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Final report:

The effect of grassland abandonment on organic carbon and nitrogen in subalpine soils
Auswirkung eines Landnutzungswechels auf Menge und Umsatz von Kohlenstoff und Stickstoff in subalpinen Böden
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Introduction

Mountain ecosystems are particularly subject to land-use changes. The European Alps have experienced human-induced land-use changes with increasing damage to ecosystem services due to the onset of socio-economic transformations during the last 150 years. In the course of tertiarization and depopulation, less accessible mountain areas have been abandoned increasingly since the late last century. *Tappeiner* et al. (2008) estimated that within a period of 20 years (1980-2000) on average 20% of the usable agricultural areas have been abandoned.

Until today it remains unclear to what extent the abandonment of mountain grassland affects the soils' function to store organic carbon (SOC). Previous findings of the Air pollution / Climate group of ART show that mountain soils contain high amounts of labile carbon (C) but the sink/source potential in relation to the current trend in land use and climate warming remains an open question.

Within the framework of COST-Action 639 "Greenhouse gas budget of soils under changing climate and land use" the effects of grassland abandonment on SOC distribution, dynamics and stabilization were studied. The results of this project shall also lead to an improved evaluation of SOC fluxes in national greenhouse gas inventories. This final report relates to the whole project period (2008-2012) including the financial support of SBF.

Methods

To capture the current trend of grassland abandonment we studied two management intensity gradients both including hay meadows, pastures and abandoned grasslands in two typical mountain climates (Figure 1). A first land-use gradient was located at a moist site in the Stubai Valley in Tyrol (Austria) (N47°07', E11°18'/19') at 1820-1950 m a.s.l. (Stubai site). A second, drier site was located in the inner-alpine Matsch Valley in South Tyrol (Italy) (N46°42', E10°38') at 1790-1860 m a.s.l. (Matsch site). At the two sites, mean annual precipitation is 1097 mm and 527 mm, and mean annual temperature is 3°C and 6.6°C, respectively. Soils at both sites were Cambisols. Using this gradient approach we substituted time by space in order to analyze in parallel three different systems at two mountain valleys.

