Net root C input as determined by ^{13}C natural abundance correlates with aboveground net primary productivity across different ecosystem types

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INTRODUCTION

The ^{13}C natural abundance method provides an 'in-situ' method by which to quantify the relative contribution of new C in soil-plant systems where the ^{13}C signal of the C input is different to the native SOM (e.g. C_3 plants grown in C_4 soils or *vice versa*). This method was used to quantify net belowground C inputs (C_{NEW}; i.e. *net* rhizodeposition), an important, yet rarely quantified component of the global C cycle, in four different ecosystem types: forest, grassland, apple orchard, and vineyard. C_{NEW} values were compared with measures of ecosystem productivity (i.e. GPP and ANPP) to assess possible drivers of belowground C dynamics and partitioning.

STUDY SITE AND METHODS

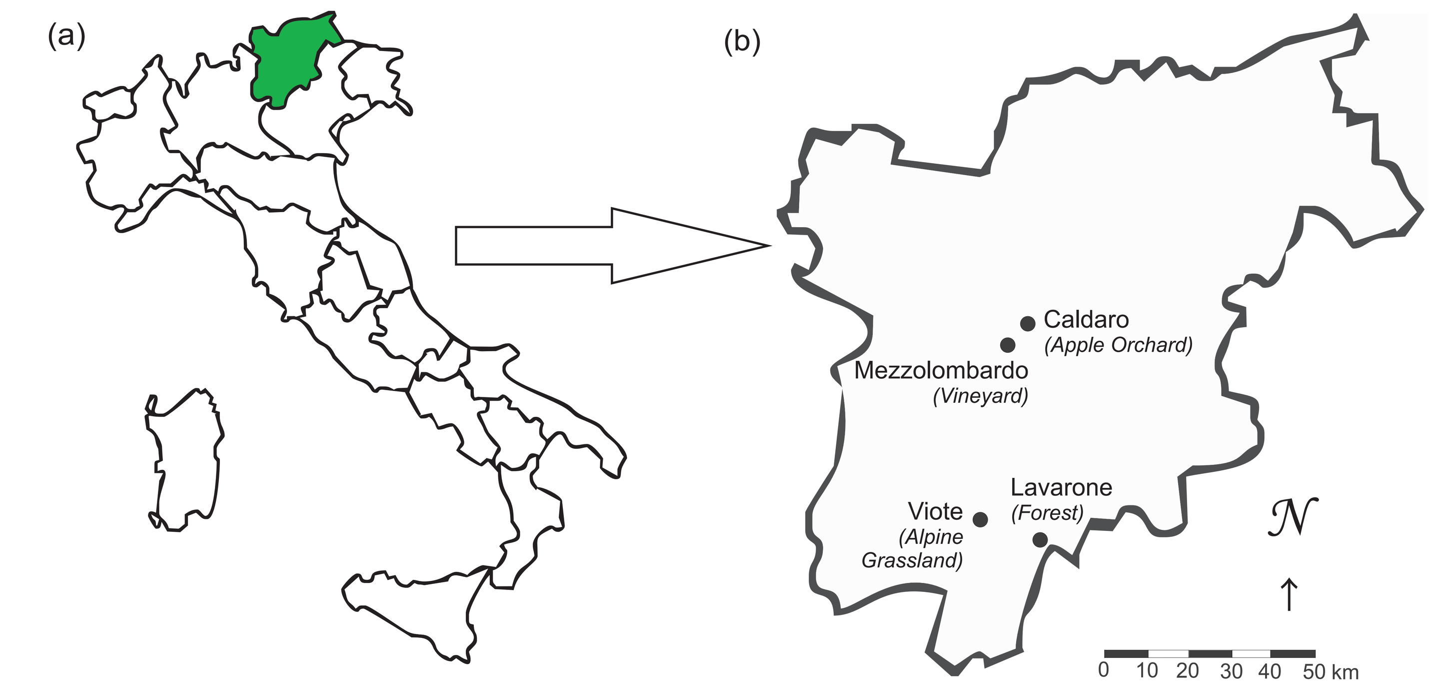


Fig. 1: (a) Location map of study in northern Italy; (b) location of study sites (Lavarone, Viote, Caldaro, and Mezzolombardo) within the Trentino-Alto Adige region; (c) C_4 soil cores.

Table 1: Study site characteristics.

