Experimental drought and soil amendments affect grassland above- and belowground vegetation but not soil carbon stocks ~~Spatial and temporal variability in soil and vegetation carbon dynamics under experimental drought and soil amendments~~

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Abstract

Soils are the largest terrestrial carbon (C) pool on the planet, and targeted grassland management has the potential to increase grassland C sequestration~~and grassland soils have a particularly large C sequestration potential~~. Appropriate land management strategies, such as organic matter additions, can ~~improve soil health,~~ increase soil C stocks~~,~~ and increase grassland resilience to drought by improving soil ~~moisture retention~~water retention and infiltration. However, soil carbon dynamics are closely tied to vegetation responses to management and climate changes, affecting ~~both~~ roots and shoots differently.~~However, soil C dynamics are deeply linked to vegetation response to changes in both management and climate, which may also be manifested differently in roots and shoots.~~ This study presents findings from a three-year field experiment on two Swedish grasslands that assessed the impact of ~~a~~ compost amendment and ~~of~~ reduced precipitation on plant biomass and on soil C at various soil depths~~soil and vegetation C pools~~. Aboveground biomass and soil C content (% C) increased compared to controls in compost-amended plots~~Compost addition increased aboveground biomass and soil C content (%C)~~, but because bulk density decreased, there was no significant effect on soil C stocks. Experimental drought did not significantly reduce plant biomass compared to control plots, but stunted the increase in aboveground biomass in compost-treated plots and led to changes in root traits.~~Drought decreased aboveground biomass, but did not significantly affect root biomass. Overall, the soil amendment shifted C allocation to aboveground plant organs, and drought to belowground organs. We also observed significant spatial and temporal variability in vegetation biomass and soil C over the study period.~~ These results highlight the complexity of ecosystem C dynamics and the importance of considering~~the need to consider~~ multiple biotic and abiotic factors

~~driving ecosystem C dynamics~~ across spatial scales when developing land management strategies to enhance C sequestration ~~when upscaling results from field trials~~.

Introduction

~~Management of soil health and soil carbon (C) stocks~~Soil management has been receiving increasing attention in the past years, with growing awareness that soils provide vital ecosystem services and can act as C sinks (Minasny et al. 2017, European Commission, Directorate-General for Health and Food Safety, 2020). The soil-plant system is integral to this process, as plants capture atmospheric carbon dioxide through photosynthesis and transfer it to the soil via roots and organic matter. Concerns about soil erosion and historic soil C depletion in agricultural and grassland soils (Sanderman et al. 2017, Bai and Cotrufo, 2022) have motivated the development of sustainable land management strategies, ~~sometimes~~ generally named "carbon farming" (Paul et al. 2023) and promoted by the "4 per 1000" initiative (Minasny et al. 2017). These approaches include mitigating soil organic carbon (SOC) loss in specific sites resulting from agricultural activities such as tilling, which can be achieved with~~One such strategy is~~ the use of soil C amendments ~~(Ryals and Silver 2013; Ryals et al. 2015; Keesstra et al. 2016; Fischer et al. 2019; Garbowski et al. 2023), including~~ like compost, biochar, and ~~various types of~~ manure on croplands or grasslands (Ryals and Silver 2013; Ryals et al. 2015; Keesstra et al. 2016; Fischer et al. 2019; Garbowski et al. 2023)~~.~~ ~~These treatments can be applied on croplands or rangelands, in single or multiple applications~~.~~, and can increase soil aggregation (Sarker et al. 2022)~~ Soil C management via compost ~~-~~amendments aims ~~at transferring plant-derived organic matter~~ to facilitate ~~C~~ accumulation of plant-derived C in the soil C pool~~ in specific locations~~, where it can be retained over long time scales – i.e. decades to centuries (Shi et al. 2020). If the total C inputs and accumulation in the soil exceed the total losses, C amendments can lead to C sequestration (Don et al. 2024, Moinet et al. 2023). ~~, and mitigate soil organic carbon (SOC) loss resulting from human activities such as tilling. In some cases, C amendments have even been proposed as means to actively sequester C in soils, with initiatives like the "4 per 1000" (Minasny et al. 2017)~~ have been ~~promoting their implementation as a climate change mitigation strategy. Consequently, soil C management methods aim to shift the ecosystem C balance by facilitating the movement of C from the atmosphere into vegetation and subsequently, into the soil C pool, where it can be retained over long time scales.~~

