Examining the Carbon Cycle of a Mountain Vineyard

Evidence for tree-grass ecosystem behaviour

Introduction

Vineyards have the potential to act as carbon sinks due to various characteristics such as low soil disturbance, high biodiversity and long-term carbon reservoirs. In mountainous regions where soil stability and erosion are priorities, grassed alleys are essential to vineyard management. Cover cropping is also frequently employed to improve soil conditions and provide ecosystem services. Although these practices are generally considered to have a positive impact on carbon sequestration, there is still debate over the extent of this.

Furthermore, the resulting agroecosystem consists of two separate vegetation strata with very different behaviours and impacts. Disentangling the carbon fluxes of grapevines and ground cover (as well as the in-plant allocation) is therefore essential to understanding the fate of sequestered carbon as well as the effects of management decisions and changing environmental conditions.

Site description

The experimental site was a vineyard of 0.85 ha in **Caldaro, South-Tyrol** (46° 24' N, 11° 15' E, 325 m a.s.l.) in the North of Italy. The terrain was homogenous, with a West-facing slope of 5%. The Köppen-Geiger **climate classification** is CFb (temperate oceanic) and the 30-year average temperature and precipitation (1991-2020) are 12.0 °C and 829.5 mm $year^{-1}$ respectively. **Soil texture** was sandy-loam, with a high content of stones.

Figure 1: the experimental research site in Autumn.

The **cultivars** planted were Chardonnay and Sauvignon blanc on SO4 rootstock. Vines were trained on a **vertical shoot positioning** system and cane-pruned (single Guyot). The vineyard had a **drip irrigation** system to provide supplementary water during periods of drought. Rows were North-South orientated with inter-rows 2 m wide.
Budburst occurred in early April, 50% flowering by the end of April, veraison in early August and harvest in mid-September.

The vineyard floor was grass-covered and managed by **alternating green manure (mix of cereals and legumes) and spontaneous cover crops**, which were regularly mowed. Tilling and re-sowing of green manure occurred in Autumn.

Methods

All measurements were taken between April 15th and November 15th of 2021, comprising the grapevine growing season.