	LAVARONE (FOREST)	VIOTE (ALPINE GRASSLAND)	CALDARO (APPLE ORCHARD)	MEZZOLOMBARDO (VINEYARD)
Latitude	45°57'23" N	46°00'53" N	46°21'17" N	46°11'49" N
Longitude	11°16'52" E	11°02'45" E	11°16'31" E	11°06'49" E
Elevation (a.s.l.)	1349m	1553m	240m	206m
Land Use	Forest	Alpine grassland	Apple orchard	Vineyard
Vegetation Type	Silver fir (*Abies alba*)	*Nardetum alpigenum*	Common apple (*Malus domestica*)	Common grape (*Vitis vinifera*)
Precipitation	1150mm	1189mm	1051mm	945mm
Air Temperature	7.8°C	5.5°C	11.6°C	12.6°C
Soil Type (FAO-WRB, 1998)*	Humic Umbisol	Calcaric Phaeozem	Calcaric Cambisol	Gleyic/Haplic Fluvisol

* Soil classification by A. Börner and S. Chersich (unpublished)

Sampling Protocol & Soil Processing and Analysis:

* 6 sampling points at each site, 3 replicates (i.e. 18 samples per site)
* C_4 soil ($\delta^{13}C$ = -16.7‰): US Dept. of Agriculture (USDA-ARS)
* C_4 soil cores (Fig. 1c): incubated for 12 months

BELOWGROUND CARBON INPUTS (C_{NEW})

Mass balance equation for calculating fraction of new C (f_{NEW}):

$$f_{NEW} = (\delta_{SOIL} - \delta_{OLD}) / (\delta_{VEG} - \delta_{OLD})$$

where δ_{SOIL} = $\delta^{13}C$ of C_4 soil following 1 year of field incubation; δ_{OLD} = $\delta^{13}C$ of original C_4 soil; and δ_{VEG} of roots.

Net root C input (C_{NEW}; gC m^{-2} yr^{-1}): $C_{NEW} = f_{NEW} \times \%C \times BD \times SD$

where %C = soil C concentration; BD = bulk density (0.79g cm^{-3}); SD = soil depth (30cm).

Therefore, C_{NEW} = fraction of rhizodeposition remaining in the soil after 12 months minus losses associated with heterotrophic respiration (i.e. *net* rhizodeposition).

