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Can erosion control blankets (geotextiles) aid vegetation establishment in mine restoration?

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Abstract

Establishing vegetation is a critical phase in the reclamation and restoration of disturbed sites. The canopy, stems and roots components of vegetation are able to protect and stabilise the landscape from slope degradation processes such as surface erosion, shallow mass movements and loss of organic matter. Slope erosion from plots with low growing, dense sward grasses can be as little as 0.4% of that from a bare soil equivalent. Creating a non-degrading, stable environment is vital for ecological restoration to take place successfully. However, establishing vegetation in erodible and erosive conditions characteristic of disturbed land is a major challenge for site managers, environmental engineers and landscape architects.

Vegetation establishment aids include mulching; soil amendments and conditioners; hydro- and mulch-seeding; and erosion control blankets (geotextiles). This paper collates the results of several laboratory and field-scale experimental trials where the effectiveness of geotextiles in establishing vegetation has been monitored. The studies considered different geotextile products: natural versus synthetic; woven versus non-woven; and surface versus buried mode of installation. Other variables include soil type and seed mixes applied.

To add to the evidence base, measurements of initial germination and percentage emergence under different geotextile covers are reported, as well as percentage cover achieved at the end of the trials. The latter indicates the ability of the vegetation to stabilise sites so that successful ecological restoration can take place. Results demonstrate that geotextile treatments can increase the rate of seed germination, emergence and final percentage cover, compared to bare soil control plots. Rates differ between product types and are often linked to geotextile properties such as percentage cover; material and mode of manufacture and degree of geotextile/soil contact. These characteristics affect soil moisture contents and diurnal temperature ranges which have direct impact on vegetation growth. Performance was also affected by the type of seed mix used in the trials. One unexpected result was that the geotextiles controlled the invasion of weed species that were observed on the bare soil plots.

1 Introduction

Disturbed and engineered landscapes such as mine spoils, quarries, open cast mines, mineral extraction pits, haulage roads and construction sites are associated with high erosion risk. Artificial cut and fill slopes are often over-steepened to minimise land take. Erosion rates are known to increase with slope gradient and length (Zingg, 1940; Musgrave, 1947; Wischmeier and Smith, 1978; Carson and Kirkby, 1972). Slope forming materials on disturbed sites are notoriously susceptible to erosion. Toy and Hadley (1987) conclude that soil handling techniques during land disturbance (such as topsoil removal, compaction and re-working) and stockpiling affect susceptibility of slope forming materials to erosion (erodibility). Lack of protective cover on disturbed ground can generate erosion rates several orders of magnitude greater than where vegetation is established. If the erosion observed from a bare soil plot is assigned a dimensionless value of 1.0 (= the C factor in the Universal Soil Loss Equation; Wischmeier and Smith, 1978), the erosion rate from a well-established, vegetated plot can be as low as 0.004, all other factors being equal.

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On artificial slopes, natural vegetation is often considered to be sufficient protection against erosion, providing it is well established (Rickson and Morgan, 1988). One definition of 'well established' is given by the Texas Department of Transportation in the US which stipulates minimum performance standards for 'acceptable vegetation density' of 80% and 70% cover for clay and sandy soils respectively (Northcutt, 1993).

However, establishing vegetation can be difficult under such challenging site conditions and in any case, there is a time window before vegetation has established when slope erosion is a potential problem. It is during this high risk period that commercially available establishment aids such as geotextiles may be required to enhance vegetation establishment and subsequent growth.

Geotextiles are "permeable textiles used in conjunction with soil, foundation, rock, earth or any geotechnical engineering related material, as an integral part of a man made project" (John, 1987). They include natural (e.g. jute, coir, sisal, paper, straw and wood chips) and synthetic products (e.g. nylon, polypropylene or polyester), in the form of 2D and 3D mats, sheets, grids or webs. Geotextiles are used to establish vegetation by creating more stable, non-eroding conditions by controlling erosion processes (Krenitsky and Carroll, 1994). This will result in less wash-out of seeds and seedlings from slopes, and a reduction in damage to new plants through heavy rainfall and runoff. As part of the Texas Department of Transportation and Texas Transport Institute field testing programme for erosion control products, Godfrey and Landphair (1991) and Godfrey and McFalls (1992) found that seeds washed down the slope where no erosion control was provided, leading to luxuriant growth at the bottom of the slope, but bare, eroding conditions upslope. Urroz and Israelsen (1995) evaluated the effectiveness of 19 different erosion control products (11 mulches and 8 blanket products) in vegetation establishment. They found the more soil and water retained by the erosion control product, the greater the germination rate, plant height and plant weight. Bhattacharyyaa et al. (2012) evaluated the effectiveness of a number of natural-fibre geotextiles (made from bamboo, rice straw, wheat straw and maize stalks) in establishing vegetation and found these products significantly increased aboveground biomass production and generally contributed to decreased soil loss under diverse soil and climatic conditions.