Since SOC accrual and C sequestration potential are uncertain and context dependent (Moinet et al. 2023), it is important to investigate the effects of C amendments across a range of climatic and management conditions. Grasslands and croplands converted to grasslands can store considerable amounts of soil C and are therefore ideal systems to apply C amendments. They can act as C sinks if managed appropriately (Conant et al. 2001), and can have higher root biomass C compared to agricultural lands, usually cultivated with annual crops (Beniston et al. 2014). ~~Many~~Several studies have investigated the effects of organic amendments on aboveground biomass (Ryals et al. 2016), ~~on~~ crop yields (Luo et al. 2018; Ahmad et al. 2009), and o~~f~~n roots in farming systems (Hirte et al. 2021), but fewer focus on non-cultivated grasslands. ~~i~~

C amendments add C to the soil in two ways: directly, by moving plant biomass from one location to another, and indirectly, by promoting plant growth (Ryals et al. 2016). Compost is rich in organic matter, which serves as a substrate ~~food source~~ for soil microorganisms. As microbes decompose this organic matter, they release nutrients in forms that plants can readily absorb (Malik et al. 2013). In turn, the increased vegetation growth can increase the natural rate of C input and thus potentially SOC stocks (Ryals et al. 2013). Indeed, ~~and~~ model predictions suggest that compost additions on grasslands can lead to soil C sequestration (DeLonge et al. 2013). By improving soil structure and reducing compaction, compost additions may also reduce soil bulk density. As SOC stocks are calculated by multiplying C concentration by the bulk density, improved management may also lead to net zero effects on C stock despite increased soil C contents~~Adding C to soils in the form of amendments directly increases the standing stock of SOC, but C amendments may also act as a primer to an ecosystems natural ability to sequester C via indirect effects. If C amendments promote plant growth, they also increase the natural rate of C input to the soil and thus potentially SOC stocks if the additional C input is stabilized and does not promote mineralization of native SOC~~. Considering these indirect effects requires an ecosystem-level perspective on the ~~potential~~ C ~~soil C~~ sequestration potential of~~potential~~ ~~in~~ soils that accounts for both below- and above-ground vegetation contributions to soil C stocks, as well as the soil depth at which management effects are detectable. To this end, the use of isotope-labelled compost can improve our understanding of soil C dynamics.

Land management practices—including ~~C~~compost amendments—~~-~~can significantly impact both above- and belowground plant biomass, which contribute differently to SOC storage. Root biomass~~,~~

~~belowground plant organs~~ ~~-~~and root exudates are an integral part of soil C formation and retention (Jackson et al., 2017). In fact~~;~~, roots are more recalcitrant to decomposition compared to shoots (Rasse et al. 2005, Gaudinski et al. 2000), and play a central role in C sequestration efforts. However, aboveground plant biomass should also be included in these assessments to identify potential trade-offs in above- vs.~~and~~ belowground C allocation within the vegetation pool, and to determine whether ~~there are~~ changes in plant biomass ~~vegetation C pools which may~~ affect the soil C pool (Hayes et al. 2017). ~~It is especially important to determine the proportion of plant litter that contributes to soil organic matter (SOM) formation and stabilization (Cotrufo et al. 2015).~~ Above- and belowground biomass may also respond differently to soil amendments (Garbowski et al. 2020). This variation is expected, as roots and shoots respond differently to changes in nutrient (Hayes et al. 2017) and water availability (Wilcox et al. 2017; Guasconi et al. 2023). Therefore, an approach that accounts for above- and belowground interactions is essential to understand the proportion of plant litter contributing to SOM formation and stabilization (Cotrufo et al., 2015), and to ~~get~~ achieve a comprehensive understanding of ecosystem C dynamics (Heimann and Reichstein, 2008).

~~Land management practices, whether through conventional or regenerative methods, can significantly impact soil C and plant biomass both above- and belowground. For instance, historic land use has depleted the soil of C (Sanderman et al. 2017), and agricultural lands have lower root biomass C compared to managed grasslands (Beniston et al. 2014). Organic amendments affect different properties and mechanisms in soils, including soil aggregation and structure, soil microbial communities, and plant roots, and the interactions between these elements (Sarker et al. 2022, Liu et al. 2016). Amendments provide nutrients that can stimulate microbial activity and plant growth (Hammerschmiedt et al. 2021), and increase crop yields (Luo et al. 2018).~~ Another promising application of soil organic amendments ~~-~~is their use to mitigate the negative effects of drought on vegetation and soil microbial communities, as has been observed with biochar (Fischer et al. 2019) ~~(Fischer et al. 2019)~~. Future climate projections indicate an increase in extreme weather events, including longer and more frequent droughts (IPCC, 2021). These conditions may decrease vegetation growth both above- and belowground (Guasconi et al., 2023) and modify plant carbon (C) allocation (Hasibeder et al., 2015), leading to lower C inputs to the soil and potentially decreased soil C stocks (Deng et al., 2021). ~~, which may decrease the soil C sequestration capacity of grasslands by altering plant community composition, plant C allocation and microbial processes (Bai and Cotrufo,~~

