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Optimal ground preparation treatments for restoring lowland Sand Fynbos vegetation on old fields

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Abstract

A restoration field trial was designed to investigate herbaceous weed control and Sand Fynbos plant establishment on a fallow field at Riverlands Provincial Nature Reserve located on the West Coast forelands. The objectives were to investigate optimal treatments for reducing weed cover and the interaction between weed cover and shrub establishment. Herbaceous weeds were controlled using tilling, herbicide and carbon-rich mulch in a split-plot replicated design. Seedlings of two bioassay fynbos species were planted and survival monitored. Tilling in April reduced weed cover for four months, but thereafter had no overall effect. Herbicide applied twice, in May and early July, reduced weed cover significantly for a longer period, whereas mulch had no effect. Soil nitrogen levels were slightly higher than those of untransformed Sand Fynbos soils but no effects of the treatments on nitrogen mineralization rates or total available nitrogen were found. Bioassay plant establishment was highest in the herbicide plus mulch treatment and was negatively related to herbaceous weed cover. Molerat activity, which was positively related to weed cover, was noted to reduce the establishment success of shrub seedlings. There was no overall effect of tilling and mulch on plant establishment in the field, although mulch influenced growth rates in the pot experiment. In terms of cost-effectiveness, it is recommended that herbicide treatment be used to control herbaceous weeds prior to the re-introduction of fynbos species. Other factors to consider in planning a Sand Fynbos restoration, that may impact on native seedling establishment, include whether to: burn the site to remove standing alien biomass and litter; reduce soil N levels; control molerat and gerbil colonies; control browsers; and control of regenerating invasive alien plants.

Keywords: Alien annual; Fire; Fossorial mammal; Stoloniferous grass; Weed control

1. Introduction

Lowland Sand Fynbos vegetation types are amongst the most poorly conserved in South Africa. A large proportion of this land is degraded, primarily as a result of invasion by alien plants and transformation by agricultural and urban developments (Low and Rebelo, 1995). Along the Western Cape forelands, Cape Flats Sand Fynbos has been classified as “Critically Endangered” and Atlantis Sand Fynbos as “Endangered” in the recent National Spatial Biodiversity Assessment (Rouget et al., 2005). The two most important management objectives, both within the current conservation estate and in any future land areas acquired for conservation, are alien plant control and fynbos restoration. Many of the extant remnants are fragmented and isolated, and successful restoration protocols could improve the conservation network via the creation of functional corridors linking remnants to reserves and the creation of buffer zones around key intact remnants.

Studies on the effects of invasive alien species in Sand Fynbos ecosystems indicate significant impacts on ecosystem-level processes. Yelenik et al. (2004) found that the woody alien legume species (*Acacia saligna* (Labill. Wendl.)) causes a shift from low to high nitrogen-cycling rates and an increase in the total soil nitrogen pool. This change in soil nutrient status facilitates the establishment and growth of weedy grasses and annuals (Yelenik et al., 2004), which then may out compete the slower growing fynbos species, especially in the seedling establishment phase. Similarly, alien grasses and annuals readily colonize fallow fields that may have elevated nutrient levels following cultivation and fertilization. Although largely overlooked in South Africa until recently, alien grasses have been noted as invasive and a potential threat to the flora along the West Coast forelands (Milton, 2004; Musil et al., 2005).

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As in other parts of the world, alien grasses have the potential to alter ecosystem structure and functioning and fire cycles, which in turn affect nutrient-cycling and regeneration processes (D'Antonio and Vitousek, 1992; Vila et al., 2000). A decline in species richness following invasion by alien grasses has been noted for different vegetation types in the Western Cape (Campbell et al., 1980; Vlok, 1988; Jobst, 1996). A high density or cover of weedy grasses may suppress indigenous seedling recruitment, as was noted for a renosterveld restoration pilot study on the Cape Flats (Holmes, 2002a) and in other Mediterranean–climate ecosystems internationally (Eliason and Allen, 2000; Cione et al., 2002). At a Cape Flats site, the experimental removal of grass cover significantly increased fynbos seedling emergence (Wilson, 1999), indicating that grasses suppress fynbos recruitment.

Invasive alien species may impact negatively on fynbos seed banks and fynbos recovery potential. However, whereas soil-stored seed banks form an important basis for restoring fynbos after alien clearance in the mountains (Holmes and Cowling, 1997; Holmes and Marais, 2000), in the lowland sand plains seed banks are less persistent, particularly those of the longer-lived shrub and graminoid components (Holmes, 2002b). Sand Fynbos recovery following alien tree removal tends to be dominated by short-lived herbaceous species. Thus following a disturbance such as invasion by alien trees or cultivation, it is essential to re-introduce the longer-lived components of the vegetation, either by sowing or planting propagated plant material, to prevent a dense herbaceous layer from developing.

