 ^a
<i>D. amplexens</i>		9.50 ^{abc}		41.50 ^a
<i>E. curvula</i>	11.00 ^b	7.33 ^{bc}	35.75 ^a	33.00 ^a
<i>E. lehmanniana</i>	7.00 ^{ab}	7.33 ^{bc}	29.00 ^a	32.66 ^a
<i>E. gumiflua</i>		4.00 ^{bc}		16.00 ^a
<i>E. villosa</i>		12.00 ^{abc}		36.00 ^a
<i>E. plana</i>		12.00 ^{abc}		59.00 ^a
<i>E. patens</i>		6.66 ^{abc}		36.33 ^a
<i>Forb</i>	4.30	2.00 ^b	8.00 ^a	56.50 ^a
<i>H. contontus</i>		7.50 ^{abc}		27.00 ^a
<i>P. squarossa</i>		5.00 ^{abc}		13.00 ^b
<i>P. maximum</i>	4.50 ^{ab}	3.00 ^{abc}	14.00 ^a	7.00 ^b
<i>Sedge</i>	3.52	5.00 ^b	7.00 ^a	26.50 ^a
<i>E. chloromelas</i>	7.00 ^{ab}		27.00 ^a	
<i>D. eriantha</i>	7.00 ^{ab}		27.00 ^a	
<i>C. gayana</i>	3.00 ^{ab}		21.00 ^a	
<i>U. mosambicensis</i>	6.00 ^{ab}		93.50 ^b	
<i>P. notatum</i>	8.00 ^{ab}		40.00 ^a	
<i>M. repens</i>	7.50 ^{ab}		11.36 ^a	

Mean in the same row followed by different lowercase letters are significantly different at ($p \leq 0.05$) using a t-test. Underscores denote the absence of a grass species on each site.

3.3 Herbaceous biomass production harvested from Kleinkopje colliery.

Broadly, the total biomass production was higher on the rehabilitated site comparative to that which was recorded on the natural veld (Fig. 4). The results showed that *U. mosambicensis*, *P. maximum* and *C. dactylon* produced high biomass of 3.87, 4.12 and 4.35 kg DM h⁻¹ on the rehabilitated site, respectively. This was followed by significant different ($p \leq 0.05$) biomass production recorded for *D. eriantha* (3.32 kg DM h⁻¹, $p < 0.001$) on the rehabilitated site. Whereas on the natural veld *C. dactylon*, *H. contortus* and *E. curvula* produced high biomass of 3.30, 3.62 and 3.93 kg DM h⁻¹. Amongst the biomass producing grass species on the natural site, *E. lemaniana*, produced high total dry biomass of 2.62 kg DM h⁻¹. Other presented plant species in Fig. 3.2.7 produced low biomass on both sites.

In general, the results have shown that biomass production was generally higher in the rehabilitated site than natural site. Firstly, this could be ascribed to additional soil nutrients that are added to support germination, growth and development of planted species during mine rehabilitation. Secondly, the additional grass species such as *D. eriantha* and *C. gayana* were absent on the natural veld but present on the rehabilitated site produce high biomass production per hectare (Fig. 4). However, in most cases coal mine disturbed areas are characterized by low organic matter in the soil due to leaching of essential elements. Nevertheless, some plants have a homeostatic mechanism that controls the uptake of toxic ions and reduce potential damage in the plant cell. This phenomenon is known as compartmentalization of toxic ions and these plants are referred to as ion excluders (McGrath et al. 2001). Grass species such as *Cynodon dactylon* have been widely investigated and reported to be tolerant in contaminated soils by Wong et al. (2003) in China, by Wu et al. (2010) in Hong Kong and by Boshoff et al. (2014) in Belgium. Furthermore, *Cynodon dactylon* was considered as forage grasses with a potential to produce high biomass under contaminated soils. Biomass production differs in forage grasses due to different characteristics of tolerance and recovery pathways in heavy metal toxicity during the process (Teng et al. 2008). In Southern Africa, the most popular forage grasses are *Chloris gayana*, *Cynodon dactylon*, *Panicum maximum*, *Cynodon aethiopicus*, *Atriplex nummularia* and *Eragrostis curvula* etc and could be used in restoration programs of degraded lands (Truter et al. 2015).