~~2022).~~ Organic soil amendments can enhance resilience to drought by increasing soil's water-holding capacity ~~to retain soil moisture~~ (Fischer et al. 2019; Haque et al. 2021). These effects ~~of soil amendments on water retention capacity~~ are modulated by soil texture, by the quantity and quality of soil organic matter (Rawls et al. 2003; Yang et al. 2014; Franco-Andreu et al. 2017; Sarker et al. 2022) and by ~~the~~its chemical composition ~~of the compost~~ (Franco-Andreu et al. 2017). ~~This~~The increased moisture retention can also indirectly benefit the ecosystem C balance by partly compensating the drought-induced loss of plant biomass (Kallenbach et al. 2019; Ali et al. 2017).

~~Many studies have investigated the effects of organic amendments on aboveground biomass (Ryals et al. 2016) and on crop yield (Luo et al. 2018; Ahmad et al. 2009, Hirte et al. 2021), but fewer focused on roots and on non-cultivated grasslands. Garbowski et al. (2020) observed that soil amendments can have an effect only on aboveground biomass or only on belowground biomass, which may be expected since roots and shoots respond differently to changes in nutrient (Hayes et al. 2017) and water availability (Wilcox et al. 2017; Guasconi et al. 2023). Furthermore,~~ S~~s~~oil and plant communities can show great variability in response to both drought (Guasconi et al. 2023; Canarini et al. 2017) and soil amendments (Gebhardt et al. 2017). This variability derives partly from the variable physical properties of soil, but can also depend on land use history or on small- and large-scale topography (Wang et al. 2020)~~.~~, and highlights the need for more field-based data collections—in particular under experimental conditions that combine soil amendments and drought.~~This may partly explain why results from field vs. lab experiments can differ considerably (Canarini et al. 2017), and highlights the need for more field-based data collections—in particular under experimental conditions that combine soil amendments and drought.~~

Here, we present the results of a field experiment designed to assess the effects of ~~a soil amendment~~compost and of reduced precipitation on both soil and plant biomass after three growing seasons. ~~vegetation C pools, where we observed changes~~The changes were observed at various soil depths, in two grasslands, and at two catenary positions, i.e. at the top and at the bottom of a slope. ~~Because the effects of already partly decomposed organic amendments can be expected to be longer-lasting than those of easily decomposable ones (Sarker et al. 2022), we applied a one-time compost treatment coupled to a yearly growing season drought and investigated their effect on the soil C stocks after three full growing seasons. We measured soil organic C contents (mass of C per unit mass of~~

~~soil) and soil C stocks (calculated as C content × bulk density × layer thickness) at different depths within the soil profile, and vegetation biomass (encompassing both root biomass and aboveground biomass, including plant litter). ~~We tested the hypotheses that:

1) compost amendment increases soil C content and plant growth (both having positive effects on C stocks), while decreasing soil bulk density (having a negative effect on C stocks); we expect that these mechanisms have counteracting effects on net soil C storage;

2) d~~D~~rought will have a weak negative or non-detectable effect on SOC by decreasing both productivity (organic C input) and respiration (microbial decomposition of SOM)~~by decreasing both productivity (organic C input) and respiration (microbial decomposition of SOM), drought will have a weak or non-detectable effect on SOC~~;

3) compost amendment mitigates the loss of soil moisture under drought which may alleviate loss of plant growth under drought.

~~Because of the sensitivity of vegetation to natural variability in precipitation (Liu et al. 2020) and potential effects of landscape heterogeneity on both soil C dynamics and plant growth (Sharma et al. 2022; Guo et al. 2018), the analyses include testing for differences in the control plots between the start and the end of the experiment, as well quantifying the variability given by grassland and catenary position, which we expect might lead to variations in all C pools.~~

Methods

Site description and experimental setup

The experimental site was established in summer 2019 in the proximity of Tovetorp Research Station south of Stockholm, Sweden, and consists of two former arable fields (hereafter called "Tovetorp" and "Ämtvik"), each with an upper and a lower catenary position (hereafter called "high" and "low"). Today, the land management consists of cow grazing and hay production (see Roth et al. 2023)~~the fields are managed for grazing and haymaking~~. Soil in all locations is rich in clay and ranges from silty clay to silty loam (table S1).

