The impact of mulch type on soil organic carbon and nitrogen pools in a sloping site

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Abstract

Three mulch treatments were tested for their ability to control erosion on a sloping site. Additionally, choice of mulch can also enhance revegetation success and improve soil organic matter input. This study aimed to investigate the effects of three mulching treatments, hydro-seeding, granite mulch and forest mulch, on soil C and N pools at different positions on highly erodible slope with approximately 30% gradient. Soil moisture, total C (TC), total N (TN), hot-water extractable organic C (HWEOC), hot-water extractable total N (HWETN), microbial biomass C and N (MBC and MBN), inorganic N and potentially mineralisable N were measured. All variables were significantly higher in soils amended with forest mulch than those with hydro-seeding and granite mulch, for the same slope positions. Soil moisture was significantly higher in the lower slope position than middle and upper slope positions in hydro-seeding and granite mulch treatments whereas no slope effect was observed on soil moisture under the forest mulch application. In the forest mulch treatment, the upper slope position had higher soil TC, TN, HWEOC, HWETN, MBC, MBN, NO_3^--N and total inorganic N (TIN) than the

middle and lower slope positions. Five years following mulch application, forest mulch still exerted a significant influence on soil fertility compared to the other treatments and the influence on soil moisture suggests that this treatment would be the most effective in the control of water-driven soil erosion on this steep site.

Introduction

Mulching is a technique widely used in horticulture to control weeds and, more importantly, to prevent loss of soil moisture. Depending on the type of mulch used, mulching preserves soil water and consequently promotes seedling establishment (Benigno et al. 2012; Woods et al. 2012) mainly by reducing the soil surface exposure to direct solar radiation. This is particularly important in Australia, where drought is a common environmental condition (Samyn and De Vos 2002; Close and Davidson 2003). There are clear benefits for using mulching as a site preparation technique in other areas of agriculture. It has been estimated that up to 90% of seedling mortality may be due to drought and this is regarded as one of the main causes for land rehabilitation failure in Australia (Benigno et al. 2012). Mulch also works to reduce soil temperature thereby increasing seedling survival under extreme conditions (Murungu et al 2011). Personal observation in field conditions in south east Queensland has shown a reduction in soil surface temperature of 10°C under a 10 cm layer of organic mulch (pers comm Blumfield).

Mulch may also play an important role in controlling erosion on steep slopes and consequently contribute to the establishment of vegetation for the control of soil erosion. The success of revegetation is particularly crucial in steep areas subjected to rainfall driven erosion which can lead to the loss of soil structure (Gholami et al. 2013; Shi et al. 2013). Disturbed slopes in particular are more vulnerable to soil erosion (Grismer and Hogan 2005b). When soil is transported by water movement, valuable nutrient and organic matter are either lost from the site or accumulate in the lower slope position. For instance, Tsui et al. (2004) reported higher nutrient availability such as calcium (Ca) and magnesium (Mg), in the lower slope position but lower organic C and available N in a rainforest in Taiwan. Mulch application may therefore play an important role in improving soil quality in revegetated areas. It has been shown that mulching prevents further loss of soil in slopes (Gholami et al. 2013; Shi et al. 2013). In a study, straw mulch was applied (0.5 g m^{-2}) and it decreased soil erosion and runoff significantly (Gholami et al. 2013). Revegetation of slopes without mulching was not as effective as revegetation with mulching to alleviate soil loss and water runoff due to inadequate ground coverage in the absence of mulching (Grismer and Hogan 2005a).

Mulching may affect soil organic matter (SOM) through decomposition and soil moisture preservation (Youkhana and Idol 2009). The materials used in organic mulches contain a high percentage of organic matter which can be incorporated in soil and improve soil properties including the size and activity of the soil microbial community (Huang et al. 2008a; Chaparro et al. 2012). Inorganic and synthetic mulches do not have a high organic matter content, but they may improve soil properties through soil water preservation which accelerates soil organic matter decomposition. Different studies have shown an improvement in SOM due to mulching under different tree systems including plantation (Huang et al. 2008a, 2008b) and forest (Barajas-Guzmán et al. 2006). In this study, three different mulch treatments were originally applied to stabilise the surface of a highly erodible slope and assess whether mulching is an effective approach to mitigate the effects of slope. We hypothesised that these treatments would have a significant effect on the soil moisture, C and N pools and consequently on the ability of these areas to support revegetation.