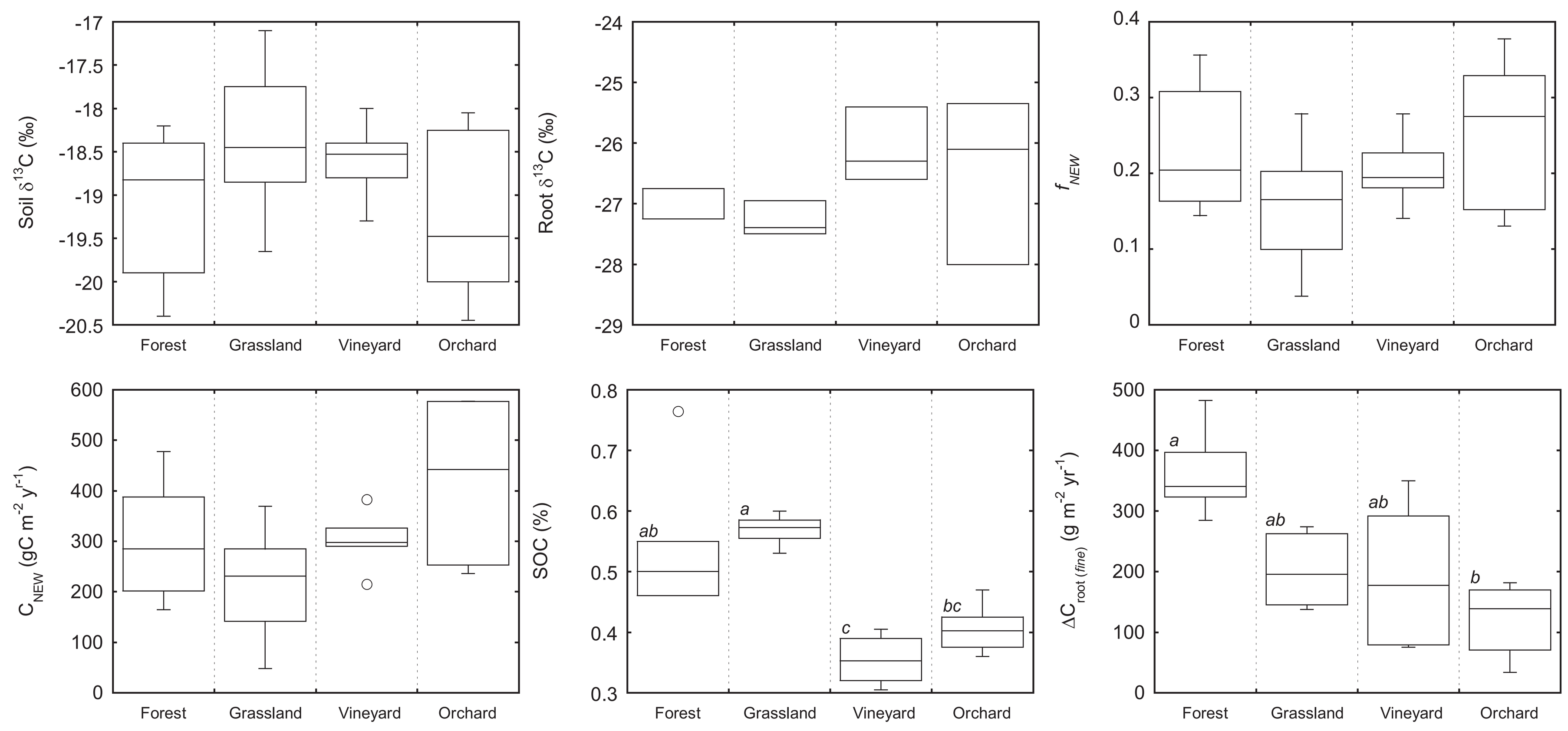


Fig. 2: Box-plots showing differences among the four study sites for the various soil properties within the in-growth soil cores. Outliers are displayed as individual points. Different letters indicate a significant difference among sites (p <0.05).

* C_{NEW}: ranged from 217 ± 111.8 gC m^{-2} yr^{-1} (grassland) up to 421.5 ± 155.9 gC m^{-2} yr^{-1} (apple orchard), but no statistically significant differences observed between sites.

* Annual fine root C accumulation ($\Delta C_{root\ (fine)}$): highest at forest site (366.9 ± 28.6 gC m^{-2}) and lowest at apple orchard (122.3 ± 23.9 gC m^{-2}), statistically significant difference (Kruskal-Wallis *H*-value = 13.18; p < 0.01)

ECOSYSTEM FLUXES (GPP, ANPP AND BNPP)

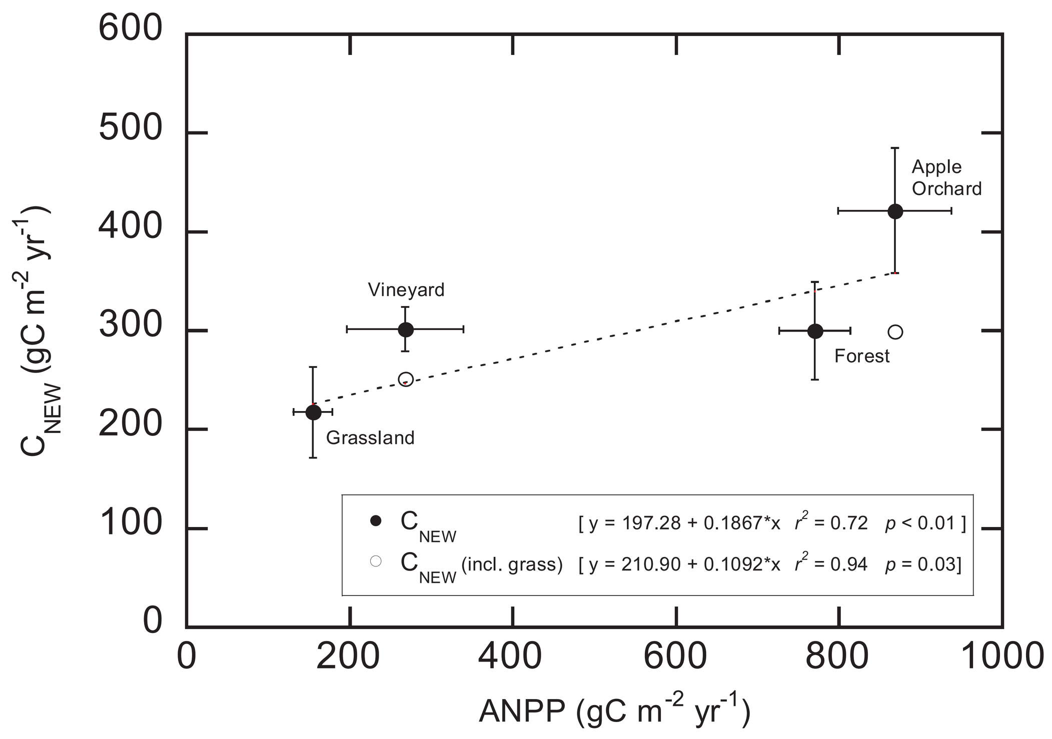
GPP: site-specific eddy covariance data (Baldocchi *et al.*, 1988)
ANPP: inventory approach (sum of total above-ground biomass production)
BNPP: sum of $\Delta C_{root\ (fine)} + \Delta C_{root\ (coarse)} + C_{NEW}$ (Giardina *et al.*, 2005)