In each of these four locations, four treatments~~ (compost, drought, drought-compost, control)~~ were applied in three replicates, resulting in 12 plots per location and 48 plots in total: compost, drought, drought-compost, control (ambient precipitation, no compost treatment). Each plot measured 2x2 m. ~~Soil in all locations is rich in clay and ranges from silty clay to silty loam. ~~Because the effects of already partly decomposed organic amendments can be expected to be longer-lasting than those of easily decomposable ones (Sarker et al. 2022), we applied a one-time compost treatment ~~coupled~~combined with~~ to~~ a ~~yearly~~ growing season drought and investigated the effects on the soil C stocks after three full growing seasons. The compost was made of *Zea mays* with a C:N ratio of 9.8 and $\delta^{13}C$ value of about -15.39‰. -After the seasonal corn harvest (summer 2019) the green parts of the plants were collected in an open field. The piled material was regularly stirred to promote the composting process, and the resulting compost was collected and ~~and was~~ applied in mid-February 2020 as a thin surface layer of ca. 11 kg per m^2 (wet weight), similar to the procedure described in Ryals and Silver (2013). The total amount of C added is ~~estimated to be~~on average ~0.54 kg C m^{-2}. The $\delta^{13}C$ isotope ratio of the compost is higher than that of bulk soil (-15.39 and -27.25, respectively), which means that the $\delta^{13}C$ isotope ratios of different treatments can be used to assess if and where in the soil the compost material is retained after the three years of treatment.

The drought treatment followed the guidelines of the Drought-Net Research Coordination Network (Knapp et al. 2017; Yahdjian and Sala, 2002), and consisted of 12 rainout shelters (3 per location) with roofs made out of evenly-placed v-shaped polycarbonate strips designed to exclude 60% of the precipitation during the entire growing season (in place from beginning of July to end of October in 2019, and from beginning of April to end of October in 2020, 2021 and 2022). This precipitation reduction corresponds to the 1st quantile of the local 100-year precipitation record (Swedish Meteorological and Hydrological Institute, 2021). Each shelter covered two plots, one for the drought treatment and one for the combined drought-compost treatment. A rubber sheet, approximately 40 cm in depth, was inserted in the soil around each shelter to isolate the study plots from the ambient soil moisture. Pictures and sketches of the sites and of the experimental design are presented in Roth et al. (2023). Total annual precipitation during the study years was retrieved from the records of Tovetorp Research Station (table S2). We note that while the precipitation in the growing seasons 2019 and 2022 (April through August) was roughly the same (157 mm and 156 mm, respectively), the 2019 sampling followed an extremely dry summer in 2018, when the study area received only 77 mm of precipitation, about half of the precipitation compared to the average 1961-1990 (historical data from SMHI, 2021). Conversely, the 2022 sampling followed the very wet 2021, when the area received almost 140% of the normal precipitation over the same time period (250 mm).

Soil and vegetation sampling and analyses

Soil and root samples were collected in three replicates from each of the four sites and treatments (one sampling per plot) at the end of the first growing season in 2019 (August - September), and again at the end of the experiment in 2022 (August and October). ~~Soil and root samples were collected in all plots at the end of the first growing season in 2019 (August-September), and again at the end of the experiment in 2022 (August and October). Samples for soil bulk density were collected to a depth of 45 cm with a large fixed volume root auger with a sharpened cutting edge (8 cm diameter; Eijkelkamp, The Netherlands).~~ Samples for soil bulk density were collected with a large fixed volume root auger with a sharpened cutting edge (8 cm diameter and 15 cm in length; Eijkelkamp, The Netherlands). Three 15 cm segments were collected sequentially using the same hole, reaching a total depth of 45 cm. Upon extraction, the cores were cut into 5 cm segments, and the bulk density was determined after drying the samples at 105 °C~~The cores were taken incrementally every 15 cm and then divided in 5 cm segments, and the bulk density was determined after drying the samples at 105 °C~~. After drying, a subsample from the same core was used to calculate the soil organic matter (SOM) content through loss on ignition at 550 °C for 4 h. A subset was further burned at 960 °C in order to determine the presence of inorganic C, which was ~~very~~ low (0.5 %), indicating that the total C can be considered equal to organic C (OC). Samples for total C and N and $\delta^{13}C$ were taken to a depth of 1 m with a Pürckhauer soil corer (2.5 cm diameter; Eijkelkamp, The Netherlands) in 5 cm increments. The analyses for total C and N contents, and for $\delta^{13}C$ were carried out on a subset of the samples by the Stable Isotope Facility at UC Davis (California). A subset of these samples was sent to a commercial lab and used for pH measurements (measured in a commercial lab using distilled water with a Mantech Automax 73, Guelph, ON., Canada) and nutrient content analyses (P, Ca, Mg and K; Avio 500 ICP Optical Emission Spectrometer, Perkin Elmer, Waltham, MA; USA) (Table S3). Soil moisture was measured every three weeks throughout the growing season (2019 through 2022) from one access tube (1 m long) permanently installed in each plot, using a PR2 profile probe (Delta-T Devices Ltd, Cambridge, UK). The values used in the analyses are growing season averages of volumetric soil water content (%) in the first 30 cm in each plot.