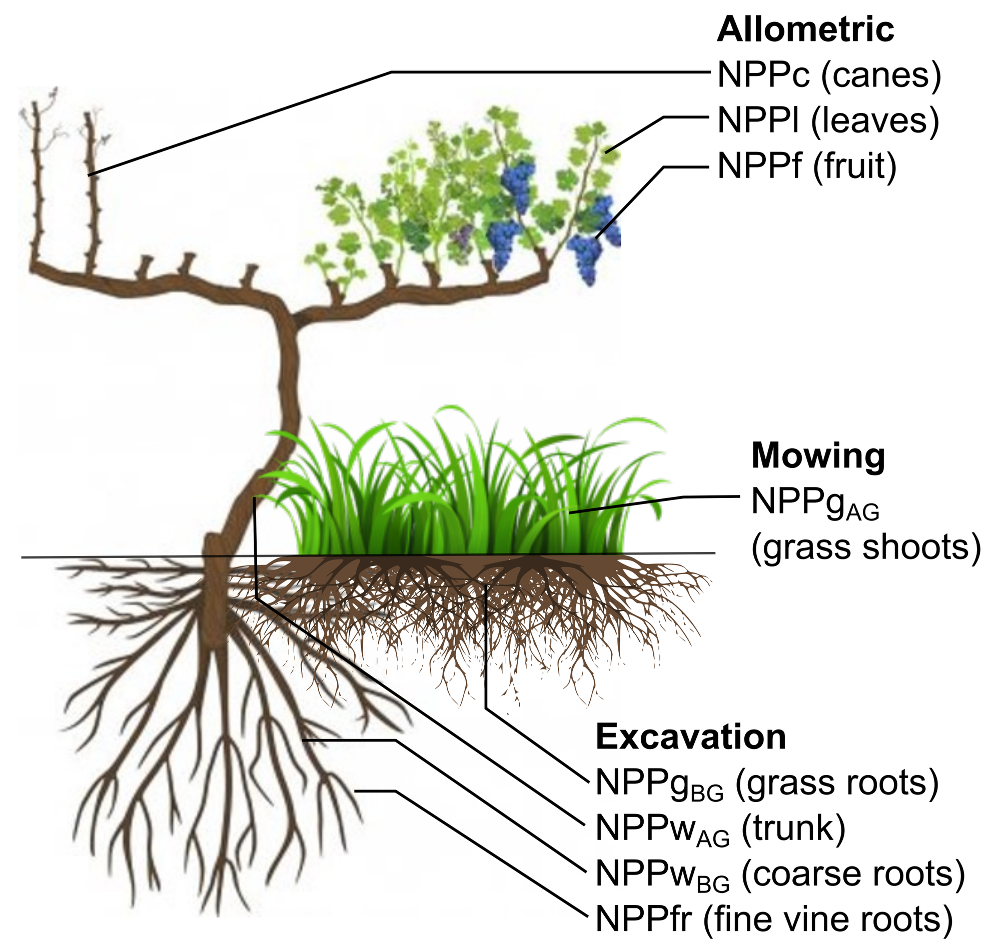

Figure 2: schematic of biometric measurements performed

Net Primary Production (NPP ≈ plant growth) was estimated for each ecosystem component (see Fig 2) using a combination of methods to regularly assess biomass. Grass was destructively mown and biomass of annual vine organs quantified by constructed allometric equations. Permanent vine and below-ground biomass were assessed through destructive excavation at the end of the season.

Net Ecosystem Exchange (NEE) of the vineyard was observed continuously by **eddy covariance** (Li-7200 gas analyzer; Gill R3-50 3D sonic anemometer; 6 m above ground). NEE was partitioned into **Reco (ecosystem respiration)** and **GPP (Gross Primary Production)**.

Complementary **soil respiration** measurements were taken using a Li-8100 (Li-Cor) gas analyzer and survey chamber, measuring both **total soil respiration (Rs)** and **heterotrophic respiration (Rh)**.

Figure 3: the eddy covariance tower

Figure 4: soil respiration survey equipment on a trenched plot, giving Rh.

Results

The vineyard was a **moderate carbon sink** during the growing season (**NEE = -246 ± 54 g C m^{-2}**), with very large **large GPP (2409 ± 35 g C m^{-2}) and Reco (2163 ± 88 g C m^{-2})**.

The seasonal pattern was strongly defined by two periods of drought occurring in June-July and August-September, which **increased NEE.** Irrigation was supplied to the vines during these periods.

