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Soil organic matter dynamics and nitrogen availability in response to site preparation and management during revegetation in tropical central Queensland, Australia

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Abstract

Purpose: There is considerable interest in finding a cost effective method of site preparation that effectively controls weeds during planting and further reduces the need for recurring herbicide applications. In this study, two weed control methods, herbicide and scalping, were examined. Both methods may have implications for SOM dynamics and nitrogen (N) which could consequently affect plant survival and vegetation establishment. This study aimed to investigate the dynamics of SOM, carbon (C) and N pools under site manipulation practices and the associated early plant survival and growth in tropical Australia.

Materials and methods: A field trial was established in Central Queensland to examine the recovery of SOM, C and N pools following scalping and the alternative site preparation technique of sequential herbicide application. Both were contrasted with control plots which received neither treatment. Plant survival and growth were also monitored to improve our understanding of plant response to site preparation practices.

Results and discussion: Scalped plots showed significantly lower values for labile C and N pools compared with the herbicide treatment and control. Generally, there was no significant difference between the herbicide and control for any of the parameters tested. Our observation indicated that herbicide application was significantly less effective than scalping to control weeds. A general decline in SOM parameters was observed in all the plots, including the control during the trial. Drought conditions were considered to be a major factor in the overall decline of SOM. Despite removal of the top soil, there was no significant difference in plant survival between herbicide and scalped areas (81% and 79% survival respectively). Plant growth was not affected by the treatments in the first six months when weed competition in the herbicide areas and low nutrient availability in the scalped plots would have been significant factors in controlling growth rates. However, plants in the herbicide areas, irrespective of species, showed stronger growth than those in the scalped plots at week 61 when they had outgrown the weed competition. It is likely that differences in plant growth response to treatments will become negligible over time.

Conclusions: Top soil removal was more effective than the use of herbicide in the long term control of weeds. However, lower SOM and N availability in the scalped areas did not affect plant survival rates when compared with that of the herbicide areas. Whilst the preservation of soil organic matter is considered to be vital in short term cropping systems, our results indicate that this is not the case for woody vegetation establishment and, in terms of cost and reduction of chemical use, removal of the organically rich top soil, with its accompanying seed burden may be both practical and desirable.

Keywords Herbicide application • Revegetation • Site management • Soil C and N pools • Soil organic matter • Top soil removal

1 Introduction

Infrastructure projects, mining and petroleum activities involve some degree of vegetation clearance leading to land degradation and biodiversity loss. Revegetation schemes are part of the response to vegetation destruction (Lamb et al. 2005) and there is a legislative obligation for such many infrastructure operations to revegetate or offset areas of destroyed vegetation leading to an improvement in ecosystem function and biodiversity. In many countries, including Australia, revegetation schemes are increasing (Paul et al. 2002). Approximately 52,000 ha of lands have been restored in north and east of Australia with rainforest and mixed hardwood planting (Erskine et al. 2005).

Site management practices (including weed control) are one of the main driving factors for revegetation success. These practices have the potential to alter soil biotic and abiotic conditions which could lead to an alteration in SOM and soil nutrient availability particularly C and N cycling (Tan et al. 2005; Xu et al. 2008). Weed control also accounts for the greatest expense associated with revegetation and there is considerable interest in finding a cost-effective method of site preparation that effectively controls weeds during planting and further reduces the need for subsequent herbicide applications.

SOM parameters such as available organic C, N and microbial biomass C and N are used to indicate soil quality and fertility (Schoenholtz et al. 2000; Singh et al. 2001; Chen and Xu 2005; Xu et al. 2008). Soil available C may facilitate N dynamics in soil leading to soil quality improvement as well as ecosystem productivity enhancement (Ibell et al. 2010; Moreira et al. 2011). Revegetation or plantation establishment may affect SOM dynamics and nutrient pools through different factors including: site management (Xu and Chen 2006; Huang et al. 2008a; Xu et al. 2008, 2009), climatic conditions, previous land use and soil characteristics (Paul et al. 2002; He et al. 2009). There is little known about the associated C and N dynamics in the soil under revegetation ecosystems particularly in Australia.

Herbicides control weeds and improve early establishment success (Powers and Reynolds 1999; George and Brennan 2002). However, these chemicals can also target soil micro-organisms, causing them to either stimulate (Araújo et al. 2003) or suppress (Busse et al. 1996; Busse et al. 2006) their activities leading to an alteration in C and N dynamics (Huang et al. 2008a, b; Ibell et al. 2010). Other equally efficient methods are required to reduce the reliance on herbicide application. One such is top soil removal (scalping) which may be considered as an alternative method of weed control at revegetation sites (Harper et al. 2008; Graham et al. 2009). Scalping may suppress weeds through removal of the seed bank, expose mineral nutrients, increase soil temperature and affect soil moisture (Spittlehouse and Childs 1990). These changed soil abiotic conditions may enhance or reduce soil microbial activities (Hendrickson et al. 1985) and may accelerate nutrient loss (Zabowski et al. 1994) and soil erosion leading to alteration of plant survival and vegetation establishment.

Site manipulations at revegetation sites seek to: decrease potential competitors and improve early survival (Benayas et al. 2002) and growth (MacDonald and Thompson 2003; Graham et al. 2009); manipulate soil conditions providing higher resource availability; and also maintain long-term productivity in the ecosystem. There are studies investigating SOM and nutrient dynamics under afforestation or plantation establishment (Paul et al. 2002; Zinn et al. 2002; Xu et al. 2008) but limited information is available regarding revegetation schemes in Australia. Therefore, this study aims to assess the impacts of site manipulation on SOM dynamics, N availability and early plant survival and establishment.