Root biomass was collected in September 2019 and in August 2022 with one soil core sampled with a root auger (8 cm diameter; Eijkelkamp, The Netherlands) by placing the auger on top of the plants, but living aboveground plant biomass and fresh litter were removed and not included in the soil samples. Samples were taken to a depth of 30 cm in all plots and to a depth of 45 cm in a subsample of 16 plots (used as control for maximum rooting depth), with soil cores divided into 5 cm segments. The roots were rinsed with water on a 0.5 mm mesh sieve to remove soil, then placed on a transparent tray, covered with water and scanned with a flatbed scanner at 600 dpi (grey scale), followed by drying at 60 °C for 48 h to obtain the dry weight. The scanned images were analyzed with WinRhizo (Regent Instruments, Québec, CA) to obtain root volume, length and diameter, used to calculate root mass density (g roots cm^{-3} soil), specific root length (cm g^{-1} roots) and root tissue density (g roots cm^{-3} roots).~~The roots were rinsed with water on a 0.5 mm mesh sieve to remove soil and then scanned, followed by drying at 60 °C for 48 h to obtain the dry weight. The scanned images were analyzed with WinRhizo (Regent Instruments, Québec, CA) to obtain root volume, length and diameter, used to calculate root mass density (g$_{roots}$ cm^{-3}$_{soil}$), specific root length (cm g^{-1}$_{roots}$) and root tissue density (g$_{roots}$ cm^{-3}$_{roots}$).~~ Aboveground biomass was harvested from one quarter (1 m^2) of each plot every year in mid-July, by cutting at ground level (including moss and dead biomass, table S4). More details of the sampling design are presented in the Supplements (~~Table ~~table ~~T1~~S5).

Statistical analyses

Because of the sensitivity of vegetation to natural variability in precipitation (Liu et al. 2020) and potential effects of landscape heterogeneity on both soil C dynamics and plant growth (Sharma et al. 2022; Guo et al. 2018), the analyses include testing for differences in the control plots between the start and the end of the experiment, as well quantifying the variability given by grassland and catenary position, which we expect might lead to variations in all C pools.

The measured soil organic C contents (mass of C per unit mass of soil) at different depths within the soil profile were used to calculate ~~and ~~soil C stocks (~~calculated as ~~C content × bulk density × layer thickness)~~ at different depths within the soil profile, and vegetation biomass (encompassing both root biomass and aboveground biomass, including plant litter)~~. ~~Total C content was calculated for all 48 plots as % of total mass, and C stocks were calculated using total C content, bulk density and SOM dataTotal C content (as % of total soil mass) and soil C stocks normalized by soil sample thickness (kg/m^3) were calculated for all 48 plots using the total C content data (available for a subset of the samples) and the bulk density and SOM data (available for a complementary subset of the samples).~~The soil C stocks ~~These ~~were then normalized by soil sample thickness (kg ~~/~~m^{-3}) to allow comparisons among soil layers with different thickness. Because C contents were not measured in all samples, ~~A~~ a regression was performed to calculate SOC from SOM data (which was available for all samples) and thus obtain a complete dataset,

$$\mathrm{SOC} = 0.328 \times \mathrm{SOM} + 0.217, \qquad (1)$$

where SOC and SOM are expressed in kg/m^2 (Fig. S1).

The fraction F of compost-derived C detected in the soil in year 2022 was calculated with a two end-member mixing model, as in Poeplau et al. (2023),

$$F = \frac{\delta^{13}\mathrm{C}_{compost\ treatment} - \delta^{13}\mathrm{C}_{control}}{\delta^{13}\mathrm{C}_{compost} - \delta^{13}\mathrm{C}_{control}}, \qquad (2)$$

where δ^{13}C was measured in both compost-amended (compost or compost-drought) and control (no compost or drought-no compost, respectively) plots.