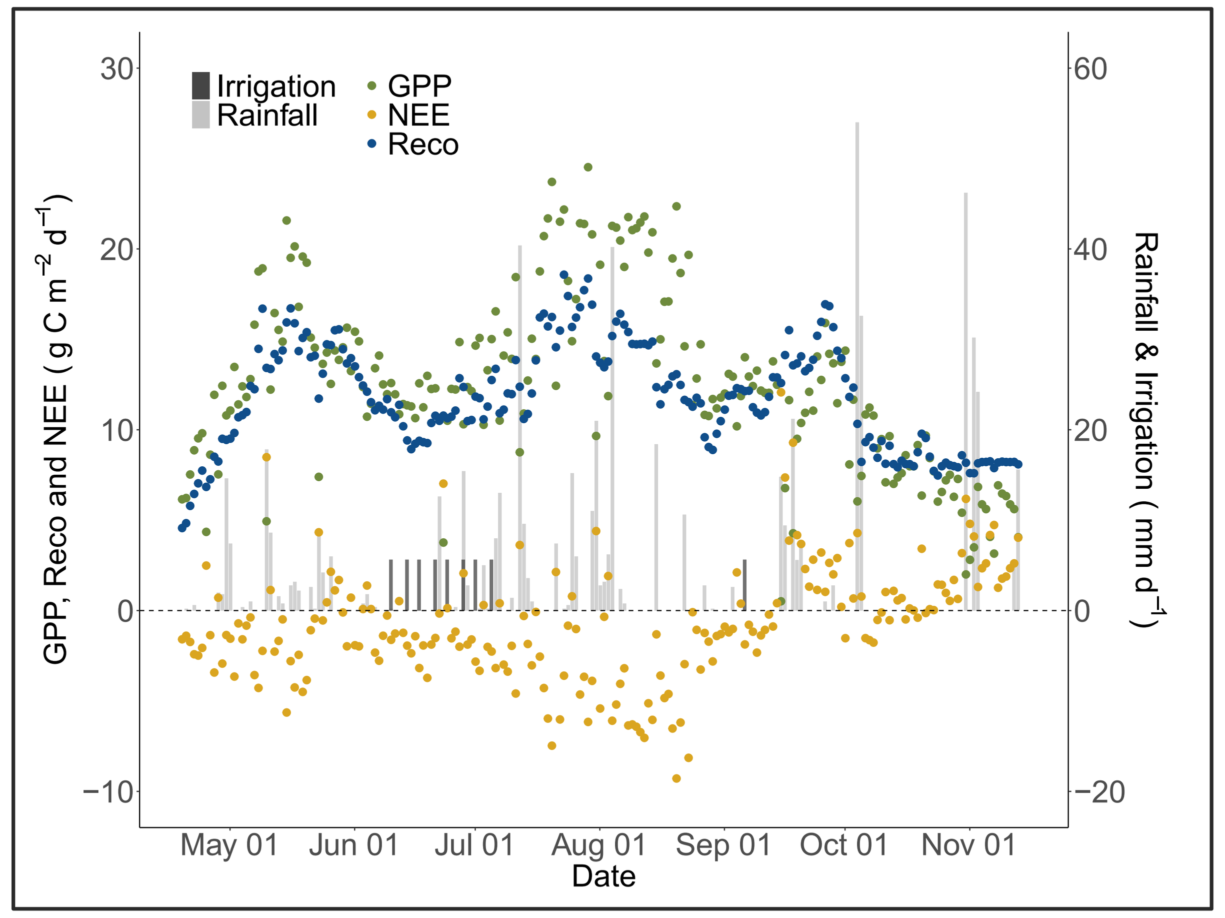

Figure 5: seasonal pattern of daily carbon fluxes measured by eddy covariance, with irrigation and precipitation events.

Biometric measurements showed that the **ground cover vegetation contributed a large portion of total carbon accumulated**. Grapes were the second largest carbon sink during the season, but were exported after harvest, decreasing Net Ecosystem Carbon Balance (NECB) with respect to NEE.