2 Materials and methods

2.1 Site description

The experimental site was located at Stanwell ($23^0$31’24 S, $150^0$18’14 E), approximately 25 km southwest of Rockhampton, central Queensland, Australia. Before plantation establishment, the site had a history of disturbance, being used previously for growing grapes and most recently as poor quality pasture. The soil is a sandy loam containing 22%, 12% and 66% clay, silt and sand content respectively. Total C (TC) was 1.90% and pH was 5.7. The average maximum monthly temperature of 28℃ ranged from 22℃ to 33℃ and rainfall of 620 mm were recorded for the period of this study (from June 2009 to August 2010). The site is sub-humid and precipitation occurred in only 4 months throughout the study period and for short period of time each month (Fig. 1).

The experiment was a randomized complete split block design with four blocks and 32 plots. The treatments were weed control (herbicide vs. scalping) and fertilisation regimes (fertilisation vs. non-fertilisation). Fertiliser was applied to individual plants and no significant difference was observed between fertilised and non-fertilised plots therefore soil sampling was conducted only in the herbicide and scalped areas with 8 replications. The 4 control plots were established in an area adjacent to the trial plots. The plots were 12 m × 12 m consisting of six planting rows and on average eight seedlings (tubestock) were planted at each row with 1.5 m × 1.5 m spacing. Prior to planting, each row was ripped to a depth of at least 30 cm. The three seedling species, *Acacia disparimma* (Fabaceae), *Melaleuca quinquenervia* and *Eucalyptus crebra* (both Myrtaceae), were planted randomly in the plots. In the herbicide plots, glyphosate was applied on two occasions before plantation establishment at normal rates within 60 days (April and June 2009) and the follow up spray after plantation was a monocotyledon specific herbicide called Verdict^{TM}540. In the scalped plots, approximately 10 cm of top soil was removed in the scalped plots to control weeds and decrease potential competition. No herbicide was applied in the control plots. Herbicide was applied two weeks prior to scalping in order to allow the herbicide to take effect on the weeds. All treatments were applied on sunny days under stable conditions.

2.2 Soil and plant sampling

Soil sampling was conducted six times over the period of 14 months from June 2009 to August 2010 at 1, 7, 16, 27, 36 and 61 weeks following the treatment application. The soil samples (0–5 cm) were collected at five positions in each plot using an auger (60 mm internal diameter). The sampled soils in each plot were bulked and well mixed. A sub-sample of the soil was air-dried and the rest was refrigerated at 4℃ and processed shortly after sampling within first month after sampling. Soils were passed through a 2-mm sieve prior to any analyses. At weeks 27 and 61, the number of surviving plants was recorded and the percentage of plant survival was calculated. Plant height (growth) was also recorded at weeks 27 and 61.

2.3 Soil analyses

Total C (TC), total N (TN), C isotope composition ($\delta^{13}C$) and N isotope composition ($\delta^{15}N$) of air-dried samples were determined. The air-dried soil was ground to a fine powder using a Rocklabs^{TM} ring grinder. Then, approximately 40 mg of ground soil was transferred to tin capsules (5 mm × 8 mm) to measure TC, TN, $\delta^{13}C$ and $\delta^{15}N$ using a mass spectrometer (GV Isoprime, Manchester, UK) according the method of He et al. (2008).

NH_4^+-N and NO_3^--N were determined by hot water extraction using a SmartChem 200 Discrete Chemistry Analyser (DCA). To measure potentially mineralisable N (PMN), briefly, two sub-samples (5 g) of air dried sample were weighed. One sub-sample were added to 25 ml water and incubated at 40℃ for seven days. After incubation, 25 ml of 4 M KCl was added to the samples and the suspension was shaken for 60 minutes and centrifuged for 20 min at 2000 rpm. After centrifuging, the samples were filtered by a Whatman No. 42 filter paper. The second sub-sample of soil was added to 50 ml of 2 M KCl and processed as above but without incubation. Inorganic N of both samples were determined using SmartChem 200

Discrete Chemistry Analyser (DCA) and the PMN was calculated as described by Blumfield et al. (2006). The non-incubated KCl extractions were also used to determine total organic C (TOC) and dissolved organic N (DON) using a Shimadzu TOC-$V_{CSH/CSN}$ TOC/N analyser (Chen and Xu 2005).

Labile C and N fractions were investigated using hot water extractable organic C (HWEOC) and total N (HWETN). Briefly, 35 ml water was added to 7 g of air-dried soil and the samples were incubated in a capped and sealed tube at 70℃ for 18 h. Following incubation, the suspension was shaken by an end-over-end shaker for 5 min followed by centrifuging at 10000 rpm for 10 min. The suspension was filtered through a Whatman 42 filter paper followed by filtering though a 33 mm Millex syringe-driven 0.45 µm filter. The concentration of filtered solution was measured using a Shimadzu TOC-$V_{CSH/CSN}$ TOC/N analyser (Chen and Xu 2005).

To measure microbial biomass C (MBC) and microbial biomass N (MBN), in brief, two 10 g sub-samples of fresh soil were weighed; one of the sub-samples was fumigated by chloroform for 24 h. Both fumigated and non-fumigated sub-samples were mixed with 50 ml of 0.5 M K_2SO_4 and the mixture was shaken with an end-over-end shaker for 30 min, followed by filtering through a Whatman 42 filter paper. The TOC and TON of both extractions were measured using a Shimadzu TOC-$V_{CSH/CSN}$ TOC/N analyser (Chen and Xu 2005). The MBC and MBN were derived as described by Vance et al. (1987) and Brookes et al. (1985) respectively.

2.4 Statistical analysis

Analysis of variance (ANOVA) was conducted to explore the dynamics of soil fertility parameters throughout the sampling period as well as plant survival and growth. The Tukey HSD test at $P<0.05$ was used to determine the significance of differences between the treatment means. A linear regression was performed to indicate the trend of SOM during the period of study. Statistix software (Version 8) was used for all the statistical analyses.

3 Results

3.1 Soil temperature and moisture

Soil temperature in the herbicide and scalped areas did not differ significantly at 5 cm depth. Soil temperature at the scalped areas was lower than the herbicide areas after week 27 (see Fig. 1). Soil moisture was significantly affected by site preparation ($P<0.05$) and scalped areas showed a significantly lower soil moisture than that of the herbicide and control plots.