As well as providing a non-eroding environment for vegetation establishment, geotextiles can also alter the micro-climate at the soil surface (Sutherland et al., 1998; Allison, 1973; Reynolds, 1976; Krenitsky and Carroll, 1994). Diurnal temperature ranges can be modified by the geotextile, with peak daytime temperatures being reduced as the geotextile absorbs the sun's energy. During the night geotextiles can prevent heat loss through insulation, so increasing relative temperatures. This results in a reduced diurnal range of maximum and minimum temperatures. These effects depend on the type, composition, colour and thickness of the geotextile and its coverage. For example, Reynolds (1976) found that the darker the material, the more light energy was absorbed, so increasing surface temperature. Where geotextiles give cooler daytime soil temperatures, this can help retain soil moisture content, another factor affecting vegetation growth.

There is evidence that geotextiles affect soil moisture (Kertesz et al., 2011; Scruby, 1991; Krenitsky and Carroll, 1994; Jason Consultants, 1985). Due to the lower daytime temperatures, evaporation from the soil will be reduced. The high levels of water holding capacity of some geotextiles, notably natural products such as jute and coir textiles, will also increase soil moisture available to establishing vegetation. Reynolds (1976) found that a jute woven geotextile was able to absorb the equivalent of 2 mm of rainfall. Rickson (2000) found significant differences in water absorption rates for different products, with some natural products being able to retain up to six times their dry weight in water. These products also held moisture even after 48 hours of free drainage (Table 1).

Reynolds (1976) found that at sites where low soil moisture restricted plant growth, vegetative yields increased as volume of geotextile product increased. Moreau (1994) studied the micro-climatic effects of non-woven linseed fibre geotextiles on seed germination rates compared to a bare soil. The geotextiles gave moisture contents between 3–5% higher than the control, but this had no effect on germination rate.

However, after 10 days, the mean percentage of germinated seeds was always greater for the geotextiles than the control. As well the fibres themselves, water holding capacity can be affected by the configuration of the fibres. Fibres that are tightly spun are less able to absorb and hold water under surface tension. Rickson (2000) found that the tightly spun fibres of a coir woven product had lower water holding capacity than a loosely spun jute product of the same mass per unit area.

Table 1 Water holding capacity of selected geotextiles

Type of Geotextile	Mean Saturated Weight (as % of dry weight) (n = 4)	Weight After 24 Hours (as % of dry weight) (n = 4)	Weight After 48 Hours (as % of dry weight) (n = 4)
Woven jute 500 g m^2	641	268	116
Woven jute 300 g m^2	472	203	101
Wood shavings in light degradable mesh	389	129	103
Nylon 3 d mat	232	100	100
Polypropylene 3d mat	183	100	100
Coir woven product 750 g m^2	314	187	104

Finding the optimum cover which protects the surface from erosion, yet does not hinder emergence is a challenge. Placing a cover on the soil surface may stabilise the surface, but it may also reduce light interception by emerging vegetation, as a function of geotextile mesh size (aperture) and light interception capacity. Referring to mulches, Morgan (2005) identified 65–75% cover as the optimum for erosion control and plant emergence. Reynolds (1976) found no reduction in germination or initial rate of establishment for a woven polyethylene mesh with a small mesh opening size (5 mm), because the material had a high light interception capacity of 80%. However, once emerged, the seedlings did have problems penetrating the geotextile. Similarly, Fifield et al. (1988; 1989) and Fifield and Malnor (1990) found vegetation under heavy geotextiles could become etiolated (light starved), restricting future growth. Rickson and McIntyre (1994) found the use of a non-woven, needle-punched linseed straw geotextile with 100% ground cover significantly reduced vegetation growth compared with other geotextile treatments and the bare soil control. Krenitsky and Carroll (1994) found thicker products (e.g. loose wood fibres held together in a lightweight mesh) restricted seedlings growth, but once the plants emerged through the mat their growth was not affected, and the final percentage cover was 12% higher than the bare soil control.

