Plant species effects on soil carbon stocks - a pot study

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Abstract

Soil carbon stocks may decrease or increase following land use change (LUC) from one ecosystem to another. Several factors may influence such gain or loss of soil carbon and we hypothesise that the species growing before and after the transition is one such factor. A 1-year pot experiment was designed to test the above hypothesis in a glasshouse independent of soil disturbance and other management effects of LUC. Two grass species (*Themeda triandra* and *Austradanthonia racemosa*) and two tree species (*Pinus radiata* and *Eucalyptus globulus*) were sown in pots. Half of the grass pots were defoliated monthly to test for any cutting effect. *Themeda* growing in topsoil from a pine plantation forest significantly increased soil carbon, but *Austrodanthonia* did not. Cutting the grass only eased *Themeda*'s effect on soil carbon. Pine seedlings reduced soil carbon, especially when grown in top soil from a native pasture, but the *Eucalyptus* seedlings did not. The soil carbon reduction under *Pinus* was due to *Pinus* trees contributing much less new carbon to the soil than old carbon was released from the soil. We conclude that choice of species involved in afforestation and deforestation projects can influence the potential net soil CO_2 storage or emission after LUC.

Media summary

Whether the soil stores or emits CO_2 after afforestation or deforestation from or to pasture depends on the species of tree and grass used. It can go either way.

Key Words

Soil carbon, species, *Pinus radiata*, *Themeda triandra, Eucalyptus globulus*, and *Austrodanthonia racemosa*.

Introduction

Soil carbon stocks are, on average, increased by land use change from forest to pasture (Guo and Gifford 2002), and can be reduced by woody plant invasion into grasslands (Goodale and Davidson 2002; Jackson *et al.* 2002), or by planting conifer trees onto pasture, but not by planting broadleaf trees (Guo and Gifford 2002). There are many management changes after LUC that might influence soil carbon changes but we hypothesised that variation between tree and grass species could alone play a role in the above findings. A one-year pot experiment in a glasshouse was designed to test the hypothesis of rapid effects of tree and grass species on soil carbon stocks.

Methods

Experimental design

The1-year pot trial was conducted in a temperature-controlled glasshouse having a mean temperature 22?C (26?C day and 18?C night) from April 2001 to April 2002. We designed the experiment to utilise the fact that new carbon fixed during the experiment can be distinguished from older soil carbon by planting C_4 plants on soil obtained from a C_3 ecosystem or *vice versa* (Cardon et al. 2001). A factorial design was used in this experiment to test the effects of the imposed factors: i) species: two native grass species in

Australia, *Themeda triandra* (C_4) and *Austrodanthonia racemosa* (C_3), and two tree species, *Pinus radiata* (a fast-growing conifer species planted widely in many parts of the world) and *Eucalyptus globulus* (a fast-growing native species planted increasingly in Australia and widely in the world); ii) soil source: top soils (0-20 cm) from native pasture with *T. triandra* dominant and 13 year old *P. radiata* plantation at Billy Billy in Kowen Forests, ACT, Australia; and iii) cutting (two grasses only): grasses were cut monthly to imitate defoliation via hay harvesting or grazing, and compared with no cutting. Hence, there were 42 pots: 2 soil types ? (4 species + 2 ? 1 cutting treatment to each grass + control with soil only) ? 3 replicates.

Materials

Roots and gravel were removed from the soils by sieving before sowing seeds. Samples of this sieved soil were taken for "initial soil" analysis. Twenty five *T. triandra* seeds, 45 *A. racemosa* seeds, 15 *P. radiata* seeds, or 45 *E. globulus* seeds were sown into each pot (diameter = 250 mm, height = 240 mm), which was filled with soil medium up to 20 mm from the top (the initial soil characteristics are showed in Table 1). Each pot had a dish underneath to prevent water-loss. All pots were moved into glasshouse as soon as seeds were sown. They were randomly arranged and rotated periodically around the benches. Water was applied manually onto each pot at the rate of 20 mm per week (about 1000 mm/year) to keep the soil moist all the time. If more than 3 seedlings established in each pot, they were thinned to 3 after the first three months. At the same time, the grass cutting treatment was introduced.

Table 1. Soil characteristics for the pot study under controlled environment.