The soil moisture, irrespective of site preparation, ranged from 1.71% and 6.50% without taking into account the soil moisture of week 36 (Fig. 2). At week 36, there was a significant rainfall which increased soil moisture significantly ($P<0.05$) in all treatments.

3.2 TC, $\delta^{13}C$,TN, $\delta^{15}N$ and C:N ratio

The herbicide and control plots had significantly higher TC than the scalped plots ($P<0.05$) in both weeks 1 and 61 (Table 1). TC did not vary significantly from week 1 to week 61, irrespective of the treatments, ranging from 1.78%, 1.10% and 1.85% at week 1, and 1.66%, 1.15% and 2.01% at week 61 in the herbicide, scalped and control plots respectively. $\delta^{13}C$ ranged from –19.2‰ to –20.4‰ and did not vary significantly in response to either site preparation method or sampling time. TN was significantly affected by site preparation at week 61 ($P<0.05$) but not at week 1 (see Table 1). TN in the control plots increased significantly over the period of study (0.10% vs 0.12%, $P<0.05$) whereas it declined in the herbicide (0.11% vs 0.10) and scalped plots (0.10% vs 0.07%, ns). $\delta^{15}N$ was significantly affected by site preparation ($P<0.10$) only at week 1 but not at week 61. In all treatments, $\delta^{15}N$ was significantly enriched at week 61 compared to week 1 ($P<0.05$). C:N ratio was significantly affected by site preparation only at week 1 ($P<0.05$) (see Table 1) and C:N ratio in the scalped areas was significantly lower than that of the herbicide and control plots. The C:N ratio significantly increased between week 1 and week 61 only in the scalped areas (11.5 vs 16.2; $P<0.05$). No significant difference was detected in C:N ratio of the herbicide and control plots between weeks 1 and 61 (see Table 1).

3.3 NH_4^+-N and NO_3^--N

NH_4^+-N and NO_3^--N were significantly affected by site preparation ($P<0.05$) (Table 2). NH_4^+-N dominated inorganic N in the herbicide and control plots whereas NO_3^--N was usually dominant in the scalped areas, except at weeks 27 and 61 (see Table 2). The scalped areas typically had an NH_4^+-N concentration around half that of the herbicide and control plots. The highest NH_4^+-N was observed at week 27 for all the treatments. The lowest value of NH_4^+-N was in the scalped plots, 26.8 µg g^{-1} observed at week 7 whereas the lowest concentration of NO_3^--N was in the control plots 1.88 µg g^{-1} indicated at the week 7 following the treatment applications (see Table 2).

3.4 PMN, DON, TOC, HWEOC and HWETN

PMN showed a significant response to site preparation ($P<0.05$). PMN of the scalped areas was significantly lower than that of the herbicide and control plots and no significant difference was observed between herbicide and control plots. PMN varied from 72.0 to 407 µg g^{-1} among all the treatments. DON, in general, did not show a significant response to site preparation and ranged from 9.64 to 36.9 µg g^{-1} (see Table 2). TOC was significantly affected by site preparation after week 16 ($P<0.05$) (Fig. 3a) and the scalped areas showed lower values than the herbicide and control plots. The scalped plots had significantly lower HWEOC and HWETN compared with the herbicide and control plots ($P<0.05$) (see Fig. 3b and c). No significant difference in HWEOC and HWETN was determined between the herbicide and control, with the only exception observed at week 27 when HWEOC in the herbicide plots were significantly lower than in the control plots, two thirds of the control values (322 µg g^{-1} vs 490 µg g^{-1} respectively). A significant decline in soil HWEOC and HWETN was observed in all the plots as indicated through a linear regression (Table 3) ($n=24$, $R^2=0.52$ and $R^2=0.37$ respectively, $P<0.05$).

3.5 MBC and MBN

The scalped plots had significantly lower MBC and MBN compared with the herbicide and control plots ($P<0.05$) (Fig. 4a and b). There was a significant difference in MBC between the herbicide and control plots only at week 16. MBC ranged from 108 µg g^{-1} to 396 µg g^{-1} and MBN from 10.8 µg g^{-1} to 49.8 µg g^{-1}. No significant difference in MBC between the herbicide and control plots was observed at weeks 36 and 61. A linear regression between sampling weeks and MBC/N showed a significant decline of MBC and MBN over the period of study as reflected through a linear regression (see Table 3) ($n=24$, $R^2=0.63$ and $R^2=0.36$ respectively, $P<0.05$).

3.6 Plant survival and growth

Plant survival, irrespective of plant species, was not significantly affected by site preparation at both weeks 27 and 61 (Fig. 5a). Plant survival significantly decreased between weeks 27 and 61, 19% and 20.2% reduction in the herbicide and scalping areas respectively, ($P<0.05$). The survival rate was 81% and 79.8% in the herbicide and scalping plots respectively at week 61. Plant growth (height), irrespective of plant species, did not vary significantly at week 27 and it was 51.8 cm and 51.2 cm in the herbicide and scalped areas respectively (see Fig. 5b). A significant difference of plant growth was evident at only week 61 ($P<0.05$). Plant growth in the herbicide areas was greater than that of the scalped areas, 114 cm and 92.1 cm respectively (see Fig. 5b).

4 Discussion

4.1 Effects of site preparation on SOM

The scalped plots showed significantly lower TC, TN, inorganic N, HWEOC, HWETN, MBC and MBN, compared with the herbicide and control plots. SOM is considered as a readily decomposable substrate which governs the metabolic activity of soil microbes (Janzen et al. 1992). Labile organic matter provides a readily available source of plant nutrients and enhances soil microbial activity (Xu et al. 2008; Ibell et al. 2010). Soil microbial activities are essential for maintaining soil quality (Bastida et al. 2007) and nutrient cycling and dynamics (Roldan et al. 1994). Therefore, any alteration associated with C and N inputs could affect other parameters in the soil. For instance, weed control in general could reduce the soil labile C pools due to decreased inputs of root exudates, root mortality and litter fall leachates (Li et al. 2004; Ibell et al. 2010).