By the time biodegradable or photodegradable geotextiles have decayed, the emerging vegetation should be sufficient to control erosion successfully by itself. In temperate climes, this would generally be within 1–2 growing seasons, except on harsher sites. In tropical conditions, this may take considerably less time, but this is balanced by a reciprocal increase in rates of geotextile decay.

Until recently, there were very few studies which quantified geotextile performance for vegetation establishment. Even fewer studies attempted to explain how different types of geotextile interacted with soil properties and subsequent plant growth. Specification and selection of products (if at all) was based on intuition or qualitative experience, rather than on objective data. Much can be learnt from the literature on the effects of mulches and mulching (McCalla and Dudley, 1946; Barkley et al., 1965; Allison, 1973) but there is little evidence for the different types of geotextile currently on the market. The purpose of this paper is to provide quantified data on the effectiveness of different types of geotextile in the germination, emergence and growth of vegetation, which is an important stage in process of reclaiming disturbed land.

2 Methodology

A clay loam soil (Endostagnic Luvisol) (FAO, 1998), two seed mixes and 12 geotextile treatments (including a bare soil control) were used in this study. The seed mixes comprised a UK standard Highways Agency seed mix and conservation mix (Highways Agency, 2006). The latter is often used by highway engineers in the UK to create a more ecologically and aesthetically pleasing result (Coppin and Richards, 1990). Tables 2, 3 and 4 show the geotextile products tested, soil characteristics and the seed mixes respectively.

Table 2 Geotextile products used in the vegetation establishment trials

Product	Material	Mean Mesh Opening Size (cm^2)	Mode of Application: Surface/Buried	Unit Weight ($g\ m^2$)
Geojute	100% jute woven	1.53	S	500
Soil Saver	100% jute woven	1.60	S	500
Antiwash	100% jute woven	1.42	S	500
Erosamat	100% jute woven	1.55	S	500
Grassmat	Jute non-woven reinforced with polyethylene mesh	0	S	950
Geomat	100% coir woven	1.05	S	700
Greenways Culture Quilt	Straw blanket with jute mesh	0	S	650
BonTerra SK	50% straw 50% coir blanket with jute mesh	0	S	250
BonTerra K	Coir non-woven fibres held in polypropylene mesh	0	S	250
Enkamat	Nylon 3D mat	0.18	B	265
Tensarmat	Polypropylene 3D mat	0.03	B	450

Table 3 Soil properties used in vegetation establishment trials

Property	
Fine sand	5.6%
Medium sand	20.2%
Coarse sand	6.7%
Silt	19.7%
Clay	47.7%
Organic matter	3.4%
Bulk density ($Mg\ m^3$)	1.2

Table 4 Seed mixes used in vegetation establishment trials

Seed Mix	Vegetation Species	% Composition
Highways Agency seed mix	Amenity perennial ryegrass	25
	Strong creeping fescue	20
	Hard fescue	30
	Smooth stalked meadow grass	10
	Highland browntop bent	10
	Huia white clover	5
Conservation seed mix	Chewings fescue	25
	Slender creeping red fescue	20
	Crested dogstail	20
	Sheeps fescue	20
	Small leaved timothy	10
	Highland browntop bent	5

Standard seed trays (measuring 35 x 22 x 6 cm = 770 cm^2 surface area), were filled with the same weight of soil, which had been sieved through a 2 mm sieve. The soil had been air dried to a uniform moisture content, and compacted to a uniform bulk density of 1.2 Mg m^3. The trays were thoroughly irrigated with a fine-rose watering can, with each tray receiving the same quantity of water to ensure adequate initial moisture content for seed germination.

For the surface-laid geotextile treatments and the bare soil control, the trays were hand broadcasted with 1.47g of seed ≈ 20g m^2 application rate, as recommended by the local authority (Bedfordshire County Council, personal communication). It was assumed that all seeds were viable and had equal chance of germination within the uniformly prepared seed trays. Samples of the different geotextile products, cut to the exact size of the trays, were then laid on the soil surface and pinned in place, following the conventional method used on slope protection work by contractors. The trays were then watered again.