Materials and methods

Site description and treatments

The experimental site was located at Stanwell (23°31′24 S, 150° 18′14 E), approximately 25 km southwest of Rockhampton, central Queensland, Australia. The rainfall recorded for 2012 for this region was approximately 780 mm with average maximum daily temperate of 28°C. The experimental site was established in 2007. The experimental area had a uniform slope of approximately 30% and the slope was divided into nine plots each 10 m × 34 m and treatment layout was a complete block with three replications. Three different mulching treatments were applied, namely, hydro-seeding, granite mulch and forest mulch. Hydro-seeding is a standard technique where the seeds are mixed with a slurry of fibrous material, often paper waste, and then sprayed on to the site. The Hydro-seeding component failed with no germination of the native trees species that were applied and this area was subsequently colonised by native grasses dominated by *Bracteantha bracteata* (Asteraceae). Despite the fact that hydro-seeding failed, we decided to include the data from this treatment because it had become a *de-facto* control having received the same site preparation but without the introduction of the ground-cover, shrubs and trees that the other 2 treatments received. Tube-stocks were planted in to the granite and forest mulch and regularly irrigated for the first 6 months. Plants were locally available native species including *Breynia oblongifolia* Muell.Arg. APNI (Phyllanthaceae), *Acacia podalyriifolia* A.Cunn. ex G.Don APNI (Fabaceae) and *Backhousia citriodora* F. Muell (Myrtaceae); all plots were covered by the same plant species at the same plant density to remove the effect of vegetation on soil properties. The granite mulch consisted of particles of granites around 100-150 mm in size to a nominal 100 mm depth; as far as possible gaps between the rocks were avoided. The forest mulch was standard mulch available from landscape suppliers applied to the soil surface to a thickness of 100 mm. The soil was a sandy loam containing 21%, 13% and 66% clay, silt and sand content respectively. Neither mulch treatment nor slope position significantly affected soil pH and on average hydro-seeding, granite and forest mulch had pH of 5.47, 5.70 and 5.98 respectively.

Soil sampling and analyses

Soil sampling was undertaken in August 2012, 5 years following mulch application. Each plot was divided into upper, middle and lower slope positions. At each slope position, three soil cores were collected across the plot and samples were bulked and well mixed. Samples were taken at 0-10 cm depth. All soils were passed through a 2-mm sieve. A sub sample of each soil was air-dried and the rest refrigerated at 4°C and processed shortly after sampling.

Air-dried soil samples were ground to a fine powder by a Rocklabs™ ring grinder. The homogenised powder was used to measure total C (TC), total N (TN), C isotope composition ($\delta^{13}C$) and N isotope composition ($\delta^{15}N$) using an isotope ratio mass spectrometer (GV Isoprime, Manchester, UK).

Hot-water extractable organic C (HWEOC) and hot-water extractable total N (HWETN) were determined using 7 g of air dried soil which were added to 35 ml deionised water and incubated in a capped and sealed tube at 70°C for 18 h. Following incubation, the suspension was shaken by an end-over-end shaker for 5 min followed by centrifuging at × 6708 g for 10 min. The suspension was filtered through a 33 mm Millex syringe-driven 0.45 µm filter. The concentration of total organic C (TOC) and total soluble N (TSN) in the filtered solution was measured using a Shimadzu TOC-$V_{CSH/CSN}$ TOC/N analyser (Chen and Xu 2005).

The fumigation-extraction method was used to measure microbial biomass C and N (MBC and MBN). Two sub-samples of fresh soil (10 g) were weighed (for direct extraction and fumigation). One of the sub-soil samples was fumigated by chloroform for 24 h. Both fumigated and non-fumigated (directly extracted) sub-samples received 50 ml of 0.5 *M* K_2SO_4 and the mixture was shaken with an end-over-end shaker for 30 minutes, followed by filtering through a Whatman 42 filter paper. The TOC and TSN 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 from the equations as described in Vance et al. (1987) and Brookes et al. (1985), respectively.