In general, no significant difference in HWEOC, HWETN, MBC and MBN was observed between the herbicide and control plots. It implies that labile C and N input may have not decreased in the herbicide areas due to either weed recovery shortly after herbicide application or plant residue inputs after applying herbicide. The present results were consistent with others who observed no effect of herbicide on soil micro-organisms (Wardle and Parkinson 1991; Busse et al. 2001). Herbicides that target plant specific biochemical pathways, which are not found in soil micro-organisms, should have no significant effect on soil micro-organisms (Lupwayi et al. 2004). Verdict and glyphosate, herbicides used in this study, belong to ACCas enzyme (Secor and Cséke 1988) and aromatic amino acid biosynthesis (Lupwayi et al. 2004) inhibitors respectively. If these groups of herbicides are applied in field rates, they may not negatively affect soil microbial biomass and activity (Busse et al. 2001; Lupwayi et al. 2009).

Over period of the study, a significant decline in SOM was observed in all the plots, including the control areas, as reflected through a linear regression (see Table 3, $P<0.05$). Soil temperature and moisture were recorded throughout the trial. Soil temperature at 5 cm depth averaged 24℃ (19℃–33℃) and was not considered to be a limiting factor for microbial activity and SOM dynamics. The average temperature exceeded 30℃ during 2 months of the sampling period, the rest being lower than 27℃. However, soil moisture was very low, (2.10%–6.20%) with effective rainfall being recorded for only one month

(February 2010; week 36) providing an appropriate soil moisture. Soil moisture could be more important than soil temperature to govern changes in soil microbial properties (Chen et al. 2003). Therefore, in the present study, drought conditions are considered to be a major factor in the overall decline of SOM.

4.2 Effects of site preparation on soil N pools

N availability and dynamics were significantly affected by site preparation practices ($P<0.05$). Soil disturbance may increase N availability especially when soil temperature and moisture are optimised as indicated in other studies (Blumfield and Xu 2003; Ibell et al. 2010) or when C supply is not limited. However, this newly available N following soil disturbance could be easily lost through leaching or volatilisation (Vitousek et al. 1992). Significantly greater $\delta^{15}N$ at week 61 in all treatments may also suggest that plant residues in the soil may have been enriched in $\delta^{15}N$ as a consequence of microbial activities and loss of lighter N (Connin et al. 2001; Asada et al. 2005). Soil moisture is an important factor to alter soil N availability and mineralisation (Smithwick et al. 2005; Qi et al. 2011; Zhang et al. 2011). Soil moisture enhancement could increase microbial activity leading to greater N availability. At week 36, there was a significant rainfall event which combined with low seasonal temperatures may have resulted in a durable increase in soil moisture leading to an increased soil N availability through N mineralisation as observed in the higher increased NH_4^+-N and PMN at week 61 (see Table 2). However, increased soil moisture accelerated loss of NO_3^--N at week 61(see Table 2). This newly available N and microbial activity may have resulted in an increased $\delta^{15}N$ in all treatments at week 61.

Despite the fact that NH_4^+-N was dominant in the herbicide areas, NO_3^--N availability in both herbicide and scalped areas was significantly higher than that of the control plots. NO_3^--N could be easily lost if it is not either immobilised by soil microbes or taken up by plants because it is mobile (Nadelhoffer et al. 1994). C:N ratio of the scalped areas significantly increased from week 1 to week 61. C:N ratio is used to indicate soil fertility and N availability and is important for plant growth (Shi et al. 2010) as well as soil microbial activity (Gurlevik et al. 2004). C:N ratio enhancement may suggest an N limitation in the ecosystem (Burton et al. 2010). Increased C:N ratio in the scalped areas occurred due to N loss because C did not change. Significant rainfall at week 36 may have accelerated N loss through leaching in the scalped areas leading to increased C:N ratio at week 61.

4.3 Effects of site preparation practices on plant survival and growth

Despite the fact that, in the scalping treatment, a majority of organic matter and microbial community was removed, the survival rate did not vary significantly between herbicide and scalping treated areas. The survival rate was similar irrespective of plant species, 79.8% and 81% survival in the scalped and herbicide areas respectively, at week 61. Weed competition (Benayas et al. 2002; Rey Benayas et al. 2005; Amishev and Fox 2006) and first growing season conditions (Rey Benayas et al. 2005) could be considered as the two most important factors influencing plant survival. In the present study, environmental conditions were harsh with a long period of drought and soil moisture in the scalped areas was significantly lower than that of the herbicide areas. On the other hand, weed recovery in the scalped areas was always less than 50%, according to our observation, compared to 100% recovery of weeds in the herbicide areas shortly after herbicide application. Therefore, a better soil moisture availability in the herbicide areas and lack of weed competition in the scalped areas may explain lack of differences of seedling survival in these two treatments. Approximately, 20% of seedling mortality at both herbicide and scalped areas was observed which could be due to drought conditions in the first growing season. Despite the lack of a significant influence on seedling survival, there was a better growth response to the higher SOM and N availability in the herbicide areas compared to the scalped areas once the plants overcame the initial weed competition. Plant growth was significantly affected by the treatments at week 61 ($P<0.05$) but not at week 27, during the first 6 months after plot establishment, when weed competition would have been a significant factor in growth rates particularly in the herbicide areas. Lower growth demonstrated in the scalped areas may have been due to rapid water loss from the exposed soil surface (Flint and Childs 1987) and also lower nutrient availability (Mallik and Hu 1997). Scalping did not significantly reduce survival rates compared to herbicide treatment though there was a significant effect on seedling growth. How this translates to overall growth differences over time remains to be seen.