Re-introducing indigenous species by seed generally is an order of magnitude cheaper than by planting and offers the potential for restoring greater biodiversity (Holmes, 2002a, 2001). However, without lowering soil available nitrogen levels and reducing the vigour of herbaceous weeds, seedling and cutting establishment is likely to fail through competition with these vigourous weedy species. As a key step in restoring Sand Fynbos, it is important to investigate the optimal ground preparation treatments to implement prior to indigenous species re-introduction. Potentially useful treatments for reducing the vigour of weeds include burning, herbiciding and tilling in various combinations (Holmes, 2005; Musil et al., 2005).

In addition, the immobilization of nitrogen (N) through the application of carbon (C)-rich mulch (e.g. milled pine bark or wood chip; Zink and Allen, 1998) may also reduce weed vigour and the level of competition between weeds and indigenous species in these naturally low-nutrient ecosystems. However a mulch with a suitably high C:N ratio (exceeding 50:1) should be used to ensure the desired result (Cione et al., 2002). Once an indigenous shrub layer has established, shading will contribute towards controlling the growth of herbaceous weeds until after a subsequent fire.

This restoration study was designed to explore the feasibility of restoring old fields in the Riverlands Nature Reserve and had two main objectives:

1. to investigate optimal ground preparation treatments for reducing herbaceous weed cover; and
2. to investigate the interaction between herbaceous weed cover and fynbos shrub establishment and growth.

2. Materials and methods

2.1. Study site

The field trial was conducted at Riverlands Provincial Nature Reserve which is located immediately north of the Dassenberg Hills, 63 km north of Cape Town. The vegetation is broadly classified as Atlantis Sand Fynbos (Mucina et al., 2004), but includes a number of environmental gradients and associated plant communities; for example, from dry to seasonally wet habitats and from deep sands to shallow sands over clay soils. Riverlands was purchased by CapeNature and proclaimed as a reserve in 1985 owing to its high density of rare and locally endemic plant species. However, as a result of its land-use history, the reserve encompasses areas of fallow, previously cultivated fields and land recently cleared of dense, invasive alien vegetation (predominantly *Acacia saligna* (Labill.) Wendl. in addition to native fynbos communities. The old-field site selected for the study had been fallow for over 20 years, yet shows no evidence of re-colonization by fynbos species from relatively intact fynbos communities approximately 100 m distant.

The area experiences a Mediterranean-type climate with most rain falling during the winter months. The long-term mean annual rainfall at the field site is 367 mm, whereas during the trial it was lower, especially during the early part of winter (Fig. 1).

2.2. Experimental design

In order to keep the number of treatments (including their interactions) to a manageable level, only tilling, herbicide and C-rich mulch treatments were tested. As fynbos is a fire-prone vegetation type, burning was included as an initial restoration treatment prior to the application of the other treatments. The entire field trial site was burnt in early March 2004.

A split-plot replicated block design was used with tilling as the split-plot treatment and herbicide and mulch and their

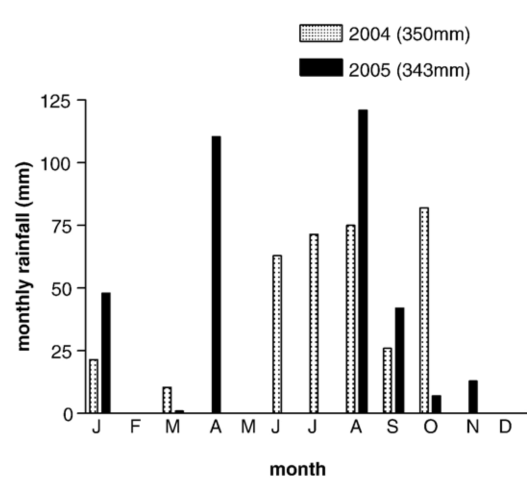

Fig. 1. Monthly rainfall at Riverlands Nature Reserve during the trial. Average annual rainfall is 367 mm.

combinations applied as the sub-treatments. The experimental site covered an area of 59×23 m and comprised five blocks (Fig. 2). Each block was subdivided into eight 5×5-m plots, with 1-m buffer strips among plots and blocks, and contained one replicate of each treatment combination. In April 2004 one half of each block, comprising four plots, was tilled and the other half left untilled. Herbicide and mulching treatments were applied at random to plots within the tilled split-plots. On half the plots, the systemic herbicide "Mamba" (active ingredient: glyphosate), was applied to foliage at a rate of 0.4l/ha at 2% concentration by knapsack sprayer: once in May 2004, to kill the undesirable perennial grass *Cynodon dactylon* (L.) Pers.; and secondly in July 2004, to kill alien annuals. Woodchip mulch of a high C:N ratio (214:1) was applied to half the plots in May 2004 at a rate of 30 kg per plot (equivalent to 12 tonnes/ha).