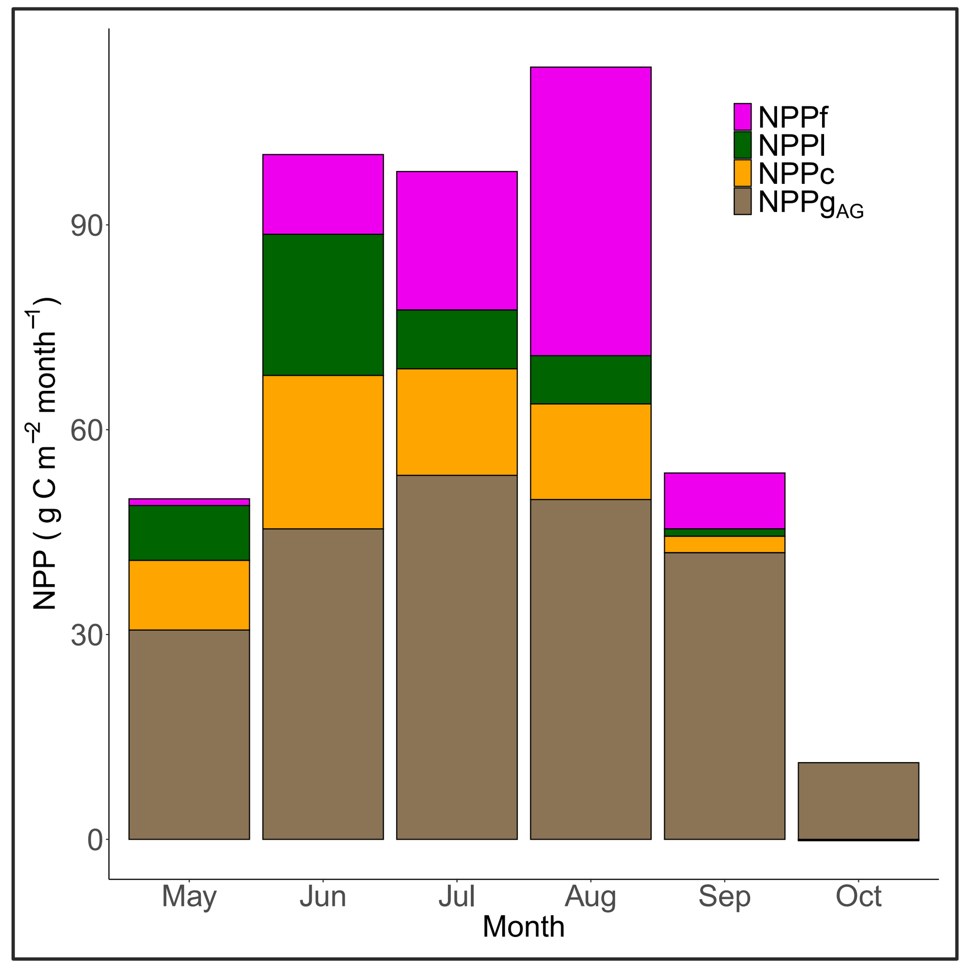

Figure 6: monthly NPP of above-ground ecosystem plant components. For seasonal totals, see Fig. 7.