5 Conclusions

Top soil removal was more effective than the use of herbicide in the long term control of weeds. However, SOM and nutrient availability were significantly impacted by this site preparation technique, demonstrating much lower indicators of soil fertility. SOM had not recovered 61 weeks after the soil disturbance and a general decline of SOM was also observed throughout the sampling period. While the preservation of SOM is important in agriculture, it may not be so in long-term woody vegetation establishment and a cost benefit analysis over time may prove that benefit from removal of the seed bank far outweighs the disadvantages of removing the SOM rich top soil particularly when plant survival and growth are not affected.

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Table 1 Total C (TC), total N (TN), C:N ratio, C isotope composition (δ^{13}C) and N isotope composition (δ^{15}N) in the presence of different site preparation techniques. Means followed by the lower and upper case letters within the same week demonstrate the significance at the level *P*<0.05 and *P*<0.10 respectively

Treatments	TC (%)	TN (%)	C:N ratio	δ^{13}C (‰)	δ^{15}N (‰)
Following treatment application					
Week 1					
Control	1.85 (0.13)a	**0.10 (0.00)a**	18.5 (1.30)a	-20.4 (0.65)a	**3.72 (0.42)A**
Herbicide	1.78 (0.09)a	0.11 (0.001)a	15.8 (0.64)a	-19.6 (0.28)a	**3.82 (0.41)A**
Scalping	1.10 (0.05)b	**0.10 (0.00)a**	**11.5 (0.48)b**	-19.3 (0.30)a	**2.68 (0.26)B**
Week 61					
Control	2.01 (0.07)a	**0.12 (0.006)a**	16.2 (0.46)a	-19.4 (0.97)a	**5.23 (0.40)a**
Herbicide	1.66 (0.07)b	0.10 (0.003)b	15.8 (0.32)a	-19.3 (0.41)a	**5.77 (0.09)a**
Scalping	1.15 (0.04)c	**0.07 (0.003)c**	**16.2 (0.36)a**	-19.2 (0.37)a	**5.90 (0.12)a**

Paired bold values demonstrate that treatment means are significantly different between the week 1 and the week 61 at the level *P*<0.05.

Values in parentheses indicate standard errors (*n*=8)

Table 2 $NH4^{+}$-N, NO_3^{-}-N, potentially mineralisable N (PMN) and dissolved organic N (DON) in response to different site preparation techniques over 61 weeks following the treatment application. Means followed by the lower and upper case letters at the same week demonstrate the significance at the level *P*<0.05 and *P*<0.10 respectively. Values in parentheses indicate standard errors

Treatments	NH_4^{+}-N (µg g^{-1})	NO_3^{-}-N (µg g^{-1})	PMN (µg g^{-1})	DON (µg g^{-1})
Following treatment application				
Week 1				
Control	58.4 (3.93)ab	13.9 (2.90)b	195 (30.8)a	17.0 (4.84)a
Herbicide	67.1 (10.2)a	23.9 (5.61)ab	204 (14.8)a	22.3 (3.70)a
Scalping	28.4 (3.04)b	38.6 (6.48)a	72.0 (11.4)b	26.7 (2.13)a
Week 7				
Control	47.1 (7.82)a	1.88 (0.44)c	225 (24.9)a	14.3 (0.38)a
Herbicide	49.0 (3.76)a	17.9 (3.95)b	235 (14.6)a	18.8 (1.22)ab
Scalping	26.8 (2.02)b	34.4 (2.90)a	105 (14.0)b	21.8 (1.17)a
Week 16				
Control	79.6 (12.1)a	3.10 (1.02)b	345 (26.3)a	15.8 (4.20)a
Herbicide	56.5 (2.93)b	50.4 (7.82)a	284 (14.8)a	20.1 (0.92)a
Scalping	37.5 (1.92)c	64.3 (4.55)a	138 (13.3)b	20.4 (1.50)a
Week 27				
Control	89.9 (8.72)a	2.13 (0.85)b	407 (24.5)a	16.4 (2.82)B
Herbicide	147 (53.5)a	78.7 (22.2)a	258 (24.2)b	36.9 (12.5)A
Scalping	70.2 (14.7)b	59.5 (18.9)a	114 (16.6)c	35.8 (6.30)A
Week 36				
Control	52.6 (5.30)a	23.9 (8.43)a	200 (37.6)a	9.64 (0.17)a
Herbicide	46.4 (3.39)a	42.7 (5.47)a	136 (32.0)a	13.0 (1.04)a
Scalping	28.2 (1.62)b	41.0 (13.0)a	30.8 (6.51)b	11.4 (1.18)a
Week 61				
Control	62.4 (11.8)a	4.50 (1.20)b	230 (40.3)a	9.97 (0.95)a
Herbicide	54.3 (1.93)a	28.8 (5.31)a	175 (34.6)a	11.3 (1.06)a
Scalping	31.7 (1.70)b	23.1 (3.96)a	66.7 (6.25)b	9.46 (0.66)a

Table 3 Linear regression between time of sampling and SOM parameters (*n*=24)

Dependent	Coefficient	R^2	F values	Probability
HWEOC	-0.03	0.52	24.3	0.000
HWETN	-0.004	0.37	13.2	0.001
MBC	-0.03	0.63	38.1	0.000
MBN	-0.25	0.36	12.6	0.001

Fig. 1 Monthly rainfall (mm) and mean temperature (℃) at 5 cm depth in herbicide (H) and scalped (S) plots of the experimental site located at Stanwell, central Queensland Australia from June 2009 to August 2010