All the results and statistical analyses are limited to the depth range of 0-45 cm. This is because this soil depth contains the majority of the root biomass (95% within the first 30 cm, mean ~17 cm)~~ and of the microbiological activity~~, and no effect of treatments could be detected below this range (data not shown).

All analyses were made in R (version 3.3.3; R core Team 2017), and statistical models were designed with the lmer function (package: lme4). Pairwise comparisons between categorical variables were made with lsmeans (package: emmeans) and p-values (α= 0.05) were obtained with the ANOVA function and the lmerTest package. Residuals from the models were checked graphically. Effect sizes were obtained by calculating Cohen's d, with the formula

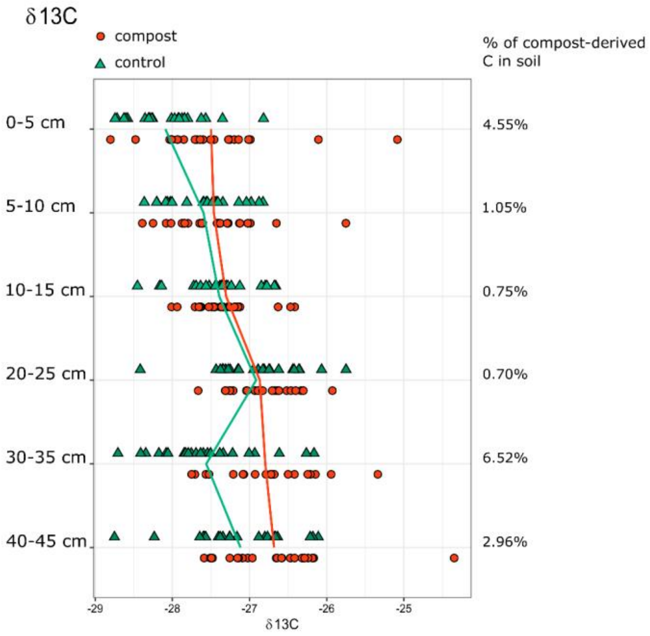
$$d = \frac{\overline{x_1} - \overline{x_2}}{s}, \qquad (3)$$

where $\bar{x}_1$ and $\bar{x}_2$ are mean values for the two groups for which the effect size is calculated, and S is the standard deviation.

The effect of the treatments was tested on all plots from the 2022 dataset. ~~, including~~ Values for root biomass and root traits ~~, for which the values~~ were log-transformed first. The model included compost (categorical variable), drought (categorical variable) and sampling depth (continuous variable) as fixed factors and plot (nested within site) as random factor. Cohen's d was calculated using the standard deviation of the control group. The effect of the compost amendment on the δ^{13}C~~C isotopic~~ ratio was tested with a mixed linear model that included compost and depth as fixed factors, and plot (nested within site) as random factor. Changes in soil C, bulk density and C stocks were also tested with a model using depth as categorical variable, to assess if changes occurred at specific depths. The ~~landscape ~~variability in plant biomass and soil properties across locations was tested on all data collected in 2019 and from the control plots in 2022. The model included grassland site, catenary position and sampling depth (continuous variable) as fixed factors and year and plot as random factors. Cohen's d was calculated using the standard deviation pooled from all groups. Temporal changes during the experiment not caused by the treatments were tested using data obtained in 2019 and 2022 from the control plots. The model included year and sampling depth (continuous variable) as fixed factors and plot (nested within site) as random factor. Cohen's d was calculated using the standard deviation of the 2019 dataset. The variable depth was not included in the models for aboveground biomass.

Results

The d~~D~~rought treatment decreased soil moisture by 16% in the upper 0-30 cm during the growing season (Fig. S2). The effect of drought was consistent over sites, years and seasons, and there were no statistically significant differences in the drought-driven soil moisture loss between locations, years, or between spring (April-May), summer (June-July-August) or growing season (April through August). There was also no significant difference in soil moisture decrease between drought plots and drought-compost plots (Fig. S3). Additionally, the compost addition did not have any significant effect on soil pH or on soil P, Ca, Mg and K. The compost addition did, however, raise the value of δ^{13}C in the treated plots (mean control plots = -27.44‰, mean compost plots = -27.10‰, $P < 0.01$), and the difference was significant at 0-5 cm, 30-35 cm and 40-45 cm. The mixing model (Eq. 2) indicated that after three growing seasons, the percentage of compost-derived C in the compost plots was 3.43 % in the 0-5 cm layer, 4.88 % in the 30-35 cm layer and 5.51 % in the 40-45 cm layer~~ in the compost plots~~. In the compost x drought plots, ~~andand ~~the percentage of compost-derived C was 4.55 % in the 0-5 cm layer, 6.52 % in the 30-35 cm layer and 2.96 % in the 40-45 cm layer~~ of the compost x drought plots~~.