2.3. Monitoring

2.3.1. Total soil organic matter and available N

Before ground preparation treatments were applied, five soil samples were collected from each block (in February 2004) to test for total % soil C (organic matter) and available N. Each sample comprised five small scoops in different microsites extracted from the upper 5 cm of soil and mixed together. An additional five samples were collected from outside the experimental area to serve as a control. Total C content was calculated gravimetrically following the loss on combustion of organic matter and total N was analyzed using the Kjeldahl method (Allen, 1989). A year later, after the ground preparation treatments had been applied, one sample per plot was collected for total soil N analysis as well as five samples from the unburnt, untreated control area.

N availability was assessed using ion exchange resin bags (Gibson, 1986). Resin bags were constructed from fine (34TT) polyester screen printing mesh sewn to measure 7.0×4.5 cm, with the opening sealed by glue gun once filled with 5 g of wet Amberlite resin (anion IRA-402, cation IR-120 plus, Rohm and Haas Inc., New Germany, South Africa). Bags were primed by shaking in 5% HCl for 30 min, repeated twice more, followed by rinsing four times in distilled water. Resin bags were kept moist in a sealed bag and in the field on June 22nd 2004, three replicate pairs of bags were placed in each plot, as well as the unburnt control plot, and marked with a metal pin and flag. A hole was dug and a spatula used to lift the soil at the side of each hole to create a slot for the pair of flattened bags beneath 5 cm of relatively undisturbed soil. After two months, resin bags were removed for analysis. Bags were eluted within 24 h, after cleaning off external dirt and roots and rinsing with distilled water. Each bag was shaken separately with 50 ml of 5% HCl for 30 min. The eluates were placed in glass vials and transported to Bemlab (Edms) Bpk (Somerset West) for ammonium and nitrate analyses.

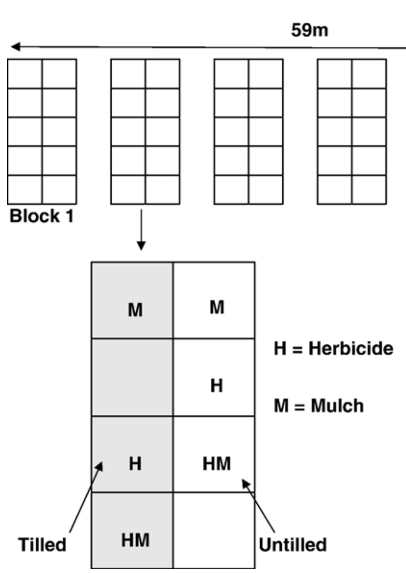

Fig. 2. Schematic depiction of the experimental layout of the weed control field trial at Riverlands Nature Reserve (not to scale).

2.3.2. Herbaceous weed cover

The percentage live cover of alien herbaceous weeds, including annual grasses, forbs and perennial grasses, was assessed visually in two 1×1-m quadrats per plot. Five data sets were collected: (1) prior to all treatments, including burning (summer baseline data set), (2) one month after the winter herbicide application, (3) at the end of spring 2004, (4) at the end of spring 2005 and (5) at the end of summer 2006.

2.3.3. Effect of treatments on fynbos shrub establishment

The effects of the ground preparation treatments on the establishment and growth of two locally common fynbos shrub species was assessed. Seed of these "bioassay" species was collected during summer 2004 and sown in trays in autumn, following appropriate treatments to break dormancy. Unfortunately, the initially selected local species (*Leucospermum parile* (Salisb. Ex Knight) Sweet (Proteaceae) and *Phylica cephalantha* Sond. (Rhamnaceae)) failed to germinate in sufficient numbers and had to be substituted late in the season by two quick-germinating serotinous Proteaceae species (*Protea scolymocephala* (L.) Reichard and *Leucadendron laureolum* (Lam.) Fourc.). On August 6th seedlings were transplanted to the field at a density of 10 *Protea* and six *Leucadendron* per plot. Seedlings were watered every second day for the first week and then weekly until the end of September to facilitate establishment. Seedling survival and growth was assessed at the end of spring 2004, and in summer and autumn 2005.