Both of the synthetic products tested (Tensarmat and Enkamat) are used as buried mats, so in these treatments, once the trays were filled with soil, the top few centimetres of soil were scraped away, the mat was pinned in place and seed broadcast. Then the removed soil was back filled into the geotextile sample.

Three replicates were used for each treatment, placed in randomised blocks in a well-ventilated glasshouse under ambient temperatures and natural light. The trays were monitored every day for signs of germination and then every few days for the rest of the trials. Irrigation was applied to all plots at the same time and in the same quantity. This was generally 500 ml of water each or every other day. Under the high temperatures generated in the glasshouse, evaporation of water from the soil was high.

A general view of the experimental layout is shown in Figure 1. Initially the number of germinating seeds was noted. After the first couple of days, the seedlings were counted on a presence/absence basis using a 100 square quadrat placed over the tray. After approximately ten days the amount of vegetation was sufficient to be monitored as percentage cover. The trials continued for 89 days.

All data were analysed using the STATISTICA data analysis software system (StatSoft Inc., 2011). Post hoc analysis of ANOVA used the Fisher LSD to identify significant differences between treatments ($p<0.05$).

Figure 1 General view of seed trays with selected geotextile treatments and establishing vegetation (Highway Agency seed mix)

3 Results

3.1 Highways Agency (HA) standard seed mix

3.1.1 Initial germination and emergence

The first appearance of germinated seeds was on the 4th day after seeding. At Day 5 (Figure 2), highest germination and emergence was observed for the loose fibre, blanket type products, with the straw/coir blanket giving significantly more seedlings (mean number = 103) than any other product. This group of products gave significantly higher initial growth than all the other products. The jute woven products were not significantly different to one another, with mean germinating seedling counts ranging from 22–30 by Day 5. However, the jute non-woven product performed significantly better than the woven jute products, with a mean count of 51 germinated seedlings. Poorest performance came from the bare soil and the two buried synthetic products, with mean counts of only 14, 16 and 17 seedlings respectively, which are significantly below any other treatment.

3.1.2 Vegetation rate of growth

Figure 3 shows the spread of % vegetation cover for the different treatments throughout the trial. The jute woven products gave around 20% more cover than the bare soil control plots for the first 20 days of the trial. The control replicates then showed a rapid increase in cover (not shown by any other treatment), resulting in the highest mean percentage cover of all treatments after 28 days, but this rate then levelled off towards the end of the trial period of 89 days. This rapid increase in cover was associated with the growth of several volunteer broad leaf weeds which colonised the bare soil plots only (see discussion below).

All the woven geotextiles (jute and coir) had very similar percentage cover throughout the trials. There was a rapid increase in cover under the straw and coir blanket from Day 49, which was not seen in other products to the same extent. Indeed a levelling or even reduction in the rate of vegetation growth was observed for the woven products at the same time. Throughout the trial, the non-woven jute product (Grassmat) failed to produce more than 5% surface vegetation cover.