Soil NH_4^+-N and NO_3^--N were determined in a 2 *M* KCl extraction using a SmartChem 200, Discrete Chemistry Analyser (DCA) and total inorganic N (TIN) was the sum of these two parameters. To measure potentially mineralisable N (PMN), briefly, two sub-samples (5 g) of air dried sample were weighed. One sub-sample was added to 25 ml water and incubated at 40ºC for seven days. After incubation, 25 ml of 4 *M* KCl were added to the samples and the suspension was shaken for 60 min and centrifuged for 20 min at × 358 g. 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 difference in inorganic N content between the incubated and non-incubated samples was considered to be the PMN (Blumfield et al. 2006).

Statistical analysis

A factorial multivariate analysis was carried out to detect the effects of mulching and slope as main effects on soil moisture, TC, TN, C and N isotope composition, HWEOC, HWETN, MBC, MBN, NH_4^+-N NO_3^--N, TIN and PMN. A correlation among all variables was performed (n=27) and all analyses were performed in IBM SPSS Statistics (Version 21).

Results

Soil moisture was significantly higher in the forest mulch treatment than the hydro-seeding and granite mulch treatments. Where hydro-seeding and granite mulches were applied, soil moisture was significantly higher in the lower slope position than in middle and upper slope positions (P<0.05; Fig. 1). Interaction between mulch treatments and slope was not significant.

Soil amended with forest mulch had significantly higher TC followed by granite and hydro-seeding in all three positions of the slope. Soil TC differed significantly according to slope position only in the forest mulch treatment, and upper slope had significantly greater TC than middle and lower slope positions (Table 1). Interaction between mulch treatment and slope was also significant for this variable.

Soil δ^{13}C was significantly more enriched in the forest mulch treatment compared to the other two mulch treatments and there was no significant difference in soil δ^{13}C between hydro-seeding and granite mulch treatment. Slope effect was significant only in hydro-seeding with the middle and lower slope positions having higher $\delta^{13}C$ than the upper slope position. No effects of slope on soil $\delta^{13}C$ were observed in either granite or forest mulch treatment.

Soil TN was significantly greater under forest mulch application regardless of slope position (*P*<0.05; Table 1). Soil TN was significantly larger in the upper slope of the forest mulch treatment than in the middle and lower positions. There was no significant difference between slope position in soil TN of hydro-seeding and granite mulch treatments. A significant interaction between mulch and slope position was observed for soil TN.

Forest mulch showed the highest soil $\delta^{15}N$ in the upper slope position followed by granite and hydro-seeding mulches. There was no significant difference in soil $\delta^{15}N$ among mulch treatments in the middle and lower slope position. Soil $\delta^{15}N$ was significantly affected by slope position in hydro-seeding mulch treatment but not in the granite or forest mulch treatment. In the hydro-seeding mulch, middle slope position had highest soil $\delta^{15}N$ compared to the upper and lower slope position.

Forest mulch had significantly greater HWEOC than the other two mulch treatments at all three slope positions (*P*<0.05; Table 2). Slope position did not affect soil HWEOC in hydro-seeding and granite mulch treatments. However, in the forest mulch treatment, upper slope position showed the highest HWEOC compared to the middle and lower slope position (*P*<0.05; Table 2).

Forest mulch showed significantly higher HWETN than that of the hydro-seeding and granite regardless of slope positions (*P*<0.05; Table 2). There was no effect of slope position in soil HWETN in hydro-seeding and granite mulches. However, HWETN was affected by slope position in the forest mulch with the upper slope position having the highest HWETN than the middle and lower slope positions.

Soil MBC was significantly higher in the forest mulch than under the hydro-seeding and granite in the upper and lower slope position (*P*<0.05; Table 2). No significant difference in MBC was observed in the middle slope position among all three treatments. Slope effect was observed only in the forest mulch with the highest MBC in the upper slope position.

Soil amended with forest mulch had higher MBN than hydro-seeding and granite in the upper and lower slope positions but not in the middle position (*P*<0.05; Table 2). There was also a significant slope effect on soil MBN in the forest mulch and middle slope position showed the lowest MBN compared to the upper and lower slope position. Interaction between mulch treatment and slope position was significant for MBN.