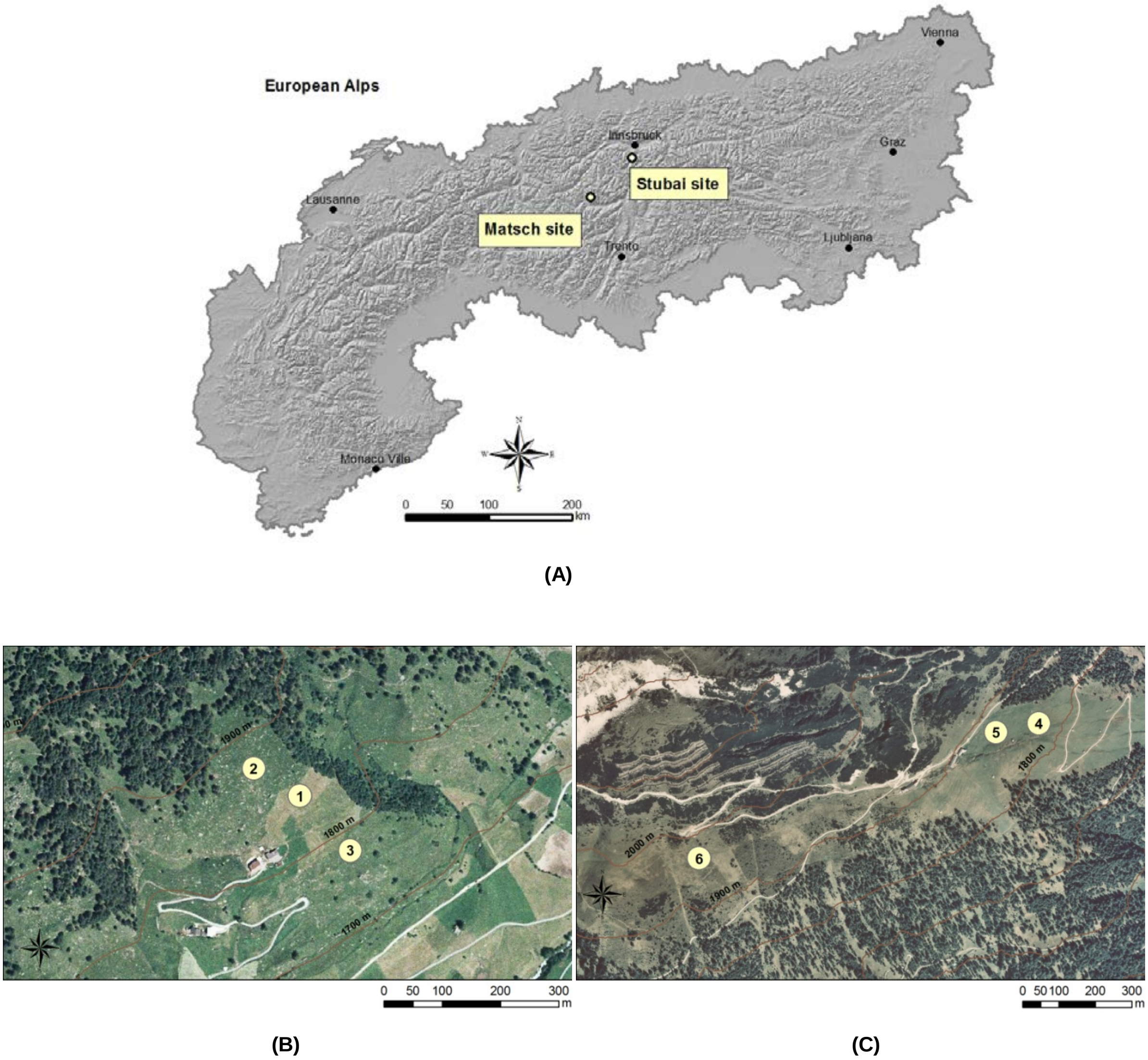

Figure 1 Location of the two study sites in the central Alps (A) and location of grasslands at (B) the Matsch site and (C) the Stubai site. 1 intensively managed meadow, 2 moderately managed pasture, 3 abandoned grassland (<10 years), 4 moderately managed meadow, 5 moderately managed pasture (<36 years), 6 abandoned grassland (<25 years).

In October 2008, soil samples were collected in each grassland type at 0-10 cm soil depth. As the short-term impact of land-use change on soil C decreases with depth, it was expected to detected changes in the top centimeters of the soil.

The soil samples were physically fractionated based on the scheme in Figure 2. Three aggregate size classes and three particulate organic matter density fractions were isolated to analyze the effect of grassland management on soil C distribution and aggregation. The general idea of the approach is that organic matter stabilization, which increases with mineral-association or spatial separation from decomposers, can be mimicked by soil physical fractionation. The fractionation (Fig. 3) includes the application of ultrasound to disrupt the soil structure and the subsequent release of occluded soil organic matter combined with a density separation to isolate light and labile from heavier and stable soil organic matter. In cooperation with national research institutes (ETHZ, University Basel) stable (^{15}N, ^{13}C) and radioactive isotopes (^{14}C) of the isolated soil fractions were analyzed.