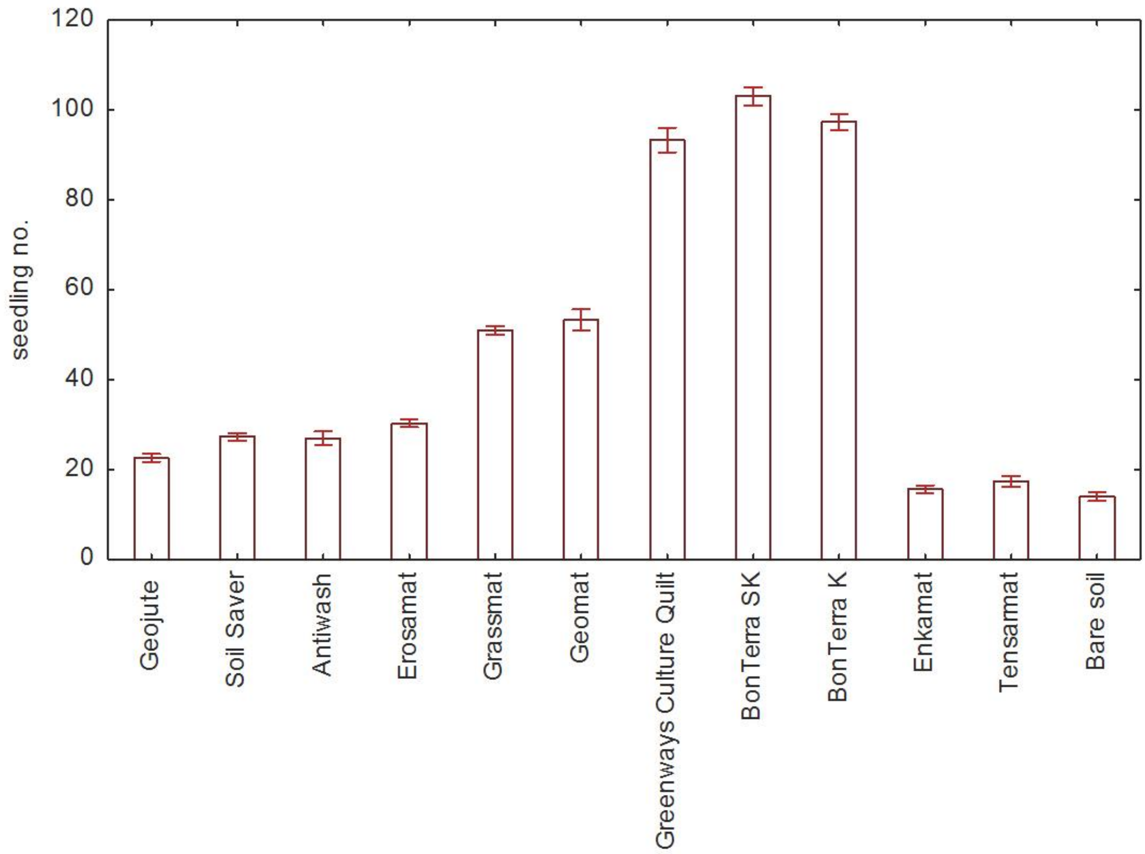

Figure 2 Initial emergence at Day 5; Highways Agency seed mix. Error bars denote one standard error of the mean

The final vegetation cover was similar for all treatments tested (range 61–86%), with the exception of the Grassmat, which was significantly lower (4%) than all other treatments. Even the bare soil control produced vegetation cover comparable to that for most of the geotextile products. Interestingly, the coir fibre blanket gave much lower % cover (61%) than the straw/coir blanket of similar construction (86%). This was surprising as the coir blanket had produced good rates of initial emergence. These two products had similar rates of growth until Day 49, after which the straw/coir product had a noticeable increase in rate of % cover from Day 69 to the end of the trial. Although the rate of growth appeared to be similar for the jute wovens throughout the trial, their final mean % cover ranged from 67–78%, as cover on the Geojute product notably increased in the last few days of the trial.

3.2 Conservation seed mix

3.2.1 Initial germination and emergence

The initial germination was similar to the HA trials described above, with the first germinating seeds being visible after four days (Figure 4). Overall, mean emergence counts for all treatments were lower than for the HA seed mix, but not significantly so. Again, the blanket products (of loose fibres held within a mesh) performed best, with the straw/coir blanket giving significantly ($p<0.05$) more emergence (mean = 92 seedlings) than any other product. The other loose fibre blankets also gave high counts (85 and 87) which were also significantly above the remainder of the treatments. The other blanket product, the jute non-woven produced significantly more seedlings than any of the woven products made from the same fibre.

The synthetic buried products give significantly lower counts than the other geotextile products. The bare soil produced only nine seedlings by Day 5 – significantly lower than all other treatments.