Table 2: Ecosystem fluxes (GPP, ANPP, BNPP), net rhizodeposition (C_{NEW}) and carbon partitioning at the four sites.

	Forest	Grassland	Apple Orchard	Vineyard
[1] GPP	2400	1086	1263	1145
[2] ANPP ± SE	770 ± 43.7	155 ± 23.7	868 ± 69.6	268 ± 71.6
[3] C_{NEW} ± SE	300.4 ± 49.5	217.7 ± 45.6	421.5 ± 63.6	301.7 ± 22.2
[4] $\Delta C_{root\ (fine)}$^ ± SE	366.9 ± 28.6	201.9 ± 23.3	122.3 ± 23.9	192.0 ± 45.9
[5] $\Delta C_{root\ (coarse)}$	154.1	N/A	13.0	30.2
[6] BNPP (3+4+5)	821.4	419.7	556.8	523.9
[7] NPP (2+6)	1591.4	574.7	1424.8	771.8
BNPP/NPP (6/7)	0.52	0.73	0.39	0.69
$\Delta C_{root\ (fine)}$/BNPP (4/6)	0.45	0.48	0.22	0.38
C_{NEW}/BNPP (3/6)	0.55	0.52	0.78	0.62

^ assuming 48% C in plant root material (Nadelhoffer and Raich, 1992)

ANPP AND C_{NEW}



Statistically significant relationship between ANPP and C_{NEW} (r^2 = 0.72; p < 0.01) (Fig. 3)

Stronger when grassed alleys between crop rows accounted for (r^2 = 0.94; p = 0.03).

Fig. 3: ANPP versus C_{NEW} (weighted linear regression). SE of the mean shown as error bars. White circles = C_{NEW} values incl. grassed alleys at vineyard and apple orchard sites.

C PARTITIONING AND RHIZODEPOSITION

$\Delta C_{root\ (fine)}$:BNPP ~ 50% for forest (45%) and grassland (48%).

Highest C_{NEW}:BNPP at cultivated sites: vineyard (62%) & orchard (78%) (Table 2; Fig. 4).