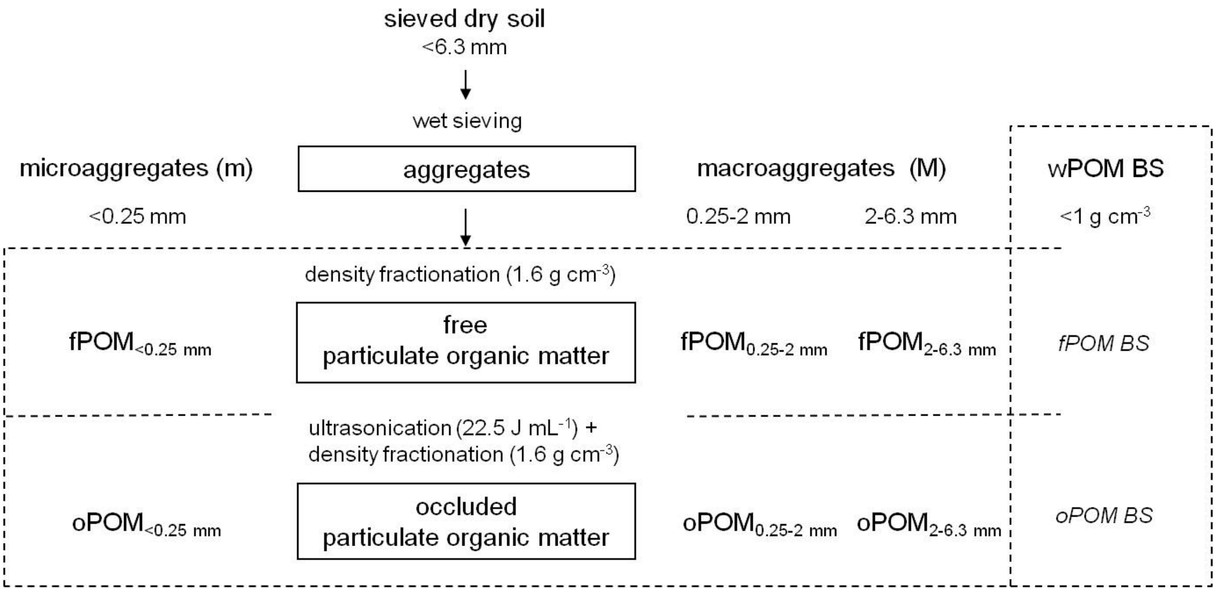

Figure 2 Physical fractionation scheme to isolate light free water floatable (w-), free (f-) and occluded (o-) particulate organic matter (-POM) of two macroaggregate size classes (0.25-2 mm, 2-6.3 mm) and one microaggregate size class (<0.25 mm). The f-and oPOM fractions of each aggregate size class were considered separately and results were numerically cumulated to receive bulk soil POM contents.

Bomb radiocarbon modeling was used to estimate carbon turnover times, accumulation rates, and thereby to assess the vulnerability of C storage to land-use change and to find the most sensitive SOM fraction to grassland abandonment (Figure 3). Because of recent land-use change abandoned grasslands are most likely not in steady state. We therefore applied steady-state modeling only to sites where steady-state conditions can safely be assumed and used non-steady-state modeling (i.e., carbon accumulation models) to derive the temporal rate of soil carbon change for abandoned sites.

Results

As planned in the project outline the physical soil fractionation and modeling techniques were succesfully applied and results now provide the first information on SOC distribution and dynamics in abandoned grasslands. As expected grassland abandonment affected mostly the labile particulate organic C (POC) in terms of distibution and biogeochemical cycling rates (*Manuscripts I, II*). The site-specific differences in POC response were independent of climate and predominantly based on the time periods since land-use change (10 vs. 36 years of abandonment).The application of bomb radiocarbon and C accumulation modeling revealed that POC accumulation is high in the first years of grassland abandonment but decreases steadily with time (Figure 4). Only the POC fractions were strongly affected by land-use change. At the warmer mountain site the stable SOC fractions showed higher C stocks but fast biogeochemical cycling rates. The bulk soil C stocks increased with grassland abandonment at Stubai but not at Matsch (Table 1). Overall, the increase in the relatively small labile fractions altered bulk soil carbon stocks only moderately and the effect cannot be generalized.