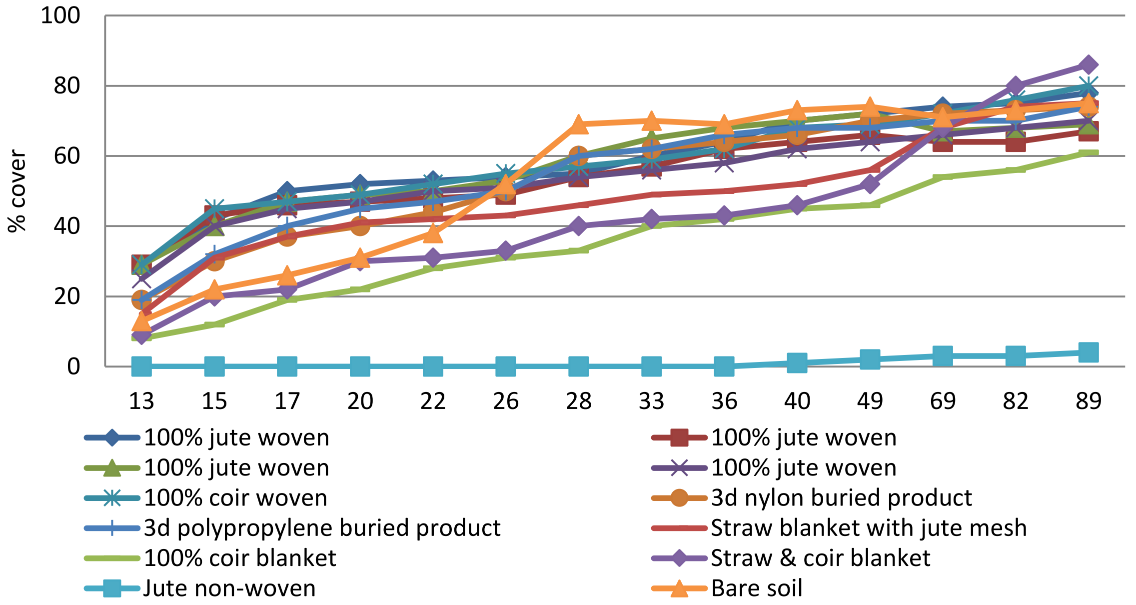

Figure 3 Mean rates of vegetation growth from Day 13–89; Highways Agency seed mix

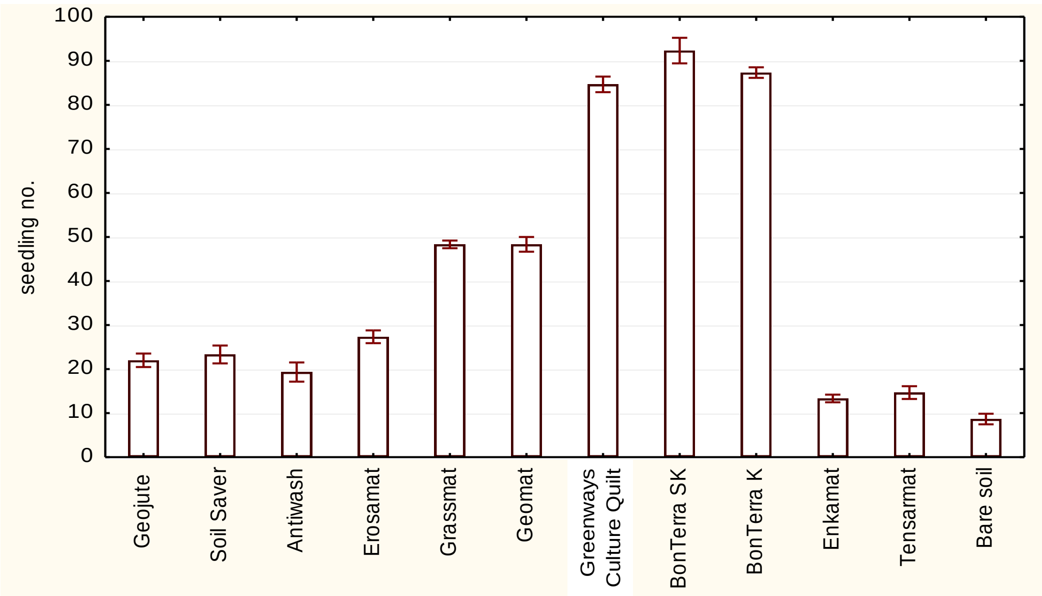

Figure 4 Initial emergence at Day 5; Conservation seed mix. Error bars denote one standard error of the mean

3.2.2 Vegetation rate of growth

The results from this trial are shown in Figure 5. The percentage cover was first measured on Day 13 with all treatments giving similar cover (range = 0.5–4%). Unlike the HA trials, vegetation establishment for all treatments was very slow and generally poor with the conservation mix. It was not until Day 22 that any of the products produced mean vegetation covers greater than 10%. By the end of the 89 day trial, the vegetation cover did not reach 50%, even on the best individual tray.

By the end of the trial (Day 89), all the geotextiles (except the jute non-woven) produced stands of vegetation significantly greater than that of the bare soil control. The mean bare soil control result was 25% cover, compared to 35–48% produced with the geotextiles. There was no evidence of the broad leaf volunteer weeds on the bare soil as had been observed for the Highways Agency seed mix. The jute and coir woven products all produced very similar establishment rates and trends.