In a pot experiment, some later-germinating *Protea* and *Leucadendron* plants were placed in bags containing soil from either the mulched or unmulched plots. These plants were kept outdoors and watered twice weekly. No plants died over the six month summer census period. Height and leaf number were recorded after planting (in November 2004) and again six months later at the end of April 2005.

2.4. Statistical analyses

Initial differences in herbaceous weed cover, soil organic matter and total available N content among blocks and control

Table 1
F-ratios from a split-plot analysis of variance testing the effects of tilling (split plot) and sub-treatments (herbicide and mulch) on a) weed cover (at various times after treatment) and b) bioassay seedling establishment, rate of N mineralization and change in total available N (* $P<0.05$, ** $P<0.005$; *** $P<0.0005$) in an old field at Riverlands Nature Reserve

a)

Treatment	*df*	Weed cover August 2004	Weed cover November 2004	Weed cover October 2005	Weed cover April 2006
Block	$F_{4,4}$	5.25	2.05	6.94*	0.97
Tilling	$F_{1,4}$	8.92*	6.04	1.40	7.13
Sub-treatment	$F_{3,24}$	153.1***	48.0***	4.02*	12.7***
Tilling X sub-treatment	$F_{3,24}$	6.57**	6.75**	0.18	2.89

b)

Treatment	*df*	*Protea* establishment	*Leucadendron* establishment	Rate of N mineralization	Change in total available N
Block	$F_{4,4}$	1.21	2.15	0.41	0.63
Tilling	$F_{1,4}$	0.08	0.18	2.28	0.31
Sub-treatment	$F_{3,24}$	12.5***	3.14*	0.21	1.33
Tilling X sub-treatment	$F_{3,24}$	2.57	0.43	0.92	0.28

were analyzed using one-way analysis of variance (ANOVA). The effects of the ground preparation treatments on weed cover, bioassay plant survival, N mineralization rates and change in total available N were analyzed using the split-plot ANOVA model in the "Genstat 5" statistical package. Percentage data were arcsine transformed prior to analysis to correct for normality and homoscedasticity. For significant outcomes, differences among subplot treatments were tested using post-hoc Newman–Keuls tests. Relationships between plant establishment and weed cover were explored using linear regression. In the pot experiment, the relative growth rates of plants in height and leaf number were calculated and the effect of the mulch treatment analyzed using Student's *t*-tests.

3. Results

3.1. Herbaceous weed cover

Prior to weed control treatments, herbaceous weed cover in 1 m^2 quadrats averaged 77.4% (range 25–100%), with no significant difference detected amongst blocks or the control ($F_{5,24}=2.33$, $P=0.072$. Tilling had a relatively short overall impact on herbaceous weed cover, causing a significant reduction in cover compared to untilled plots only in the first census at four months post-tilling (Table 1a, Fig. 3). There remained a significant interaction effect between tilling and sub-treatments at seven months, indicating some residual influence of the tilling treatment, but thereafter there was no significant effect of this treatment (Table 1a). The sub-treatments had a significant effect on weed cover throughout the monitoring period of two years (Table 1a, Fig. 3). Newman–Keuls post-hoc tests indicated that this effect was entirely due to the herbicide treatment, which significantly reduced weed cover compared to non-herbicided plots, except in the October census when annual weeds predominated: $q_{0.05,24}=5.012$ ($P=2$); q values are: 8.34 (August 2004), 15.3 (November 2004), 1.45^{NS} (October 2005), 8.81 (April 2006). No effect of the mulch application on weed cover was detected.

3.2. Bioassay plant establishment

Tilling had no impact on establishment for either bioassay species, but there was a significant effect of sub-treatment (Table 1b, Fig. 4). In *Leucadendron*, sub-treatments increased establishment in the order of: herbicide+mulch > herbicide >