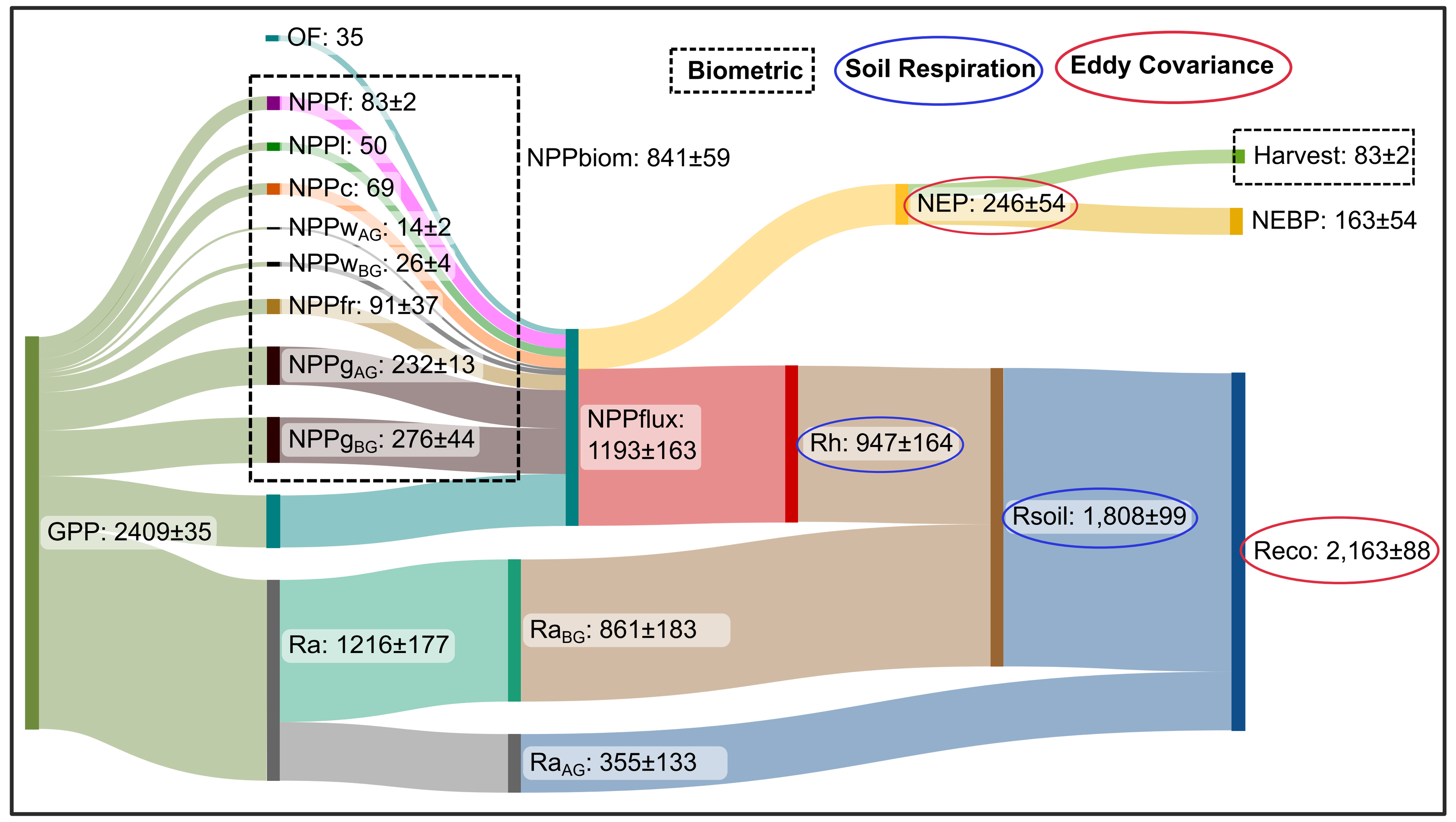

Figure 7: overview of total carbon fluxes for the growing season. Fluxes without borders indicating source were derived by mass balance, with the exception of OF (Organic Fertilizer). Ra: autotrophic respiration. Ra_{BG} and Ra_{AG}: below and above-ground autotrophic respiration. NPPflux = NEP + Rh. NPPbiom was derived from the sum of biometrically-measured NPP.

Of the remaining NECB, **24% is due to an increase in woody organ biomass** ($NPPw_{AG}$ + $NPPw_{BG}$). The rest is presumably due to increasing soil organic carbon and litter buildup.

The **soil respiration (Rs) accounted for most of Reco**, and had a **dominant heterotrophic component (Rh)**. This indicates that much of the carbon input to the system (e.g.: vine and grass leaves, winter pruning debris) is lost during decomposition.

Discussion & Conclusions

The ecosystem fluxes observed were more **similar to grasslands in magnitude and proportion** than to other tree ecosystems such as temperate forests, apple orchards or bare-soil vineyards. This behaviour is confirmed by the large contribution of grasses to NPP, and is likely a result of the open-canopy structure of the vineyard.

However, vines still contribute substantially to long-term carbon storage through increased permanent biomass and recalcitrant litter. The **grass fraction is more labile** and easily decomposed, leading to high Rh and Reco.

The increased NEE observed during drought periods was likely due to stress suffered by the unirrigated grasses, but the resolution of the $NPPg_{AG}$ measurements was not sufficient to test this. Mowing may also have distorted results.

Recommendations

In future, the **understorey should be strongly accounted for when considering carbon fluxes** in similar agroecosystems (open canopy, presence of ground vegetation). This is currently not the case in many wide-scale carbon flux methodologies (e.g.: land surface models, satelite-based remote sensing). Improving this may lead to more accurate flux prediction.

More studies describing the carbon input (GPP or NPP) of each strata in **higher temporal resolution** would help elucidate the effects of climate stress and management in more detail, as well as the **interaction between layers**.

Acknowledgements

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Authors: Torben Oliver Callesen[1]*, Carina Verónica Gonzalez[1,2,3], Flavio Bastos Campos[1], Damiano Zanotelli[1], Massimo Tagliavini[1], Leonardo Montagnani[1]

[1] Faculty of Science and Technology, Free University of Bozen-Bolzano, Bolzano, Italy.

[2] Instituto de Biología Agrícola de Mendoza (CONICET-UNCUYO), Mendoza, Argentina.

*email: tcallesen@unibz.it

[3] Facultad de Ciencias Agrarias, UNCUYO, Mendoza, Argentina.