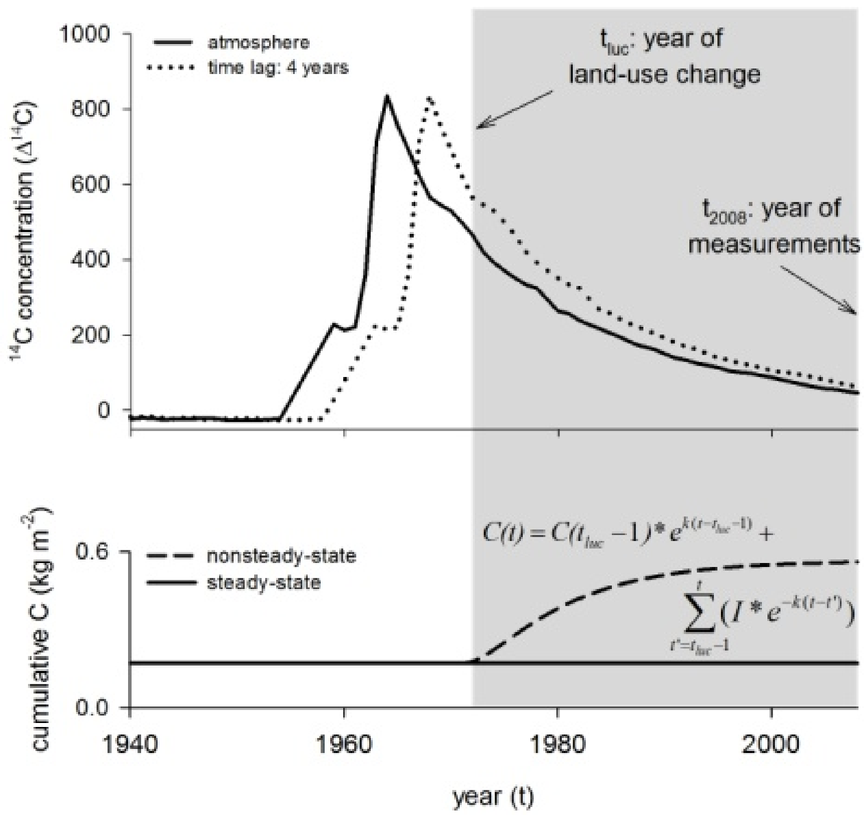

Figure 3 Upper panel: The ^{14}C concentration of the northern hemisphere. The time lag refers to the time period between photosynthetic fixation and addition to soil organic matter (SOM), which is necessary to consider for all root-derived SOM fractions. Lower panel: The generalized effect of land-use change on SOC stocks under steady-state and nonsteady-state conditions, where *C* is the SOM C stock, *I* is the C input rate and *k* the decomposition rate constant.

With up to 70% the stable C builts the major proportion of the C in grassland soils. Comparing ^{15}N, an indicator for microbial degradation, and SOC ages we found that microbial degradation continues with aging of stabilized organic matter (*Manuscript*

III). This emphasizes that stable SOC in contrast to labile SOC might play an important role under changing environmental conditions in the long term. Thanks to the cooperation with the University of Innsbruck we were able to compare our ground-based estimates of C input to flux-derived estimates for the same sites and we detected a discrepany in results with higher input rates calculated from the flux-derived estimates (*Manuscript II).* This is reasonable as both techniques cover differently active C systems in the soil and shows that results are partially method-dependent, highlighting the need for more cross-check of methods.

Table 1 C stocks of SOM fractions of grasslands at the Stubai and Matsch site (*Manuscript II*).

		C stocks (kg C m^{-2} ; 0-10 cm)		
		meadow	pasture	abandoned
Stubai	roots	0.28	0.16	0.39
	wPOM	0.08	0.11	0.83
	fPOM	0.30	0.27	1.25
	oPOM	0.32	0.36	0.42
	mOM	2.78	3.21	2.29
	SOM	**3.45**	**3.96**	**4.79**
	(1 SE)	**(0.41)**	**(0.24)**	**(0.59)**
Matsch	roots	0.12	0.28	0.30
	wPOM	0.17	0.56	0.31
	fPOM	0.37	0.57	0.54
	oPOM	0.55	0.37	0.46
	mOM	3.22	3.16	3.15
	SOM	**4.32**	**4.66**	**4.46**
	(1 SE)	**(0.10)**	**(0.24)**	**(0.32)**