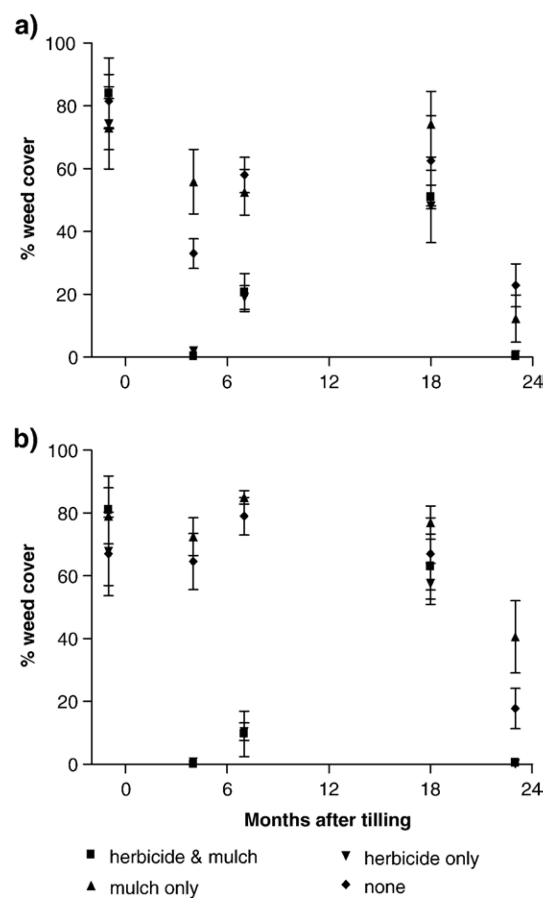

Fig. 3. Change in herbaceous weed cover following herbicide and mulch treatments: a) tilled, b) untilled (mean±SE, $n=5$) in old fields at Riverlands Nature Reserve.

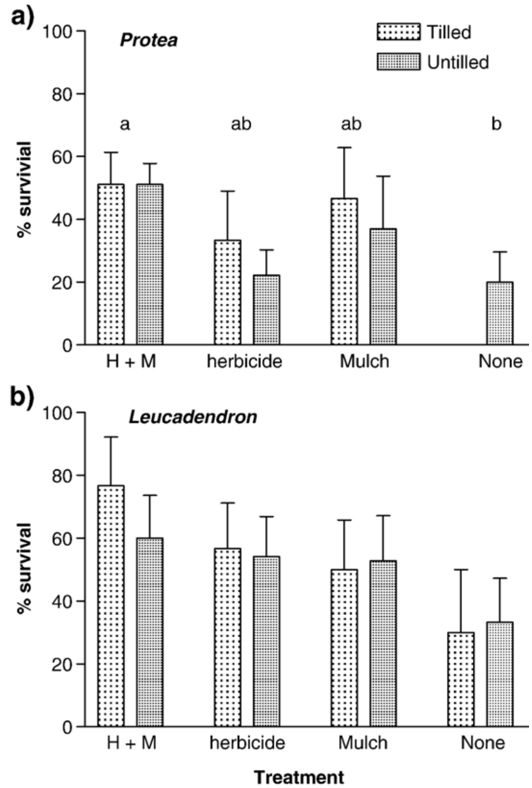

Fig. 4. Percentage survival of the two bioassay species three months after planting in old fields at Riverlands Nature Reserve: a) *Protea scolymocephala*, b) *Leucadendron laureolum* (mean + 1SE, $n = 5$); different letter superscripts indicate significant treatment effects ($P < 0.05$); H=herbicide, M=mulch.

mulch > none; however, no significant differences were detected. In *Protea*, sub-treatments increased establishment in the order of: herbicide + mulch > mulch> herbicide > none; the "herbicide + mulch" differed significantly from the "none" sub-treatment (Newman–Keuls test: $q_{0.05,24} = 5.42$). In *Protea*, there was a weak negative correlation between % survival and herbaceous weed cover at the November 2004 census ($r = 0.33$, $P = 0.04$), but not in *Leucadendron* ($r = 0.26$, $P = 0.10$). Few plants survived the first hot, dry summer season, precluding further statistical analyses.

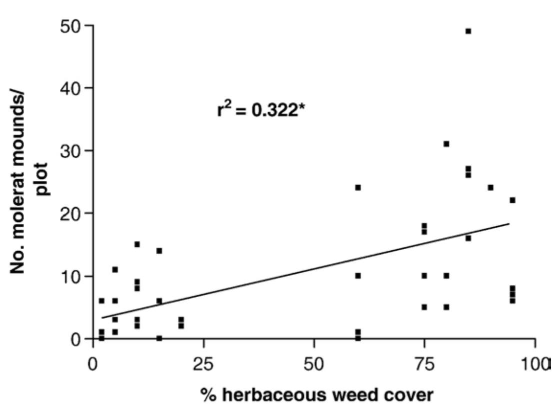

Fig. 5. Regression of molerat mound density against % herbaceous weed cover in October 2004 (*significant at $P = 0.0001$) in an old field at Riverlands Nature Reserve.

During the plant establishment census it was noted that many bioassay plants had been disrupted by molerat activity: either by burial under mounds or uprooting by tunneling; and it was further noted that molerat activity was more prevalent in the well-vegetated plots. Thus in late October 2004, a census was done in each plot of total percentage herbaceous weed cover and number of molerat mounds (as a measure of molerat activity). A significant regression of molerat mound density against weed cover was found (Fig. 5).