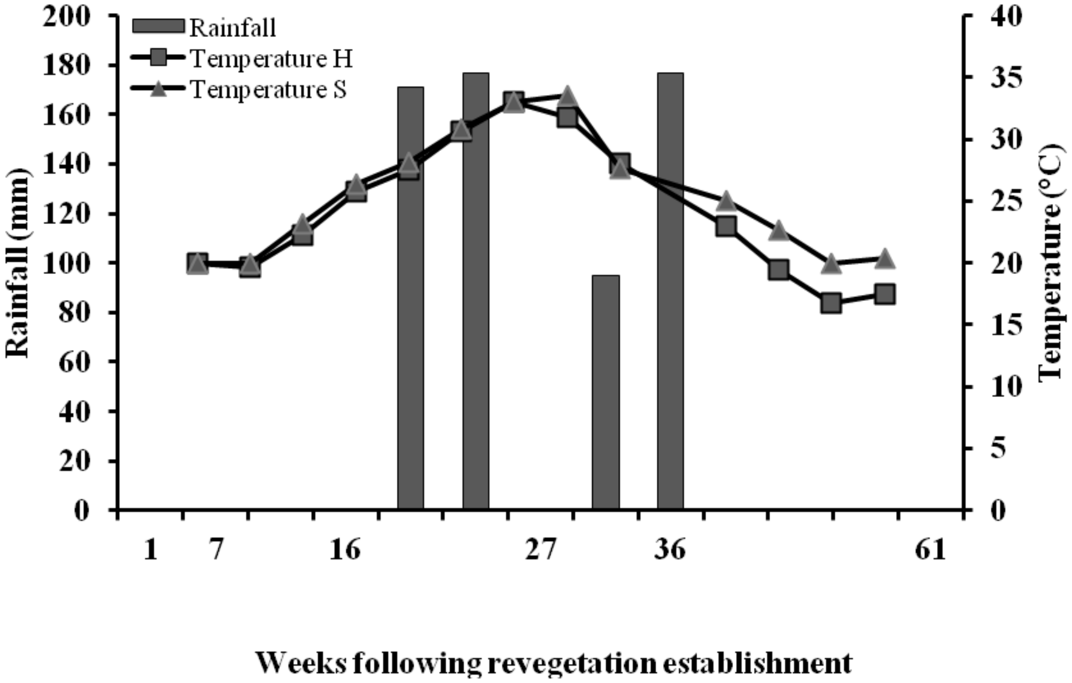
Fig. 2 Soil moisture (%) over 61 weeks after applying herbicide and scalpin

Fig. 3 The dynamics of a) total organic C (TOC), b) hot water extractable organic C (HWEOC) and c) hot water extractable total N (HWETN) over 61 weeks after applying site prepration practices. Different lower case letters at each sampling week indicate a significant difference at level *P*<0.05. Similar lower case letters at each sampling week demonstrate a non significant difference

Fig. 4 The dynamics of a) microbial biomass C (MBC) and b) microbial biomass N (MBN) over 61 weeks applying site prepration practices. Different lower case letters at each sampling week indicate a significant difference at level *P*<0.05

Fig. 5 Plant survival rate (a) and growth (b) at weeks 27 and 61 following plot establishment. Different lower case letters at each sampling week denote a significant difference at level *P*<0.05. Similar lower case letters at each sampling week demonstrate a non significant difference

Fig. 1



Rainfall
Temperature H
Temperature S
Rainfall (mm)
200
180
160
140
120
100
80
60
40
20
0
Temperature (°C)
40
35
30
25
20
15
10
5
0
1
7
16
27
36
61
Weeks following revegetation establishment

Fig. 2

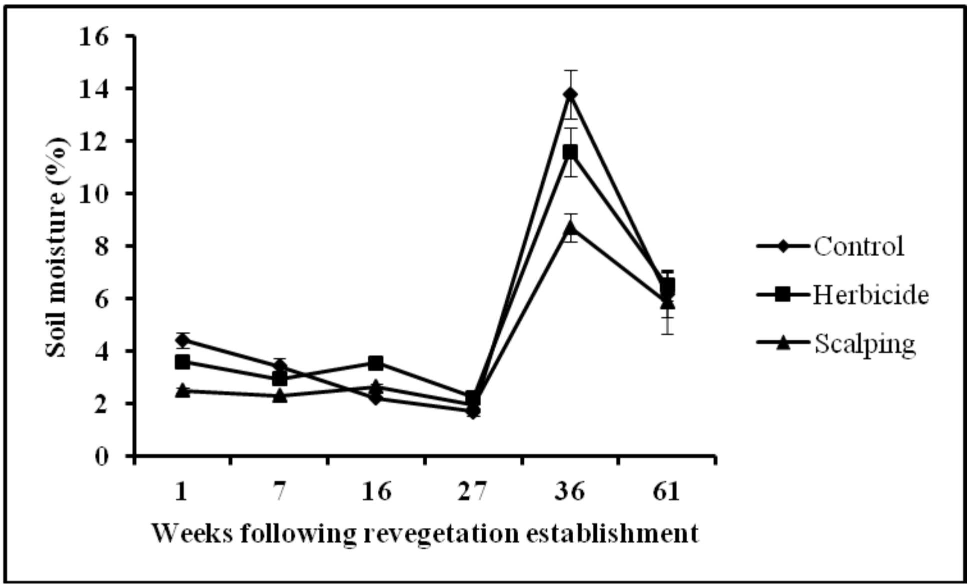

16
14
12
10
8
6
4
2
0
Soil moisture (%)
1
7
16
27
36
61
Weeks following revegetation establishment
Control
Herbicide
Scalping