Soil under the forest mulch had significantly greater NH_4^+-N than under the hydro-seeding and granite mulches in all three slope positions (*P*<0.05; Table 3). The effect of slope position was not significant in any of the three mulches. Soil NO_3^- -N concentration was significantly higher in the upper slope position of the forest mulch (*P*<0.05; Table 3) whereas there was no significant difference in soil NO_3^- -N concentration in the middle and lower slope position among all three mulch treatments. Slope effect was only significant in the forest mulch but not in the hydro-seeding and granite. In the forest mulch, soil NO_3^- -N concentration was significantly higher in the upper slope position than in the middle and lower slope position. Interaction between mulch treatment and slope was significant for soil NO_3^- -N.

Soil TIN was significantly higher under forest mulch than hydro-seeding and granite in the upper slope position (*P*<0.05; Table 3) with no significant difference observed among mulch treatments in the middle and lower slope position. In the forest mulch, soil TIN was also significantly greater in the upper slope position than in the middle and lower slope position. There was no significant effect of slope position in soil TIN in the hydro-seeding and granite mulch. A significant interaction of TIN between mulch and slope position was also observed in this study.

Whilst soil PMN was significantly higher in the forest mulch compared to the hydro-seeding and granite mulch treatments regardless of slope position (*P*<0.05; Table 3), soil PMN was affected by slope position only in the hydro-seeding treatment (*P*<0.05; Table 3), being the highest in the upper slope position followed by lower and middle slope positions. No interaction was found between mulch treatments and slope position.

The correlation among soil variables indicated that soil variables including TC, TN, HWEOC, HWETN, MBC, MBN, TIN and PMN were strongly correlated and their correlation with soil moisture was not as strong (*P*<0.05; *n*=27; Table 4)

Discussion

In the present study, forest mulch significantly improved soil moisture compared with hydro-seeding and granite and this is especially beneficial in ecosystems subjected to chronic drought such as Central Australian landscapes. Increased soil moisture by mulching has been shown in different studies (Huang et al. 2008a; Benigno et al. 2012) as mulch prevents soil exposure to solar radiation and also decreases soil evaporation. The organic matter of forest mulch is incorporated into the soil, improving soil organic matter content and therefore the ability to absorb and retain moisture when compared to soil with lower organic matter content. A trial, involving different sizes of gravel, with diameters of 0.5 cm, 2.5 cm and 4.5 cm, used for mulching found that soil under larger size gravel lost water slower than under the smaller gravel size (Yuan et al. 2009). A previously cited study found that gravel mulch of 5 cm size was able to decrease soil evaporation up to 85% (Kemper et al. 1994). However, in our study, the granite size varied between 10 and 15 cm and was less effective than forest mulch at soil moisture retention, probably due to the larger voids that occur as the size of stones increases. Small size gravel may have a better coverage compared to large size gravel used in our site but using small size gravel in steep areas may be problematic because they are likely to move easily and accumulate at the bottom of slope. The mulch involved in hydro-seeding typically disappears within a few months (Robichaud et al. 2013) and the close similarities between hydro-seeding and granite treatments suggests that the larger rock sizes have little to no influence on soil moisture retention compared to forest mulch. Consideration should therefore be given to using a mixture of sizes to overcome this effect.