Soil source	Total C (%)	Total N (%)	$\delta^{13}C$ (‰)	pH_{water}
Soil from pasture	2.92	0.16	-21.7	5.9
Soil from plantation	1.11	0.06	-23.4	5.3

Laboratory Analysis

After the one-year harvest, soil samples were taken from each pot, air-dried, ground and analysed for total carbon and $\delta^{13}C$ using an automatic carbon and nitrogen elemental analyser (Europa, ANCA–SL). New carbon addition by plants and carbon loss from soil were calculated using the following formula (Vitorello et al. 1989):

$$PCn = \frac{\delta - \delta_0}{\delta_C - \delta_0} \times 100 \qquad PCo = 100 - PCn$$

PCn: percentage of the final soil carbon that was new carbon input from the plants during the one year; *PCo*: percentage of the final soil carbon that was old carbon left in the soil by the end of the one year period; δ: $\delta^{13}C$ value of the soil at the end of the experiment; δ_0: $\delta^{13}C$ value of the initial soil before the experiment; δ_C: $\delta^{13}C$ value of the plant roots since not much above ground litter fell.

Statistical calculations

Two-way factorial analysis of variance (ANOVA) was used to test for statistical differences between soil types (from pasture and pine plantation) and treatments (including species, cutting treatment and control). Means were separated using a least significant difference test with a probability level of 0.05.

Results and discussions

After one year, the introduced species and treatment significantly affected carbon content of soils from both pasture and pine plantation (Table 2, Figure 1). *Themeda* growing in forest soil significantly increased soil carbon, but *Austrodanthonia* did not and even reduced soil carbon when grown in pasture soil. Cutting grass only eased *Themeda*'s effect on soil carbon. Pine seedlings significantly reduced soil carbon stocks, especially in pasture soil, but eucalypt seedlings made no change. Hence, the species variation, even between grass species and between tree species, did have effects on soil carbon stocks.

$\delta^{13}C$ in the control soils both from plantation and pasture did not changeafter one year (soil only) (Table 2). In the soil from pine plantation, $\delta^{13}C$ did not change under either pine or eucalypt seedlings, but increased (less negative) under *Themeda*, and decreased under *Austrodanthonia.* In the soil from pasture, $\delta^{13}C$ increased under *Themeda*, and decreased under *Austrodanthonia*, pine and eucalypt seedlings.

At the end of one year, original soil carbon was lost consistently in both soils under different species and treatments (Figure 1). The net loss or gain of soil carbon depended highly on how much new carbon was added by the plants, i.e. more or less than the loss of original soil carbon. Soil carbon increased under *Themeda* because the loss of original soil carbon was less than the addition of new carbon from plants. Soil carbon decreased under pine seedlings growing in pasture soil because the loss of original soil carbon was more than the addition of new carbon from plants. Pine and eucalypt seedlings did not seem to add any new carbon to the soil from plantation (Figure 1) since soil $\delta^{13}C$ did not change after one year (Table 2). However, it may not be possible to use $\delta^{13}C$ satisfactorily to separate original soil carbon and new carbon contributions from pines or eucalypts because the plant and initial soil isotopic signatures were similar (Table 2).

Table 2. Soil carbon, soil $\delta^{13}C$ and plant root $\delta^{13}C$ in two soils at the end of one year pot study

Soil type	Species and treatment	Total soil C (g/pot)	Soil $\delta^{13}C$ (‰)	Plant root $\delta^{13}C$ (‰)
Soil from plantation		102 ef	-23.4 f	
	S	91 g	-23.2 f	
	A	101 ef	-23.8 g	-29.3 e
	AD	101 ef	-23.7 g	-29.2 e
	T	109 d	-22.1 de	-13.1 a
	TD	106 de	-22.2 e	-12.6 a
	E	101 ef	-23.4 f	-26.9 cd
	P	96 fg	-23.4 f	-24.6 b
Soil from pasture		201 a	-21.7 b	

S	177 c	-21.8 b	
A	182 c	-22.1 de	-27.7 d
AD	184 c	-22.0 cd	-27.9 d
T	202 a	-21.3 a	-13.1 a
TD	193 b	-21.3 a	-12.3 a
E	200 ab	-21.9 c	-26.2 c
P	178 c	-21.9 c	-23.8 b
Interaction between soil type and species	***	***	*

Note: S = control (soil only); A = *Austradanthonia racemosa*; T = *Themeda triandra*; E = *Eucalyptus globulus*; P = *Pinus radiata*; D = defoliation by grass cutting monthly; * and *** denote *P < 0.05* and *0.001*; Means with different letter in same column are significantly different by Duncan grouping (n=3, *P < 0.05*)