3.3. Bioassay plant growth experiment

The addition of C-rich mulch to the old-field sandy soil had a significant effect on the relative growth rate (RGR) of bioassay plant species when grown in bags in a nursery (Fig. 6). However, the two plant species responded in opposite directions. The local Riverlands *Protea* species responded negatively: mulch caused a reduction in height RGR ($t_{28} = 3.33$, $P = 0.0024$) with a corresponding, though non-significant, decrease in leaf RGR ($t_{28} = 1.70$, $P = 0.102$); whereas in the Cape Peninsula *Leucadendron* species, mulch caused an increase in height RGR ($t_{28} = 2.34$, $P = 0.027$) with a corresponding, though non-significant, increase in leaf RGR ($t_{28} = 1.50$, $P = 0.14$).

3.4. Soil nutrient impacts

Prior to weed control treatment, percentage soil organic matter averaged 1.14% (range 0.900–2.294%) and total available soil N

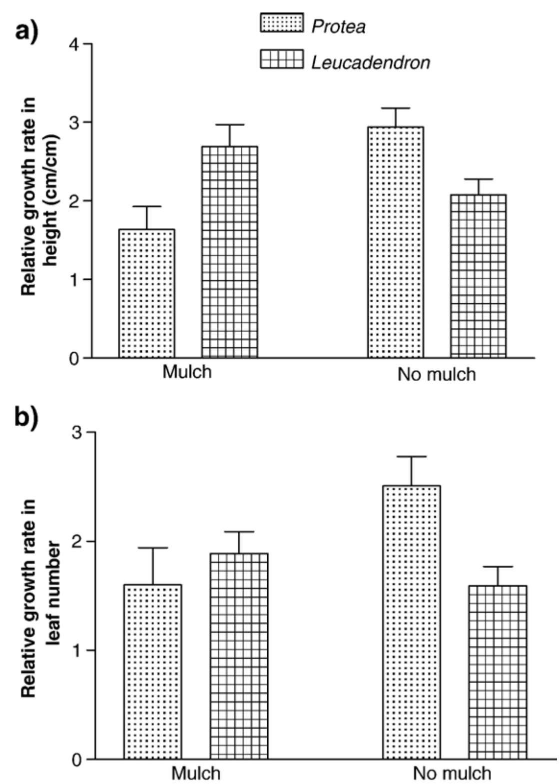

Fig. 6. Relative growth rate in bags of mulched and non-mulched field soil for the two bioassay species over a six-month summer period in a nursery: a) height, b) leaf number (mean + 1SE, $n = 15$).

averaged 365 μg/g (range 192–713 μg/g). Statistical analyses indicated no significant differences among blocks or the control area (% organic matter: $F_{5,24}$=1.915, P=0.129; total available N: $F_{5,24}$=2.44, P=0.064). However, as the total available N results suggested a gradient of decreasing N downslope (from block 1 through block 5) it was decided to present the post-treatment results as a change in total available N. Although there was a trend for the herbicide and mulch sub-treatments to independently dampen change in total available N, these effects were non-significant (Table 1b, Fig. 7).

Results of the N mineralization study indicated extremely low values with nitrate ions being at undetectable levels and ammonium mineralization rates ranging from 4.10–12.6 mg/m^2/month. Tilling and sub-treatments had no significant effect on N mineralization rates (Table 1b).

3.5. Treatment costs

Excluding the costs of capital equipment (e.g. tractor, knapsack sprayer), the treatment costs scaled up to one hectare are given below (in August 2006, 1 US$=7.5 ZAR). However, economies of scale could reduce these costs; for example, for herbicide application if done by tractor sprayer rather than manual knapsack sprayer.

1) Tilling — R800/ha (fuel) plus 3.5 days labour @ R100=R1 150/ha;