Fig. 3

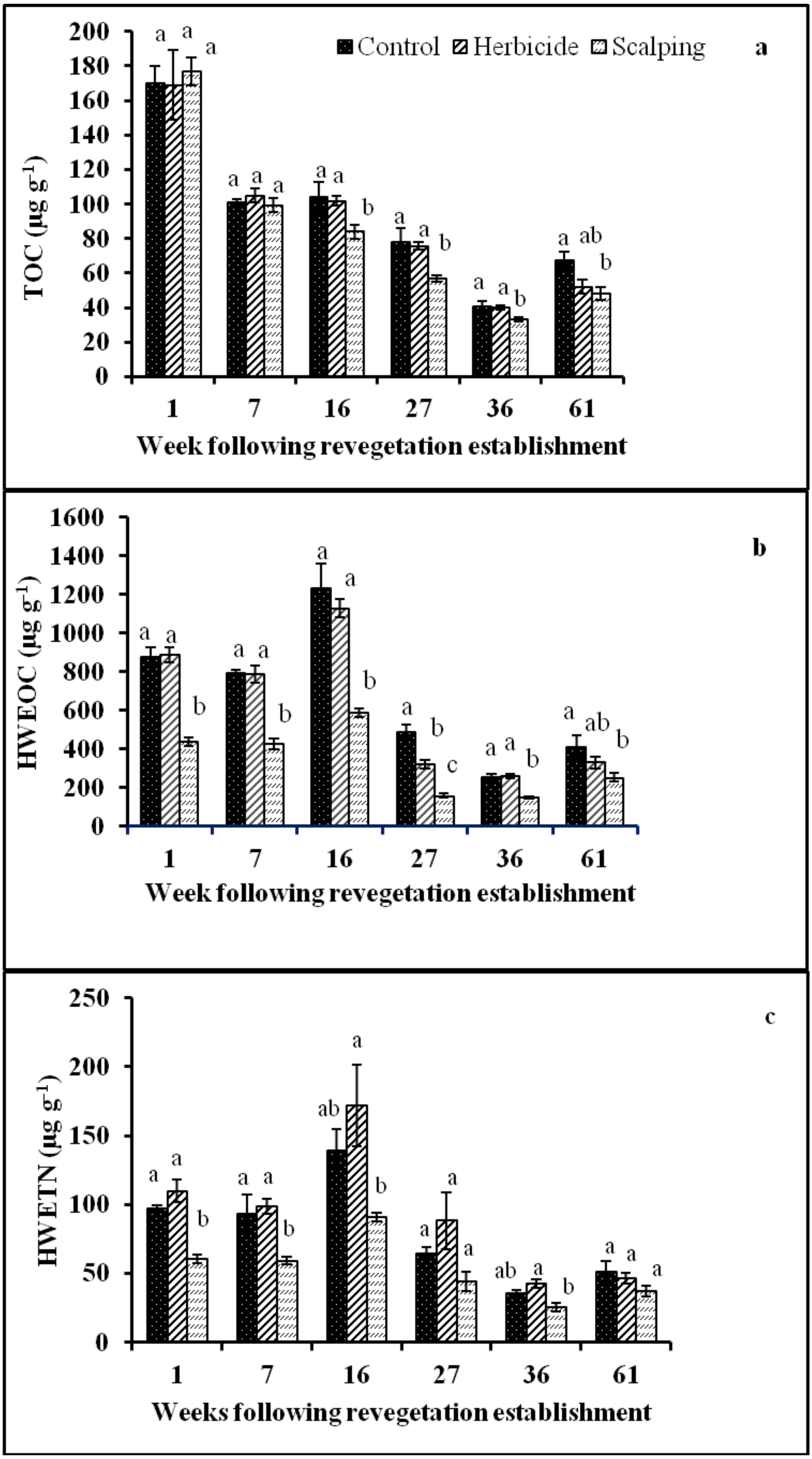

a
TOC (µg g^{-1})
200
180
160
140
120
100
80
60
40
20
0
■ Control ▨ Herbicide ▤ Scalping
a a a
a a a
a a b
a a b
a a b
a ab b
1
7
16
27
36
61
Week following revegetation establishment
b
HWEOC (µg g^{-1})
1600
1400
1200
1000
800
600
400
200
0
a a b
a a b
a a b
a b c
a a b
a ab b
1
7
16
27
36
61
Week following revegetation establishment
c
HWETN (µg g^{-1})
250
200
150
100
50
0
a a b
a a b
ab a b
a a a
ab a b
a a a
1
7
16
27
36
61
Weeks following revegetation establishment