The results show that the blanket products containing straw, which had generated relatively high levels of vegetation compared to the other products in the HA trials, produced some of the lowest results here (35% and 38% for the straw and straw/coir mix product respectively). This is also surprising as the highest cover produced by any treatment (48%) under the conservation seed mix came from the 100% coir blanket of similar construction. The buried synthetic products performed relatively better on the conservation mix than for the HA trials, with final percentage covers ranking 3rd and 4th of all treatments.

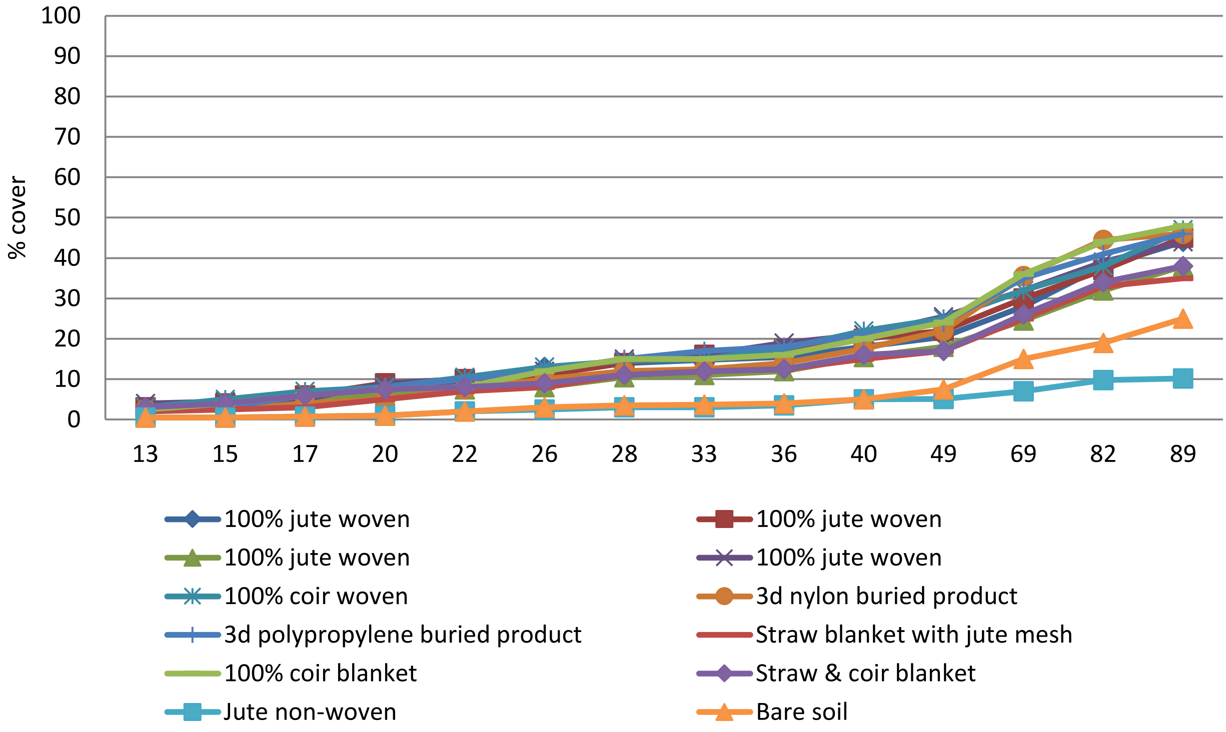

Figure 5 Mean rates of vegetation growth from Day 13–89; Conservation seed mix

4 Discussion

It was expected that the range of geotextile types used in these trials (i.e. materials used (natural versus synthetic); mode of manufacture (woven versus non-woven) and mode of installation (surface versus buried)) would yield significant differences in the following parameters: seedling germination; plant emergence; and vegetation growth. This was the case for seedling germination and emergence after 5 days – the blanket products comprised of loose fibres of straw (Culture Quilt), coir (Bonterra K) and straw/coir combined (Bonterra SK) gave significantly more initial vegetation growth for both seed mixes than any other product.