Forest mulch was the best treatment to mitigate the impact of slope on soil moisture because hydro-seeding and granite mulches did not prevent a significant water movement downwards (Fig. 1). Higher soil moisture in the lower slope position is usually found compared to the middle and upper slope position where no mulching treatments are applied (Wei et al. 2010). However, it is expected that mulching alleviates the effects of slope on water movement because it is acting as a physical barrier (Gholami et al. 2013). Forest mulch significantly increases soil organic matter as indicated by all of C variables in this study and soils with higher organic matter have a better water retention capacity as reported by different studies (Wang et al. 2002; Huang et al. 2008a). Our results are consistent with a study that compared hydro-mulch and organic mulch which reported a decreased soil loss in hydro-mulch compared to bare soil but indicated that hydro-mulch was less effective to retain water compared to organic mulch (Eck et al. 2010). This is probably due to the rapid decline in surface coverage by hydro-mulch (Robichaud et al. 2013). Despite the fact that soil moisture was higher in the lower slope position in all treatments, the difference was only significant in the hydro-seeding and granite treatments suggesting that these two treatments were less effective to alleviate the effects of slope on water movement perhaps due to poorer surface coverage and lesser organic matter incorporation in the soil compared to the forest mulch. This finding has been well supported by $\delta^{13}C$ which showed significantly higher enrichment values in the hydro-seeding and granite treatments than the forest mulch treatment. It has been well established that, in plants under limited water conditions stomatal closure increases, leading to increased $^{13}CO_2$ at the carboxylation site which enriches $\delta^{13}C$ in plant tissue and incorporation of such litter in the soil leads to soil

$\delta^{13}C$ enrichment (Xu et al. 2000, 2003). Despite the fact that water retention in the forest mulch treatment was higher, it seems that organic matter input is a stronger driving factor than soil moisture resulting in changes in soil variables.

Unsurprisingly, the greatest improvement in soil properties was observed under the forest mulch though less expected is the lack of significant difference in soil C and N pools between hydro-seeding and granite treatments. Mulch affects soil C and N pools as shown by different studies (Huang et al. 2008a; Li et al. 2010) although effects of mulch on soil C and N differ with mulch properties (Fang et al. 2011). Fang et al. (2011) used organic mulching with four different biomass materials, cogongrass (*Imperata cylindrica*), oak (*Quercus fabri*), Chinese coriaria (*Coriaria nepalensis*) and brackenfern (*Pteridium aquilinum*) in *Populus* spp. plantations in China. Those authors concluded that although mulching improved soil N, the degree of N improvement was influenced by decay rate and initial nutrient content of the mulching materials. In contrast, a trial of inorganic and organic mulches, including alfalfa straw, forest litter and polyethylene, revealed no significant difference in SOC, TN and nitrate among the treatments. Inorganic mulch materials do not have organic content but may increase soil moisture, thereby accelerating organic matter decomposition and improving their incorporation in soil (Barajas-Guzmán et al. 2006). In the present study, despite the fact granite was an inorganic mulch, the SOM under granite mulch did not differ significantly from hydro-seeding but was significantly different to the forest mulch, even though these two treatments had similar vegetative cover. This suggests that the presence of large rocks acts as a physical barrier to the incorporation of litter leaving the litter susceptible to wind and water transport processes. Greater soil improvement under forest mulch compared to hydro-seeding and granite mulches are associated with higher organic matter of the mulch content and greater soil moisture preservation.

Forest mulch had also significantly higher labile N, inorganic N and PMN compared to hydro-seeding and granite. Soil N content is associated with the rate of organic matter incorporation into soiland improved soil moisture (Barajas-Guzmán et al. 2006; Fang et al. 2011; Zhang et al. 2012). The presence of organic mulch influences soil N mineralisation and dynamics leading to improved soil N availability (Fang et al. 2011). However, Barajas-Guzmán et al. (2006) showed that mulch treatments, regardless of being organic or inorganic, enhanced soil NH_4^+-N compared to bare soil but it is likely that this was due to a higher water retention capacity of the material used. These authors reported that, in the organic mulch, the incorporation of the decomposed material in soil explained the increased soil NH_4^+-N whereas in the inorganic mulch, increased soil moisture was likely to be responsible for enhanced NH_4^+-N (Barajas-Guzmán et al. 2006). Wood based organic mulch had less total N loss compared to hydro- mulch in a study conducted in Texas, USA due to higher water preservation compared to hydro-mulch (Eck et al. 2010) or increased immobilisation. Our results show that even 5 years following the application of the forest mulch, the effects on the C and N pools were still evident and, combined with the higher soil moisture, the application of forest mulch was a significant factor in contributing to the long term fertility of the site.