We also studied the C distribution and dynamics in hay meadows along an elevation gradient (1050-1850m) at Stubai. We did not find distinct differences in SOC distribution that can be linked directly to altitudinal effects because the site-specific differences mask any possible trend. However, the information on SOC and root turnover will be used in a follow-up publication in progress, which will analyze the above and belowground C inputs to mountain grassland soils along gradients with elevation and soil depth. Furthermore, in 2008 we applied ^{13}C labeled litter to the studied grasslands to track the pathways into the soil and derive SOM turnover times. After one year we did not find any signal in the SOC fractions, except the litter fraction. Therefore we could not pursue any calculations and did not further process this data. These spots with labeled litter might now set the basis for future work as we left the possibility and space for a second sampling event, that might be conducted in several years.

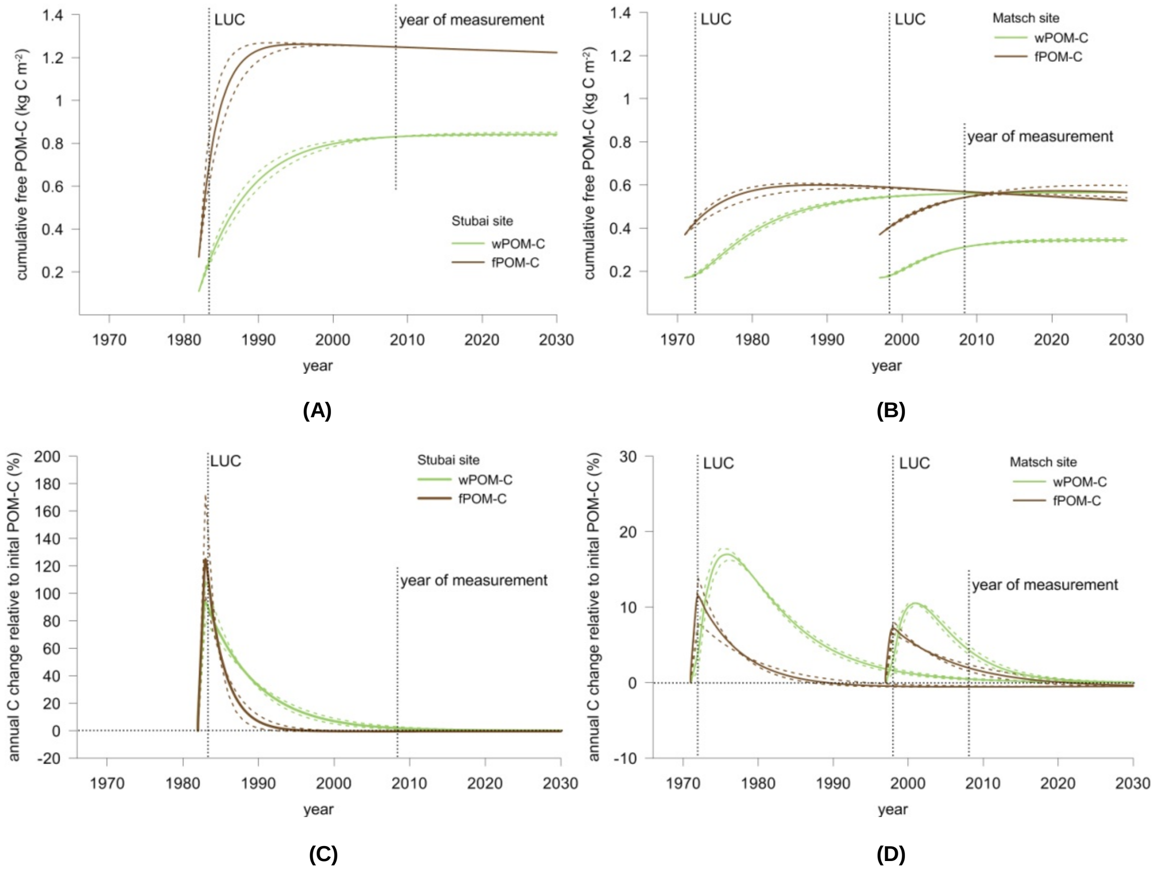

Figure 4 Carbon (C) accumulation plot of (A) water-floatable (w-) and free (f-) particulate organic matter (POM) in nonsteady state abandoned grassland at the Stubai site from start since land-use change (LUC) in 1983 predicted until 2030 and (B) w- and fPOM-C in nonsteady state pasture and abandoned grassland at the Matsch site from start since LUC in 1972 and 1998 predicted until 2030, respectively.
Annual relative change in wPOM-C and fPOM-C since start of LUC in (C) nonsteady state abandoned grassland (1983) predicted until 2030 at the Stubai site and (D) in nonsteady state pasture (1972) and abandoned grassland (1998) predicted until 2030 at the Matsch site. C stocks were measured in year 2008. Dashed lines represent 1 σ of radiocarbon measurements (*Manuscript II*).

The results are available to the public in the following manuscripts:

(I) Meyer, S., Leifeld, J., Bahn, M., Fuhrer, J. (2012): Land-use change in subalpine grassland soils: Effect on particulate organic carbon fractions and aggregation. J. Plant Nutr. Soil Sci., in press.

(II) Meyer, S., Leifeld, J., Bahn, M., Fuhrer, J., (2011): Free and protected soil organic carbon dynamics respond differently to abandonment of mountain grassland. Biogeosciences Discuss. 8, 9943-9976.

(III) Meyer, S., Leifeld, J. (2012): Soil microbial transformation continues after soil organic matter stabilization. Soil Biol. Biochem., submitted.

Conclusions and Perspectives