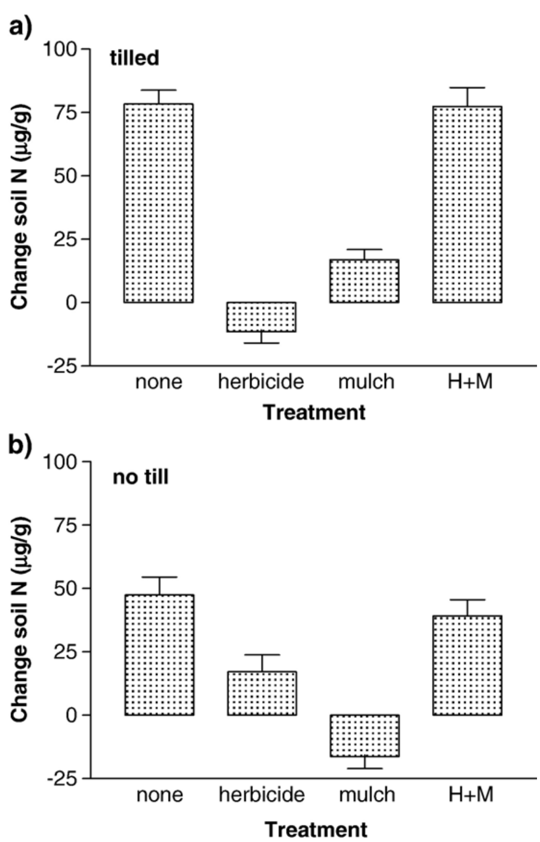

Fig. 7. Effect of ground preparation treatments (herbicide (H) and mulch (M)) on total soil available N in an old field at Riverlands Nature Reserve: a) tilled plots, b) untilled plots (means+1SE, n=5).

2) Mulch — R16 584/ha (excluding transport) plus 20 days labour @ R100=R18 584/ha;
3) Herbicide — R64/ha plus 10 days labour @ R100=R1 064/ha.

4. Discussion

The combination of a relatively dry autumn and early winter during the first year of the trial and the late germination and planting of the bioassay species may have contributed to the low longer-term establishment success of these shrubs. Thus the full assessment of shrub growth and establishment under the various ground preparation treatments could not be done. Nevertheless, in fynbos ecosystems the first winter season post-fire is the critical period for plant recruitment, and the early establishment results from this trial indicate which of the treatments are likely to best promote indigenous plant recruitment for disturbed Sand Fynbos sites.

4.1. Implications of results for herbaceous weed control

Tilling had a relatively short-term effect in suppressing herbaceous weed cover, as annuals were able to recruit during the subsequent winter season. In addition, disrupting the perennial weedy grass (*C. dactylon*) cover by tilling opened up additional niches for alien annual species to proliferate. This contrasts with results from a trial at the drier fynbos–karoo interface where tilling of sandy loam soils suppressed the alien annual component (Holmes, 2005). The herbicide treatment was applied twice, to both the perennial and annual weed component, and thus was more successful in reducing herbaceous weed cover for a longer period than tilling. A small and significant reduction in herbaceous weed cover was still evident at the end of the trial two years after the initial herbicide application. Application of C-rich mulch had no impact on weed cover in this trial. Results from the soil nutrient analyses indicated that total available N levels were only slightly higher than adjacent undisturbed fynbos soils and about one third of those measured in soils of *Acacia*-invaded fynbos (Stock and Lewis, 1986; Yelenik et al., 2004). Thus nutrient levels had already declined to a relatively low level. It is likely that nutrients added from previous fertilizer applications had been mobilized in the herbaceous biomass and volatilized and/or leached during and following fires at the site since it was last cultivated over 20 years ago (Stock and Lewis, 1986). Mulch addition would more likely have a significant effect in soils that more recently have been fertilized or cleared of dense alien *Acacia* or other legume stands (Schutz, 2003; Zink and Allen, 1998).

The relative costs of the different treatments point to woodchip mulch addition being uneconomical unless a free source is available close by (e.g. following the felling of woody alien species). However, the mulch material would require a high C:N ratio to have a beneficial effect (Cione et al., 2002) and therefore should not include N-rich foliage or seeds such as that of alien acacias. Herbicide and tilling treatments were much less expensive, but the herbicide was more cost-effective in suppressing weed cover.

In a study of invasive annual grass control at a West Coast renosterveld site, where indigenous bulbs are an important component of biodiversity, Musil et al. (2005) compared the costs and effectiveness of hand-clearing, mowing, pre-emergence herbicide and burning at two fire intensities. They found that the most cost-effective treatment that did not impact on indigenous bulbs was mowing prior to alien grass seed maturation. While this treatment may reduce the alien grass seed bank over time, in degraded fynbos ecosystems it would not reduce the cover and competition of existing stoloniferous weedy grasses and could therefore not be used to promote fynbos recruitment.

4.2. Implications of the results for fynbos shrub establishment

Earlier studies have suggested that control of herbaceous weeds is an important prerequisite for the recruitment of fynbos species (Vlok, 1988; Wilson, 1999; Holmes, 2005) and therefore it would be important in restoring degraded fynbos ecosystems. In this study, the herbicide sub-treatment improved establishment success of planted fynbos seedlings, particularly in combination with mulch addition. For *Protea* this was significantly correlated to sub-treatment effectiveness in reducing herbaceous weed cover. Weed monitoring indicated that the herbicide sub-treatment was the most influential via its effects on herbaceous weed cover and molerat activity.