Photography encouraged

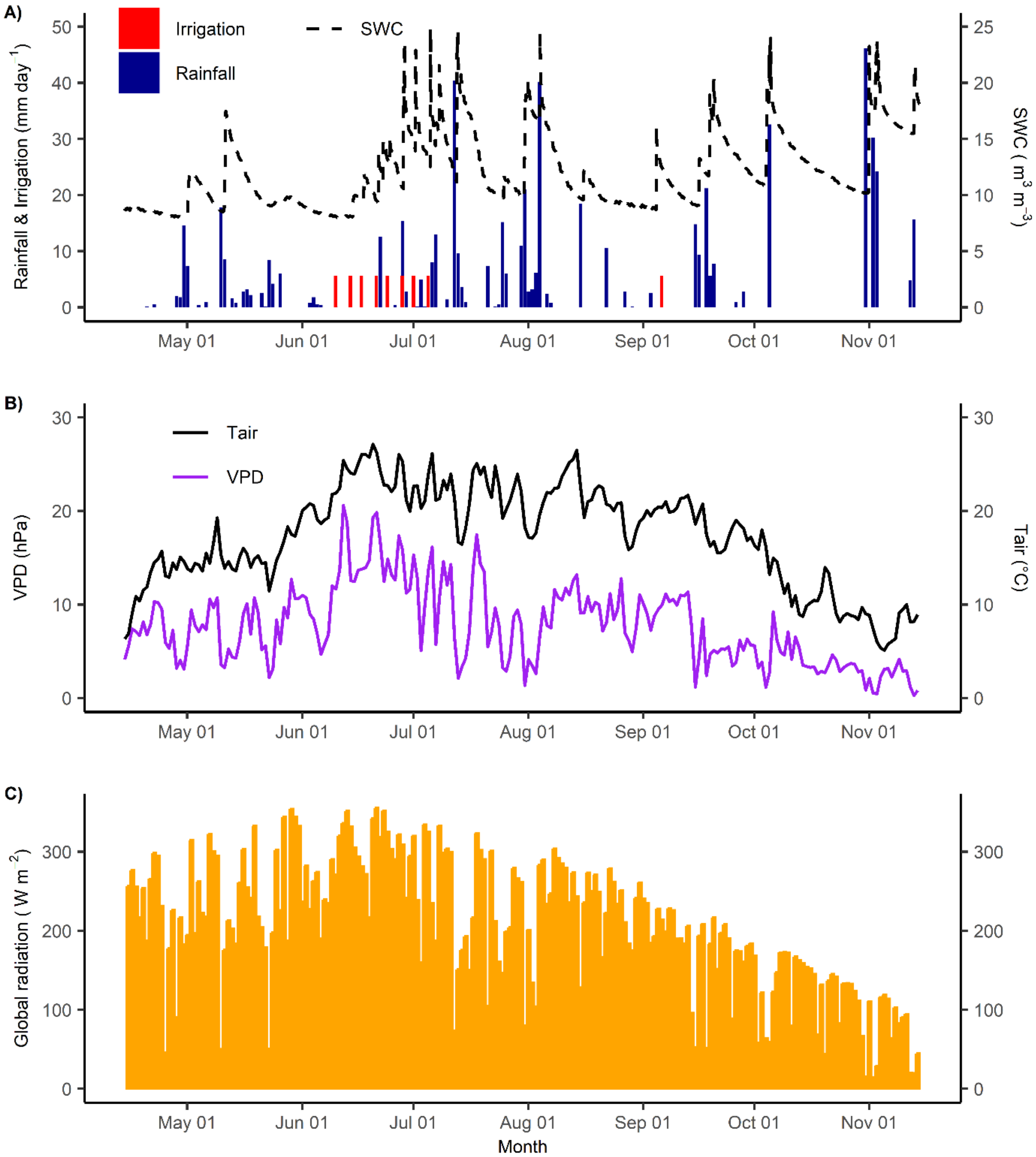

Figure 8: Climatic variables measured at experimental site during the growing season. (A) Rainfall, irrigation and SWC; (B) VPD and Tair; (C) Rg.