Soil microbes facilitate nutrient dynamics and availability and microbial biomass is a sensitive indicator of SOM regulation and transformation (Huang et al. 2008a; Gonzalez-Quiñones et al. 2011). In a Christmas tree plantation, different mulch treatments including, rubber-tire mulch and sawdust mulch were applied to investigate soil microbial biomass dynamics. Sawdust mulch showed higher microbial biomass (MB) than that of rubber-tire mulch and the authors concluded that it was due to higher N, organic matter and moisture availability in this treatment (Arthur and Wang 1999). In two plantations in Australia, a wood-base mulch was applied and it was also reported that the N transformation was linked to MB (Huang et al. 2008a). In the present study, greater soil microbial biomass in forest mulch compared to hydro-seeding and granite mulches is probably associated with higher TN and labile C and N in this treatment and this was also supported by a strong relationship between MB and TN and labile C and N (Table 4).

Finally, although granite and hydro-seeding treatments did not improve soil fertility as much as forest mulch did, they alleviated the impacts of slope on soil C and N pools. Higher soil fertility improvement and water retention observed in soil amended with forest mulch suggests that forest mulch was the most effective amendment option to improve soil structure and fertility on a sloping site.

Conclusions

Forest mulch was the most effective approach to improve soil fertility in disturbed soils on sloping lands. The measured soil C and N pools were all larger under the forest mulch treatment than under the granite and hydro-seeding treatments. If simple slope stabilisation is the goal then the use of large rocks as mulch may be adequate though there were indications of considerable down-slope movement of sediments (unpublished data). Research into using a mixture of aggregate sizes may improve the effectiveness of granite mulch for site stabilisation. Hydro-seeding failed at this site, whether from the known recalcitrance of Australian native seeds and the need for extensive seed preparation prior to application or from seeds being washed away is not known. Hydro-seeding failed as an establishment method for the Australian native plants and the resulting cover of native grasses performed no better in most indices than the rock mulch (unpublished data). Forest mulch enhanced soil fertility and provided protection from erosion on a moderately steeply sloping site. Further research is required to investigate to what extent the performance of forest mulch may be affected by the slope gradient and the length of the slope.

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Table 1: Soil total C (TC), total N (TN), C isotope composition ($\delta^{13}C$) and isotope composition N ($\delta^{15}N$) in the presence of mulching treatments under different slopes. Means followed by the lower case letters demonstrate the significance at the level *P*<0.05 among mulching treatments. Means with no letters indicate no significant difference of mulching treatments. Bold means shows the significance of slope position at the level *P*<0.05. Mean standard errors presented in the parentheses.

	TC (%)			$\delta^{13}C$ (‰)		
	Upper	Middle	Lower	Upper	Middle	Lower
Hydro-seeding mulch	1.1 (0.2)b	0.83 (0.03)b	0.90 (0.05)b	**-22.3 (0.7)a**	**-20.7 (0.3)a**	**-21.7 (0.5)a**
Granite mulch	1.16 (0.1)b	0.76 (0.06)b	0.86 (0.08)b	-22.1 (0.4)a	-21.1 (0.2)a	-21.7 (0.1)a
Forest mulch	**5.20 (0.6)a**	**2.86 (0.4)a**	**3.20 (0.1)a**	-25.3 (0.2)b	-24.3 (0.3)b	-24.5 (0.2)b
	TN (%)			**$\delta^{15}N$ (‰)**		
	Upper	Middle	Lower	Upper	Middle	Lower
Hydro-seeding mulch	0.070 (0.02)b	0.050 (0.001)b	0.056 (0.003)b	**4.13 (0.03)b**	**5.03 (0.1)**	**4.10 (0.3)**
Granite mulch	0.063 (0.003)b	0.053 (0.003)b	0.053 (0.003)b	4.70 (0.2)ab	4.90 (0.5)	4.73 (0.1)
Forest mulch	**0.37 (0.051)a**	**0.19 (0.023)a**	**0.21 (0.001)a**	5.36 (0.1)a	4.80 (0.1)	4.76 (0.2)

Table 2: Soil hot-water extractable organic C (HWEOC), hot-water extractable total N (HWETN) and microbial biomass C and N (MBC and MBN) in the presence of mulching treatments under different slopes. Means followed by the lower case letters demonstrate the significance at the level *P*<0.05 among mulching treatments. Means with no letters indicate no significant difference of mulching treatments. Bold means shows the significance of slope position at the level *P*<0.05. Mean standard errors presented in the parentheses.