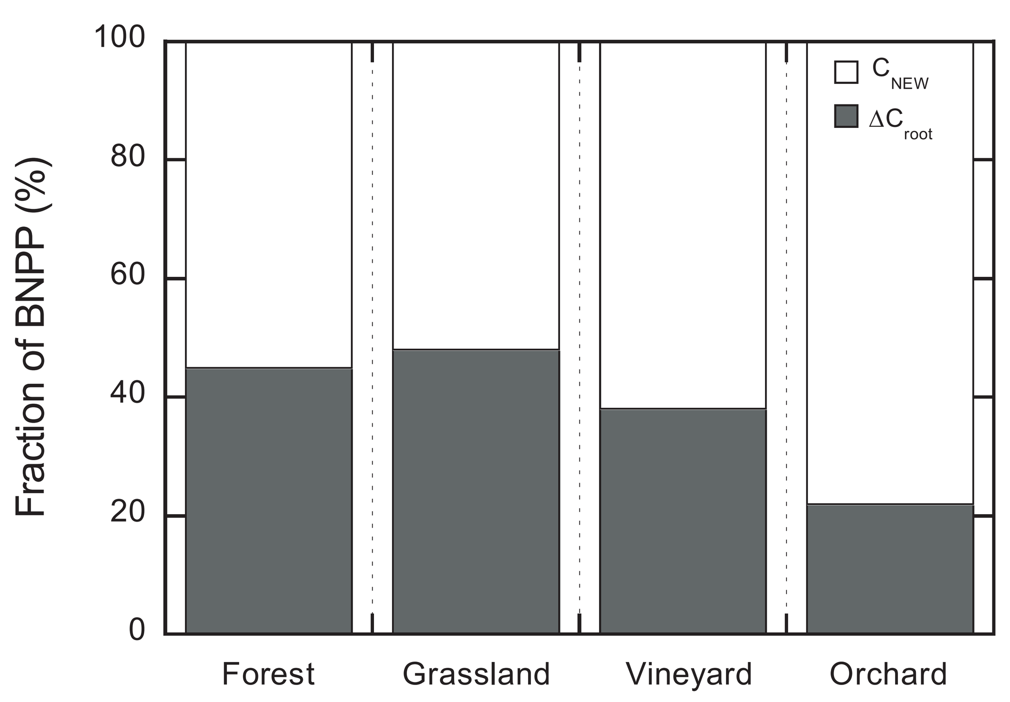


Fig. 4: BNPP carbon partitioning between root C and C_{NEW}.

Higher root turnover (i.e. mortality): due to higher maintenance costs associated with fruit production.

Tree morphology:

Vines: no need for large structural roots, invest little in belowground compartments.

Orchard: grafting on dwarfing rootstocks, restrict tree volume, operational costs (harvest/pruning), and root system.

BNPP:NPP decreased as NPP increased (Fig. 5)

Partitioning belowground is higher when resource availability is low, and *vice versa* as GPP increases and resources are no longer limiting (Litton *et al.* 2007; Palmroth *et al.* 2006).

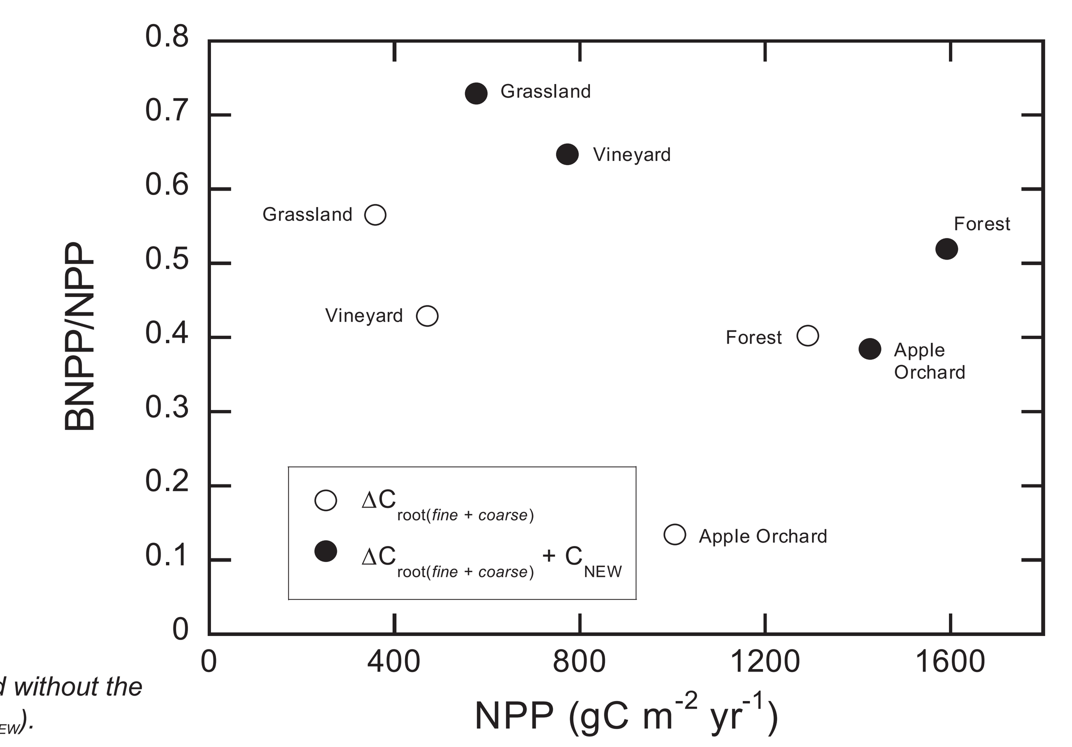


Fig. 5: NPP versus BNPP/NPP, calculated with and without the contribution of net rhizodeposition (i.e. C_{NEW}).

CONCLUSIONS

Mechnistic ecosystem C balance models could benefit from this ANPP:C_{NEW} relationship since ANPP is routinely and easily measured, and suggests by quantifying site-specific ANPP, root C input can be reliably estimated.

High levels of C allocation to BNPP resulting from net rhizodeposition, confirm the significance of this component within the global C cycle, and highlight the need for more and better measurements of these belowground C components.

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