4 Conclusion

The results have shown that the most dominating species such as *E. curvula* in natural sites have long life span. *E. curvula* is a perennial grass species and this was amongst most desirable plant traits required for re-vegetation of mined areas. Furthermore, the use of veld condition indicators such as basal cover, ecological status, and species diversity provides guidelines for the procedures that need to be followed towards preservation of the present ecosystem services on both sites. This would also play an important role in the selection of performing grass species for reseeding in the rehabilitated site.

More leaf producing grasses and high biomass production were recorded in the rehabilitated site and therefore, the built up of organic matter would be expected in the rehabilitated site as the time progresses. In addition, the highest basal cover percentage was recorded in the rehabilitated site; therefore, this site is less prone to detrimental effects that might arise as a result of soil erosion.

5 Recommendations

- Due to sensitivity of the rehabilitated site, it is recommended that species such as *C. dactylon*, should be selected for restoration.
- This is based on its creeping growth form and the ability to quickly grow and cover large surface areas. Additionally, this grass could be planted on steep areas to reduce potential soil erosion.
- Soil chemical analysis within the rehabilitated site is essential in monitoring the built-up of salt ions which have been reported to cause serious adverse effects on seed germination.
- In this regard, more grasses need to be evaluated with the idea of identifying more adaptive species.
- These would then be used to improve rehabilitation seed pack mixes.

Declarations

Conflicts of Interest:

The authors declare no conflict of interest.

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Author Contribution

1-3. All authors reviewed the manuscript.

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Data Availability

Data used in this study are available on request.