	HWOC ($\mu g\ g^{-1}$)			HWETN ($\mu g\ g^{-1}$)		
	Upper	Middle	Lower	Upper	Middle	Lower
Hydro-seeding mulch	190 (35)b	139 (19)b	149 (14)b	20.4 (4.3)b	15.2 (1.2)b	15.8 (0.7)b
Granite mulch	113 (26)b	110 (11)b	113 (15)b	14.1 (2.3)b	12.9 (1.0)b	13.2 (1.7)b
Forest mulch	**614 (142)a**	**379 (53)a**	**440 (33)a**	**63.9 (12)a**	**41.6 (5.1)a**	**46.4 (2.8)a**
	MBC ($\mu g\ g^{-1}$)			**MBN ($\mu g\ g^{-1}$)**		
	Upper	Middle	Lower	Upper	Middle	Lower
Hydro-seeding mulch	85.3 (13)b	56.9 (17)	63.3 (11)b	8.54 (5.1)b	6.25 (1.8)	9.04 (3.5)b
Granite mulch	95.3 (18)b	86.0 (25)	75.3 (10)b	11.2 (0.7)b	8.69 (1.2)	7.54 (4.3)b
Forest mulch	**383 (113)a**	**186 (54)**	**271 (35)a**	**57.0 (8.3)a**	**18.1 (6.4)**	**61.2 (14)a**

Table 3: Soil NH_4^+-N, NO_3^--N, total inorganic N (TIN) and potentially mineralisable N (PMN) in the presence of mulching treatments under different slopes. Means followed by the lower case letters demonstrate the significance at the level *P*<0.05 among mulching treatments. Means with no letters indicate no significant difference of mulching treatments. Bold means shows the significance of slope position at the level *P*<0.05. Mean standard errors presented in the parentheses.

	NH_4^+-N (µg g^{-1})			NO_3^--N (µg g^{-1})		
	Upper	Middle	Lower	Upper	Middle	Lower
Hydro-seeding mulch	7.57 (1.0)b	4.21 (0.2)b	7.16 (0.9)b	4.74 (1.4)b	1.24 (0.3)	1.38 (0.7)
Granite mulch	6.08 (2.2)b	4.66 (0.6)b	4.13 (0.2)b	1.65 (0.03)b	1.74 (0.4)	1.92 (0.7)
Forest mulch	17.6 (2.3)a	14.4 (5.1)a	18.2 (3.3)a	**64.4 (25)a**	**13.76 (2.4)**	**12.34 (2.2)**

	TIN (µg g^{-1})			PMN (µg g^{-1})		
	Upper	Middle	Lower	Upper	Middle	Lower
Hydro-seeding mulch	12.3 (1.5)b	5.46 (0.5)	8.55 (1.5)	**111 (32)b**	**36.8 (2.8)b**	**70.2 (19)b**
Granite mulch	7.74 (2.2)b	6.40 (1.0)	6.05 (0.6)	83.3 (11)b	51.7 (10)b	42.2 (12)b
Forest mulch	**82.1 (25)a**	**28.2 (7.1)**	**30.5 (4.6)**	236 (50)a	164 (33)a	224 (8.2)a

Table 4: Coefficient correlations (*r*) among soil variables (*n*=27; *P<0.05).

	Soil moisture	TC	TN	HWEOC	HWETN	MBC	MBN	TIN	PMN
Soil moisture									
TC	0.41*								
TN	0.38*	0.95*							
HWEOC	0.43*	0.96*	0.96*						
HWETN	0.40*	0.97*	0.97*	0.99*					
MBC	0.31^{ns}	0.91*	0.91*	0.94*	0.94*				
MBN	0.58*	0.84*	0.82*	0.83*	0.83*	0.81*			
TIN	0.34*	0.83*	0.81*	0.68*	0.72*	0.60*	0.71*		
PMN	0.45*	0.88*	0.87*	0.93*	0.91*	0.87*	0.80*	0.56*	1

Figure 1: Soil moisture under different mulch treatments in the upper, middle and lower slope position.