The most important conclusion that we can derive from the project is that the abandonment of mountain grassland does not provide a substantial C sink that can be accounted for in greenhouse gas inventories. Within 23 years about 11’000 ha area have been abandoned in the subalpine zone of Switzerland (estimation based on Swiss Land Use Statistics (AREA) and biogeographical elevation zones after Walter Dietl; data compiled by Erich Szerencsits, GIS, ART). Even with the higher accumulation rate at Stubai of 13.4 t C/ha with conversion of meadow to abandoned grassland within 26 years in a typical mountain climate we can derive an average yearly gain of approximately 5’700 t C/ha yr in the top 10 cm of the soil for the aggregated area of abandoned Swiss grasslands. However, the latest National Inventory Report of Switzerland 2011 states that soil C stocks decrease from 75 to 68 t C/ha from CC31 to CC32, i.e. with abandonment. Based on our measurements in two typical climates and management techniques in the European Alps we suggest that these values should at least be equal, i.e., abandonment prior to transition to forests should not be accounted for as a soil C source.

The definition of C sink implies that the sequestration is permanent. In the Swiss Jura and pre-Alps for example, high direct payments from the government induce a counteracting trend towards grassland intensification The stored labile C will likely be lost within years when abandoned grasslands are turned back into management.
Recent work from David Hiltbrunner at WSL as part of an accompanying COST project within COST 639 indicates that labile C will continue to accumulate with continuation of abandonment towards fully developed mountain forests. This is in line with recent results from a meta-analysis in the temperate zone where the accumulation of forest floor, the forest’s counterpart to labile POM in grasslands, was shown to be the most relevant response to land-use change (*Poeplau* et al. 2011). Abandoned grasslands however, as transitional stages between managed grasslands and forest with indefinite temporal dimension, do not offer a substantial potential C sink. In contrast we see a trend of increased turnover of the stable SOC fractions albeit the corresponding mechanisms are yet unknown.

Based on our results we conclude that the stable rather than the labile C deserves more attention as it is the most abundant fraction in soil. We also recommend to fortify efforts to compare various techniques for estimating C fluxes in grassland soils as results might differ.

References

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Poeplau, C., Don, A., Vesterdal, L., Leifeld, J., van Wesemael, B., Schumacher, J., Gensior, A. (2011): Temporal dynamics of soil organic carbon after land-use change in the temperate zone – carbon response functions as a model approach. Global Change Biol. 17, 2415-2427.

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