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Figures

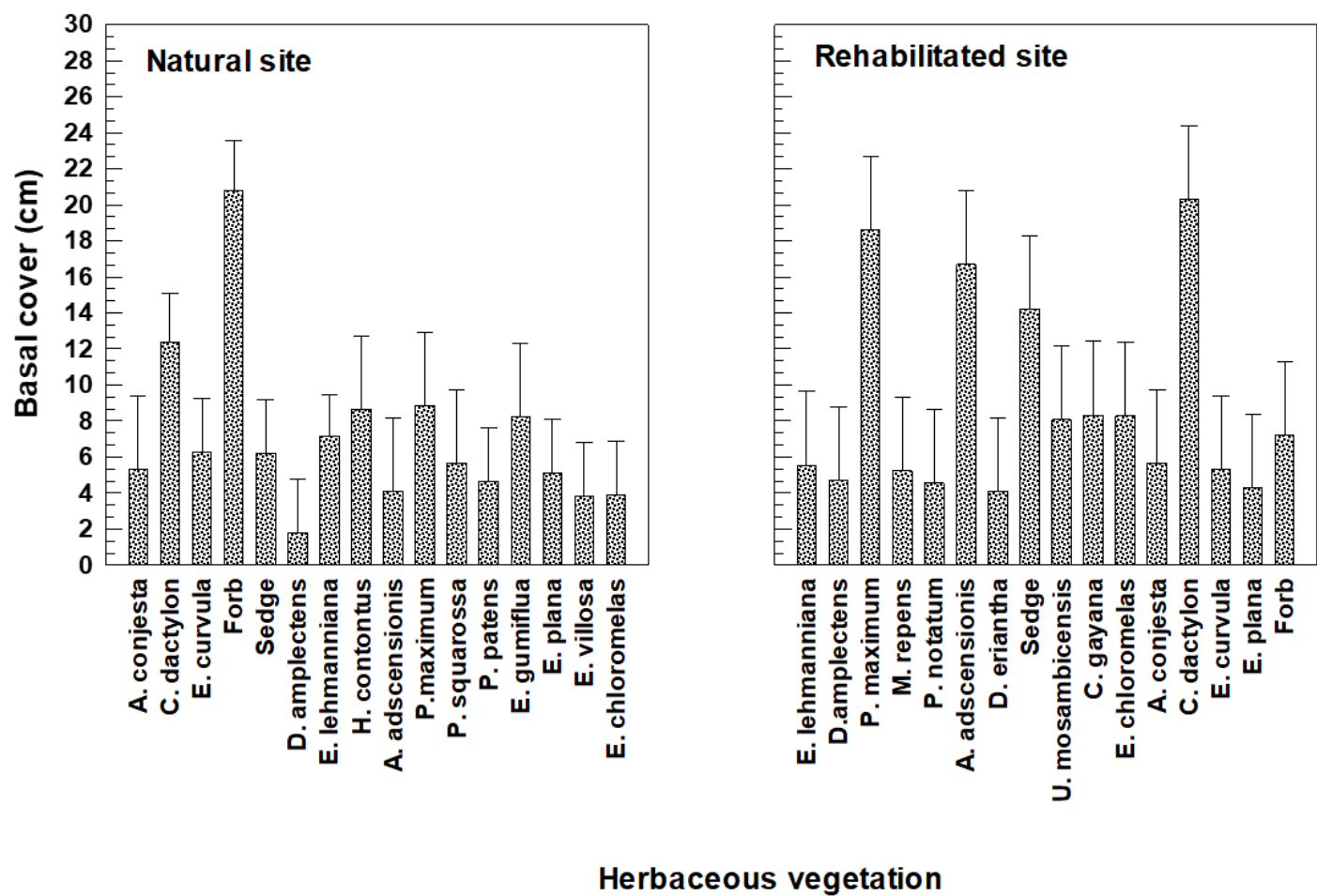


Figure 1

Basal cover (cm) in the natural and rehabilitated site