δ13C
compost
control
% of compost-derived C in soil
0-5 cm
5-10 cm
10-15 cm
20-25 cm
30-35 cm
40-45 cm
4.55%
1.05%
0.75%
0.70%
6.52%
2.96%
-29
-28
-27
-26
-25
δ13C

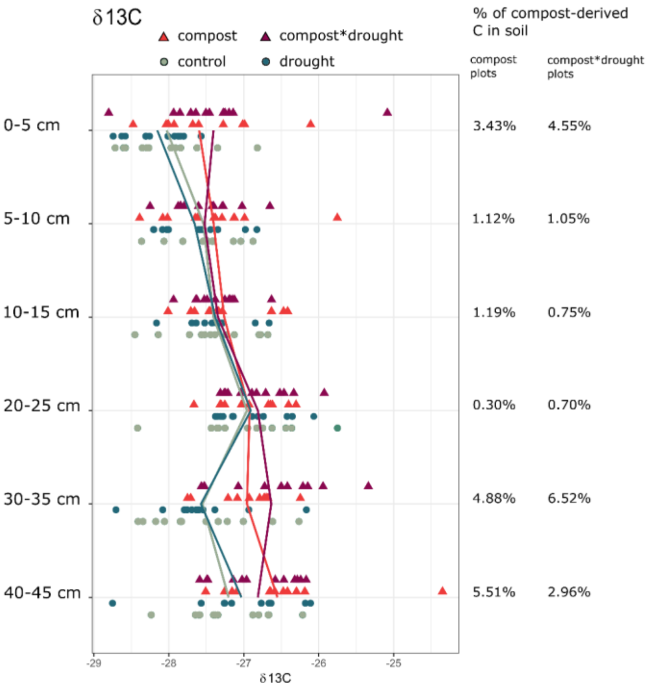


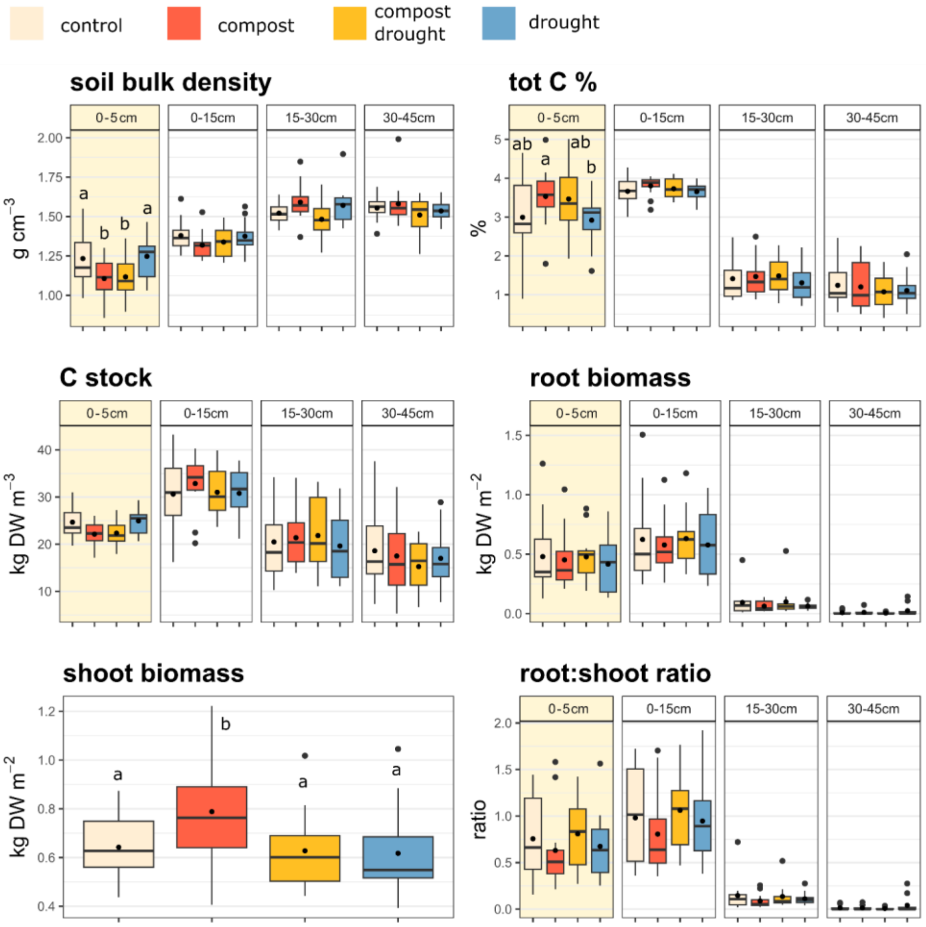
Fig 1. Values of $\delta^{13}C$ in the soil in compost-treated (~~red dots~~triangles) and untreated (control, green ~~triangles~~dots) plots under drought (dark red, dark blue) and at ambient precipitation (orange, light green) in 2022, at different depths. The percentage~~%~~ of compost-derived C in the soil was calculated with the isotope~~a~~ mixing model in ~~(~~Eq. 2~~)~~.