As the vegetation grew, differences in geotextile products were more marked for the Highways Agency seed mix than for the conservation mix. This implies that the relative performance of vegetation establishment aids is affected by seed type. However, by the end of the trials (Day 89), there were very few significant differences in percentage vegetation cover afforded by the different geotextile products for either seed mix.

Other studies have shown the importance of moisture holding capacity of the geotextile in vegetation establishment (e.g. Scruby, 1991; Krenitsky and Carroll, 1994; Jason Consultants, 1985). As a result it was expected that the products with the highest water holding capacity (i.e. the natural, especially jute products) would favour vegetation growth. This was not the case, probably because moisture was never a limiting factor in the present trials. Regular application of water meant the soils never dried out, despite the high temperatures in the greenhouse. Similar studies on a sandy loam soil (Rickson, 2000) showed more significant differences in seed germination and consequent vegetation growth as a function of geotextile type, which were explained by the different water holding capacity of the products used on these more droughty soils.

The felt-like, jute non-woven provided warm, moist conditions for initial seed germination and emergence. However, it was difficult to irrigate this treatment effectively, as the applied water would remain on the surface of the mat, where it would either slowly soak in or evaporate. Either way it was not readily available to the emerging vegetation beneath the mat.

After a few days growth, the seedlings were unable to penetrate through the dense mat. Instead, those near the edge of the tray by-passed the mat to emerge almost horizontally from the edge of the tray. Seedlings closer to the centre of the tray began to push the mat away from the soil surface. This has been observed in the field too (Jason Consultants, 1985; Rickson and McIntyre, 1994) and would have serious consequences for the erosion control effectiveness of the product in the field, as soil/geotextile contact is very important in hindering generation of potentially erosive surface runoff (Reynolds, 1976). These seedlings became etiolated due to lack of light underneath the mat, and died after a few days. The implication is that even if non-woven products appear to give good initial rates of seed germination and emergence, in the longer term, this ‘first flush’ will not be sustained as the seedlings are unable to penetrate the product and reach sunlight needed for photosynthesis and growth.

The presence of volunteer weed species on the Highway Agency, bare soil plots explains why this treatment gave the same final % cover as all other treatments, save the Grassmat non-woven which had significantly less vegetation cover. (With the Conservation seed mix, the control plots gave significantly less vegetation cover than the other treatments, save the Grassmat). These alien weeds were not found on any other treatment, presumably because the geotextiles prevented any (wind-blown) seeds landing on the soil surface. This appears to be the case even for the buried products. One explanation may be that the weeds appeared only by Day 22 when the buried products had sufficient grass cover to prevent these invasive weeds establishing.

The relative performance of the buried synthetic products compared with other geotextiles was dependent on seed mix. In the HA mix, these products gave % cover results very similar to the bare soil control. However, under the conservation mix, they performed significantly better than the bare soil and some of the other geotextile treatments. It could be that the roots of the conservation weed species prefer the looser tilth of the backfilled, buried products.

5 Conclusions

Well established vegetation is able to protect slopes from surface erosion and deeper seated instability (Coppin and Richards, 1990; Moreno de las Heras et al., 2009; Windsor and Clements, 2001; Carroll et al., 2000). Establishing that vegetation on disturbed and degraded land often requires the use of vegetation establishment aids, particularly where risk of land degradation is highest. This is important as revegetation is often the first step in mine landscape restoration (Windsor and Clements, 2001).

The aim of this research was to increase the evidence base regarding the effectiveness of geotextiles to enhance vegetation establishment and growth. Product performance was monitored and related to product characteristics with the aim of helping land managers specify and select the most effective products and help geotextile manufacturers design new products.

Rates of seed germination, seedling emergence and vegetation growth were monitored for 11 geotextile treatments on a clay loam soil, using two seed mixes. Despite the range of products tested and their inherent properties, there were few significant differences in the final surface vegetation cover after 89 days. However, the results presented here are confined to a very specific set of controlled conditions (i.e. soil type, seed mix, irrigation regime, length of growing period, glasshouse ambient temperature).

Small plots were used to minimise variability, but in doing so 'we greatly reduce our ability to extrapolate to other areas' (De Coursey and Meyer, 1977). Other research has demonstrated the effectiveness of geotextiles in establishing vegetation on slopes at risk of soil erosion. This demonstrates the site specific nature of geotextile performance, and the requirement for further investigation and better understanding of processes involved.

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