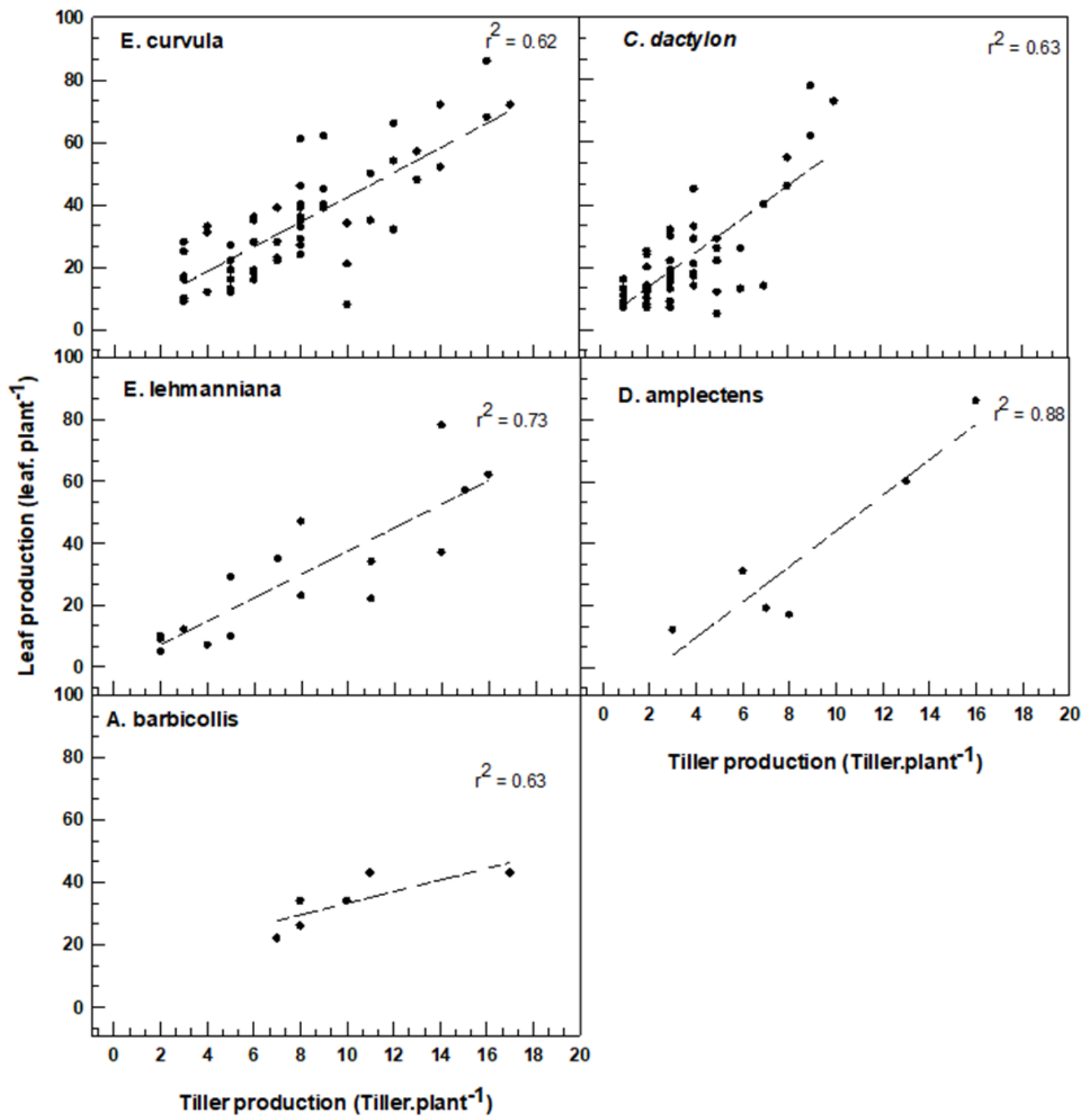


Figure 2

Tiller and leaf production per plant for common, moderate and few veld grass species in the natural veld at Klein-Kopje coal mine.