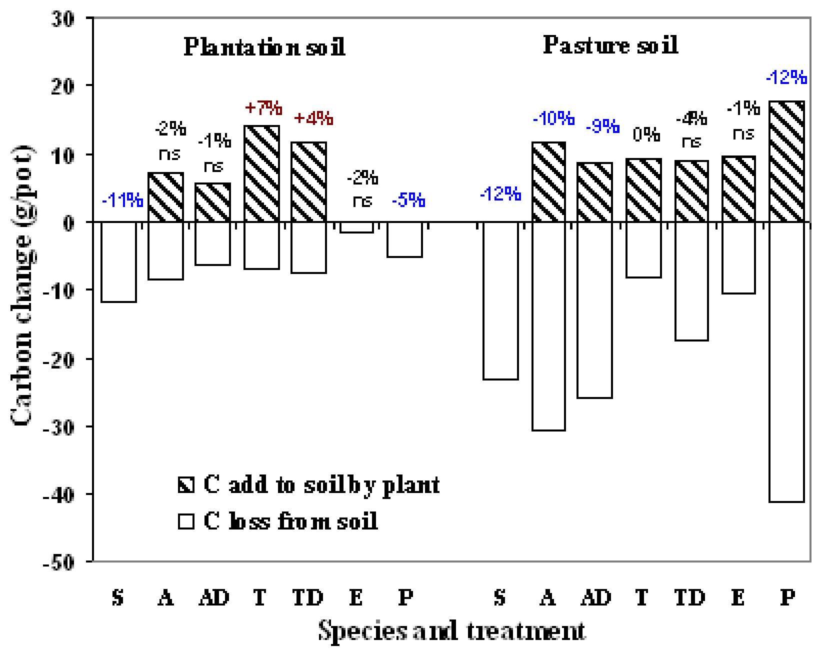

Figure 1. The soil carbon change under different species and treatments in two soils at the end of one year pot study. S = control (soil only); A = *Austradanthonia racemosa*; T = *Themeda triandra*; E = *Eucalyptus globulus*; P = *Pinus radiata*; D = defoliation by grass cutting monthly; percentages are the net carbon change relative to the initial soil carbon stock; ns denotes not significant. Note that the small differentials between the plant roots and plantation soil δ ^{13}C means that net new carbon input to that soil from pine or eucalypt may not be detectable by the isotopic method.

Davis (1995) found that soil organic carbon and total nitrogen were 15-19% lower after pine in a pot trial with tree (*P. radiata*) and C_3 grass (*Dactylis glomerata*). However, the difference not only existed between tree and grass, but also within tree species and grass species as shown in this study. Each species has a different carbon allocation strategy that results in a different pattern, rate, quality and quantity of organic carbon input to the soil (Lugo and Brown, 1993). This pot experiment clearly supports this.

Conclusion

The hypothesis was supported in that the type of species growing in a disturbed soil affects the loss or gain of soil carbon and there is variation both within and between grass and tree species in that respect. Soil carbon change depended on the balance between the loss of original soil carbon and addition of new carbon from the growing plants. *Themeda* increased soil carbon in the soil from a pine plantation since more carbon was added by the plants than the loss of initial soil carbon. Pine seedlings reduced soil carbon since they added much less carbon than the loss from the initial soil carbon pool. Hence, species planted should be a factor to be considered in land use and land use change for purposes of carbon sequestration and build-up of organic matter in the soil.

References

Cardon ZG, Hungate BA, Cambardella CA, Chapin III FS, Field CB, Holland EA and Mooney HA (2001) Contrasting effects of elevated CO_2 on old and new soil carbon pools. *Soil Biology and Biochemistry* 33, 365-373.

Davis MR (1995) Influence of radiata pine seedlings on chemical properties of some New Zealand montane grassland soils. *Plant and Soil* 176, 255-262.

Goodale CL and Davidson EA (2002) Carbon Cycle: Uncertain Sinks in the Shrubs. *Nature* 418, 593-594.

Guo LB and Gifford RM (2002) Soil carbon stocks and land use change: a meta analysis. *Global Change Biology* 8, 345-360.

Jackson RB, Banner JL, Jobbagy EG, Pockman WT and Wall DH (2002) Ecosystem carbon loss with woody plant invasion of grasslands. *Nature* 418, 623-626.

Lugo AE and Brown S (1993) Management of tropical soils as sinks or sources of atmospheric carbon. *Plant and Soil* 149, 27-41.

Vitorello VA, Cerri CC, Andreux F, Feller C and Victoria RL (1989) Organic matter and natural carbon-13 distribution in forested and cultivated oxisols. *Soil Science Society of America Journal* 53, 773-778.