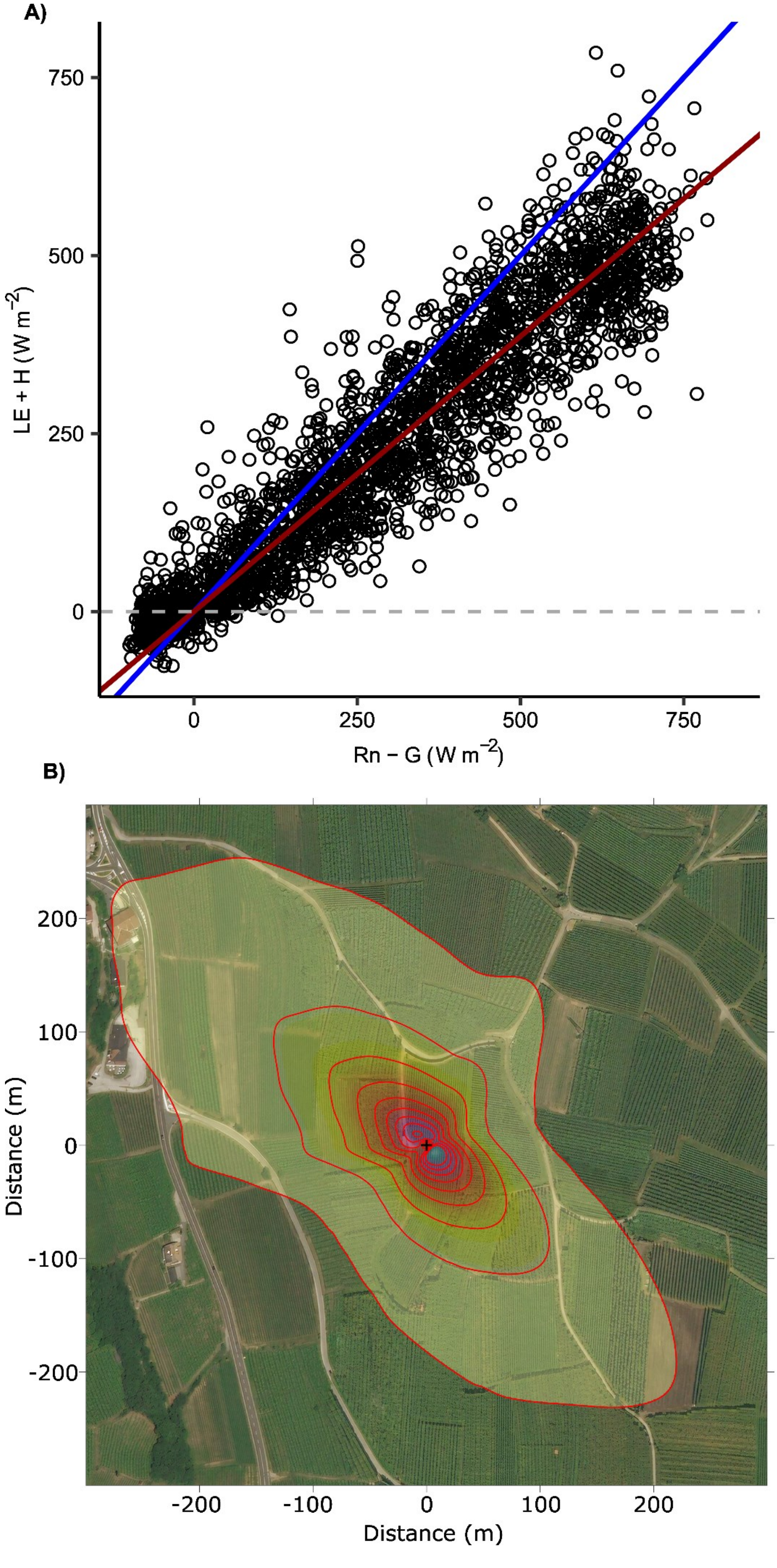

Figure 9: Characterization of the eddy covariance measurements in Plantaditsch vineyard. (A) Energy balance closure (LE+H vs. Rn-G) during the growing season (May to October 2021). Latent heat (LE), Sensible heat (H), Net radiation (Rn) and soil ground flux (G). Points represent half-hourly values. The red line denotes the simple linear regression (equation, R^2 and p-value shown), and the blue line is the ideal 1:1 line. (B) Footprint map defined following Kljun et al. (2015).