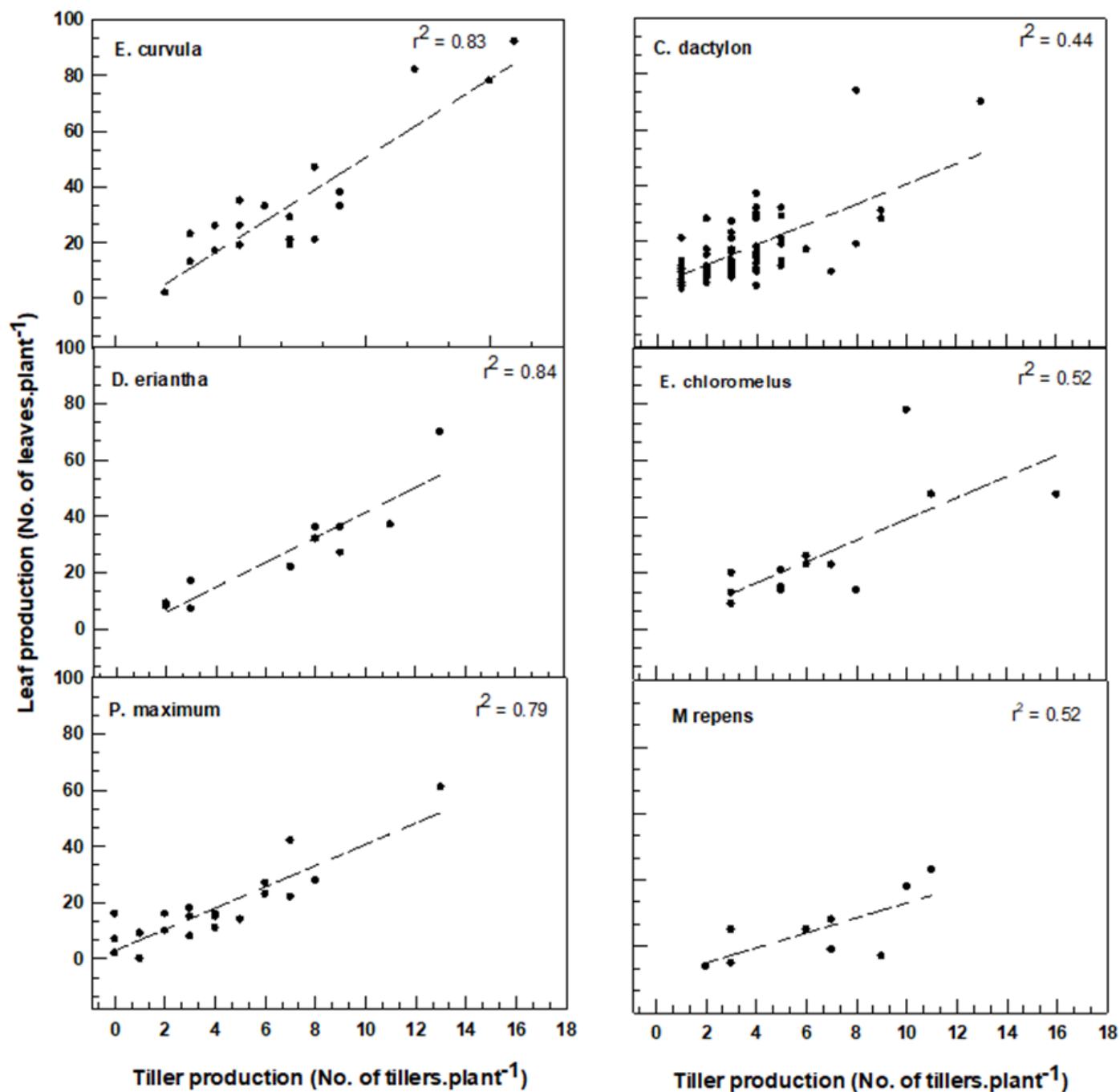


Figure 3

Tiller and leaf production per plant for common, moderate and few veld grass species in the rehabilitated site at KleinKopje coal mine.

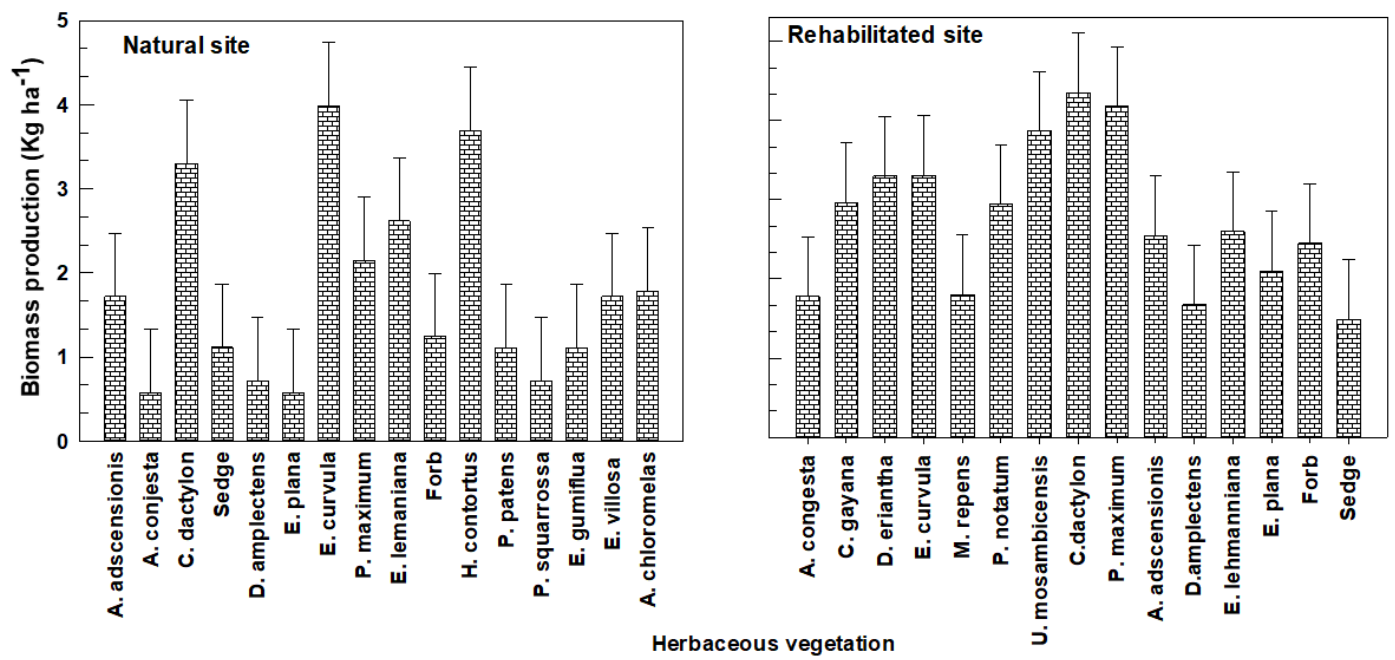


Figure 4

Oven dried herbaceous biomass production harvested at Kleinkopje colliery.