The pot experiment indicated that mulch affects plant growth. For the local bioassay species, *P. scolymocephala*, mulched soil suppressed growth in bags, indicating that the species is adapted to slightly more nutrient-rich conditions, perhaps relating to the shale substratum underlying sand at Riverlands. By contrast, in *L. laureolum* from deep nutrient-poor sandy soils on the Cape Peninsula, mulch promoted growth in bags.

Tilling did not improve the establishment success of the planted seedlings at Riverlands, in contrast to the same treatment at an arid fynbos–karoo interface site which promoted indigenous species establishment from seed (Holmes, 2005). This suggests either that the annual weed seed bank was much higher at Riverlands, or else the wetter conditions here enabled annuals to more rapidly establish following tilling. Furthermore, owing to the highly competitive characteristics of the alien annual weeds recruiting after tilling (including grasses *Bromus driandrus* Roth. and *Lolium multiflorum* Lam.; and forb *Raphanus raphanistrum* L.) it is unlikely that fynbos species re-introduced by seed would establish in competition with dense stands of these annuals.

An unforeseen outcome of the trial was the importance of fossorial mammals in the establishment success of fynbos seedlings. Where molerats are active, the soil is vigourously tunneled and a large proportion of the surface is covered by mounds, effectively smothering planted seedlings. From observations at Riverlands, it appears that molerat populations target disturbed fynbos sites, and particularly patches supporting a dense cover of the stoloniferous grass, *C. dactylon*. Thus in lowland fynbos vegetation effective herbaceous weed control is required both to reduce competition from weeds and molerat activity. If molerat activity does not decrease when a larger area is herbicided, then some local control of these mammals will be needed until fynbos plants are well established.

4.3. Recommendations for future restorations of degraded Sand Fynbos sites

Soil-stored seed banks in lowland fynbos vegetation are less persistent than those in mountain fynbos vegetation (Holmes, 2002b) and seed dispersal distances in fynbos species generally are relatively short, with dispersal modes such as ant, ballistic, passive and wind predominating (Johnson, 1992). For these reasons, weed control alone is unlikely to facilitate recovery in degraded lowland fynbos sites, and it will be necessary to re-introduce species either by sowing or planting. Further research on suitable Sand Fynbos pioneer shrubs, that readily germinate and establish, would help to improve restoration success from sowing. However, dispersal of desirable species from adjacent natural remnants would be facilitated by synchronizing controlled burning of the remnants and the restoration site. Once a functional cover (i.e. a structurally-representative stand) of Sand Fynbos has re-established, so that the natural processes of dispersal and fire are re-instated, re-colonization of species from neighbouring intact fynbos stands should increase.

The following factors should be assessed prior to restoration in degraded lowland fynbos sites and suitable actions implemented as part of the restoration plan:

1. Vegetation clearance: if the site has not burnt for a few years, or if there is a dense layer of litter or dead grass, the site should be burnt in the late summer or early autumn season prior to plant re-introduction. This treatment will kill some of the surface annual weed seed bank and expose the soil in preparation for sowing or planting. If woody alien species are present, these should be cleared and the large branches removed before burning the site. If possible, synchronize with the controlled burning of adjacent natural remnants.
2. The composition of the vegetation: perennial and annual weeds should be controlled with an appropriate biodegradable, systemic herbicide, and any indigenous species present protected from herbicide drift. If a sowing treatment is planned, the timing of herbicide application may clash with optimal sowing time. In this case, the suggested compromise is to apply one herbicide treatment to both perennial and annual weeds in early winter (first half of June), a few days prior to the sowing treatment. For planting treatments, the herbicide could be applied a week or two later to target more of the annual weed crop prior to planting.
3. Soil total available N content: if it is less than double the reference condition (e.g. for Riverlands <500 μg/g in the surface soil (Yelenik et al., 2004; Stock and Lewis, 1986)), it is unlikely to impede fynbos seedling establishment; however higher concentrations may warrant remedial action via the addition of a C-rich mulch at a rate of 12 tonnes/ha.
4. The presence of molerat or gerbil colonies: these animals may have to be controlled for a few years to allow the establishment of fynbos species; in the case of gerbils, specifically to reduce seed predation following a sowing treatment. This is more likely to be important in small-scale (<1 ha) restorations.

5. Landscape and ecological factors that may influence recovery potential: for example, it will be necessary to protect the site from fire until the introduced fynbos species have established and set seed for a few years in order to replenish seed banks (a minimum of eight years) and also where necessary to control browsing by indigenous antelope (heavy browsing on bioassay species was noted during this trial). The latter may again be a scale-dependent effect (as in 4. above).
6. Invasive alien species, if present, should be controlled regularly to prevent seeding and re-establishment.

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