Fig. 4

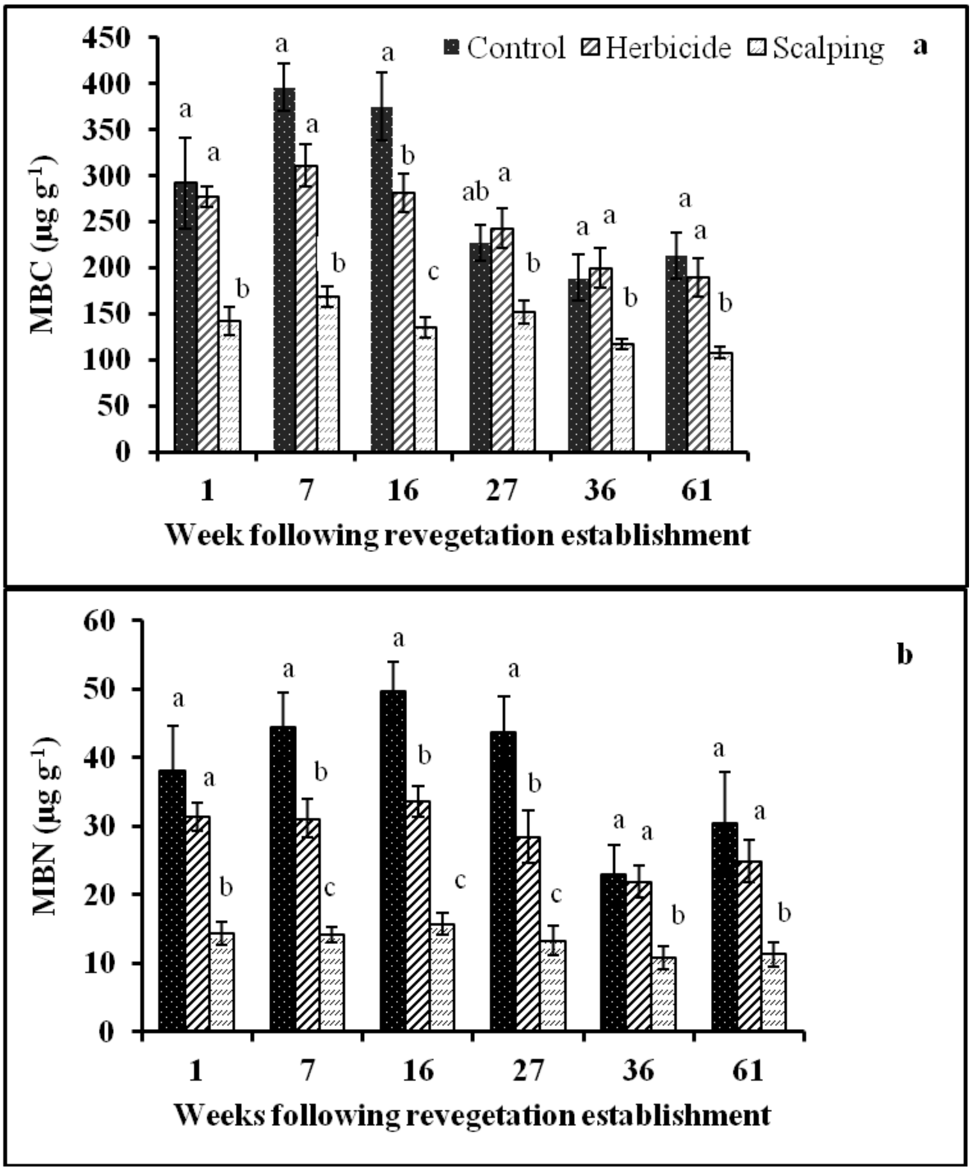
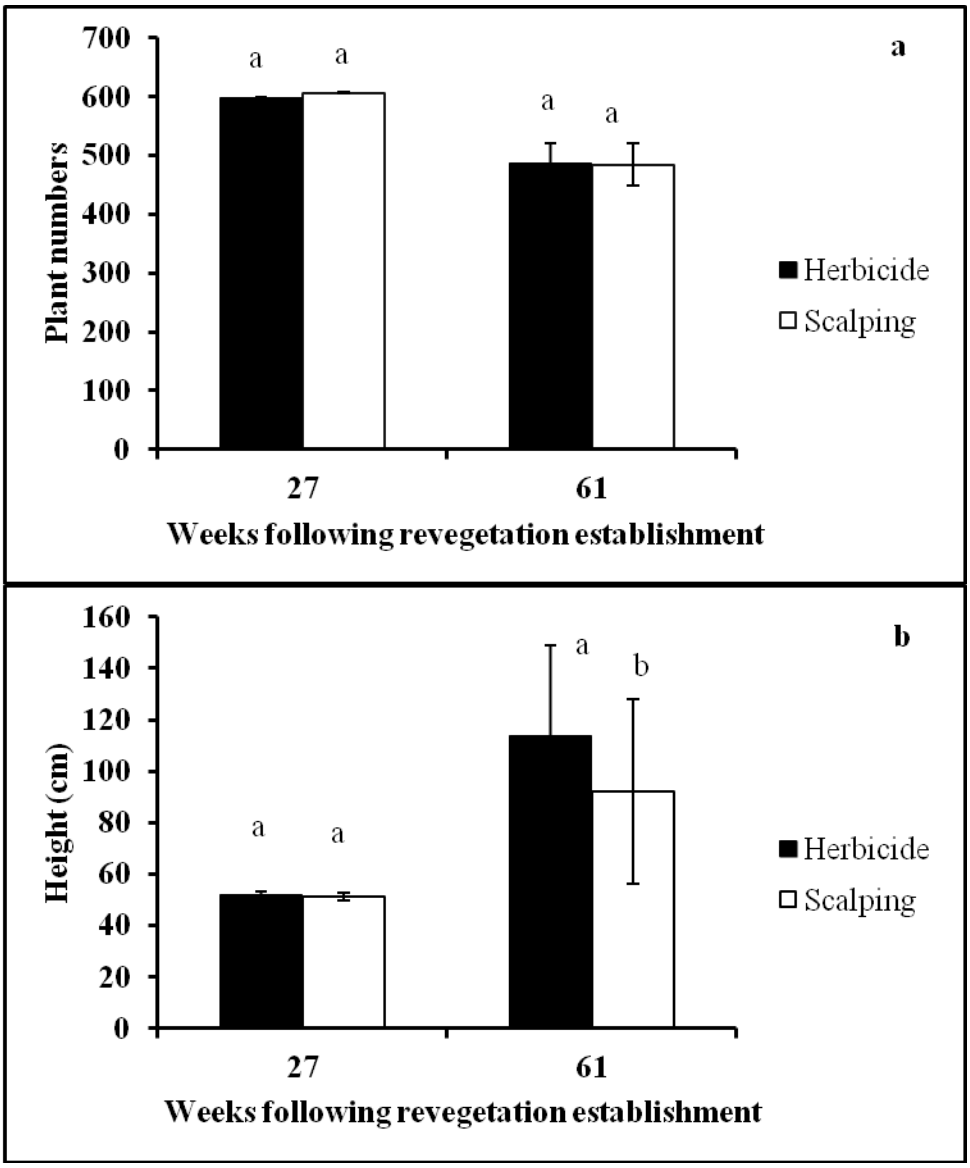

a
Control
Herbicide
Scalping
MBC (µg g^{-1})
0
50
100
150
200
250
300
350
400
450
1
7
16
27
36
61
Week following revegetation establishment
b
MBN (µg g^{-1})
0
10
20
30
40
50
60
1
7
16
27
36
61
Weeks following revegetation establishment

Fig. 5


a
Plant numbers
700
600
500
400
300
200
100
0
a
a
a
a
Herbicide
Scalping
27
61
Weeks following revegetation establishment
b
Height (cm)
160
140
120
100
80
60
40
20
0
a
a
a
b
Herbicide
Scalping
27
61
Weeks following revegetation establishment