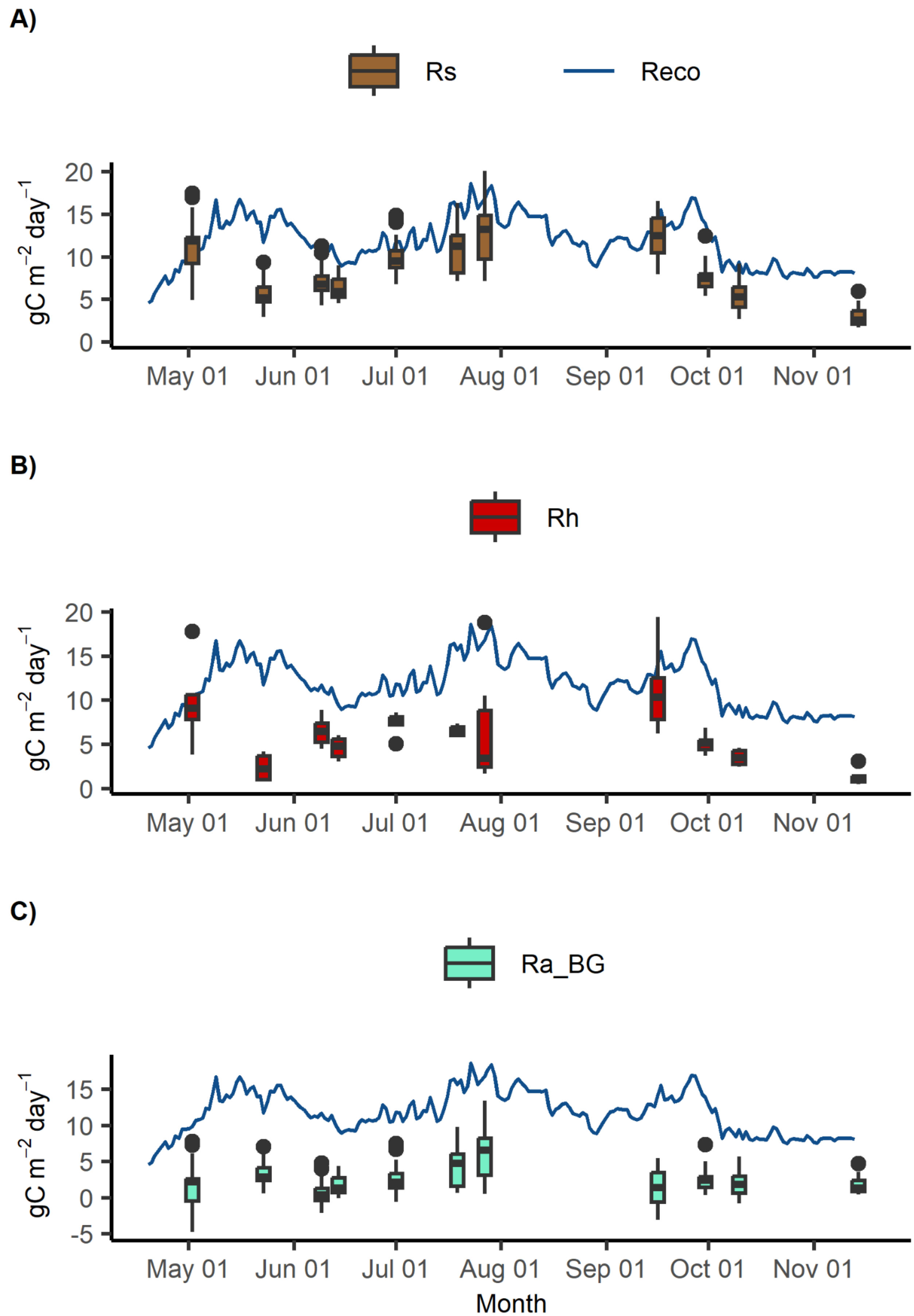

Figure 10: Soil respiration fluxes compared with eddy covariance-based Reco. (A) Reco and Rs; (B) Reco and Rh; C) Reco and Ra_{BG}.