Compost and drought effects

~~The compost treatment increased t~~Total soil C content (P = 0.04) and aboveground biomass (P = 0.04~~< 0.01~~) increased in the compost-treated plots. The latter increased by 23% (mean control plots = 642 g m^2, SD = ~~±~~ 129.23, mean compost plots = 788 g m^2 ~~±~~ , SD = 221.7). The effect on soil C was significant only in the top 5 cm layer~~topsoil~~ (~~0-5 cm,~~ Fig. 2), where ~~the relative increase of~~ soil C content ~~was~~ increased by 18% (mean control plots C content = 2~~.~~9.9~~%~~ mg/g ~~±~~ , SD = 1.03, mean compost plots = 3~~.~~5.3 mg/g~~% ±~~, SD = ~~-~~0.75). Soil nitrogen (N) was higher in the ~~topsoil~~ top 5 cm layer in the compost-treated plots (mean control plots = ~~0.24~~2.44~~%~~ mg/g ~~±~~ , SD = 0.06, mean compost plots = ~~0.28%~~2.88 mg/g ~~±~~ , SD = 0.06; $p < 0.05$), but the treatment did not significantly affect the C:N ratio. The compost treatment also decreased bulk density by 9% (P = 0.03) in the first 10 cm of soil (mean control plots = 1.34 g cm^{3}~~-~~ ~~±~~, SD = 0.18, mean compost plots = 1.22 g cm^{3}~~-~~ ~~±~~, SD = 0.17)~~.~~ ~~The compost~~ , but did not ~~correlate~~affect~~ with~~ any other variable~~did not have any statistically significant effect on other variables~~. ~~.~~

~~Experimental dDrought only had an effect on aboveground biomass, which decreased by almost 4% under the rainout shelters (mean control plots = 642 g m^{2} ± , SD = 129.23, mean drought plots = 617 g m^{2} ± , SD = 180.25).~~ The increase in the soil C content under compost addition was offset by the ~~lower~~ reduced bulk density, so that there was no statistically significant change to soil C stocks. However, we note that, albeit non-statistically significant, mean soil C stocks were 6% higher in the compost-treated (ambient precipitation) plots in the first 15 cm, slightly higher than the percentage of compost-derived C found in that layer (mean control plots = 4.02 kg m^{2}~~-~~ ~~±~~, SD = 0.92, mean compost plots = 4.26 kg m^{2}~~-~~ ~~±~~, SD = 0.59).

Experimental drought had only an effect on aboveground biomass, which decreased by almost 4% under the rainout shelters (mean control plots = 642 g m^{2}, SD = 129.23, mean drought plots = 617 g m^{2}, SD = 180.25). However, this effect was significant only relatively to the compost-treated plots ($P = 0.02$), but not relatively to untreated control. Further, there was no significant difference in plant biomass between the drought-treated plots with and without compost addition.


control
compost
compost drought
drought
soil bulk density
0-5cm
0-15cm
15-30cm
30-45cm
g cm^-3
2.00
1.75
1.50
1.25
1.00
a
b
b
a
tot C %
%
5
4
3
2
1
ab
a
ab
b
C stock
kg DW m^-3
40
30
20
10
root biomass
kg DW m^-2
1.5
1.0
0.5
0.0
shoot biomass
kg DW m^-2
1.2
1.0
0.8
0.6
0.4
a
b
a
a
root:shoot ratio
ratio
2.0
1.5
1.0
0.5
0.0

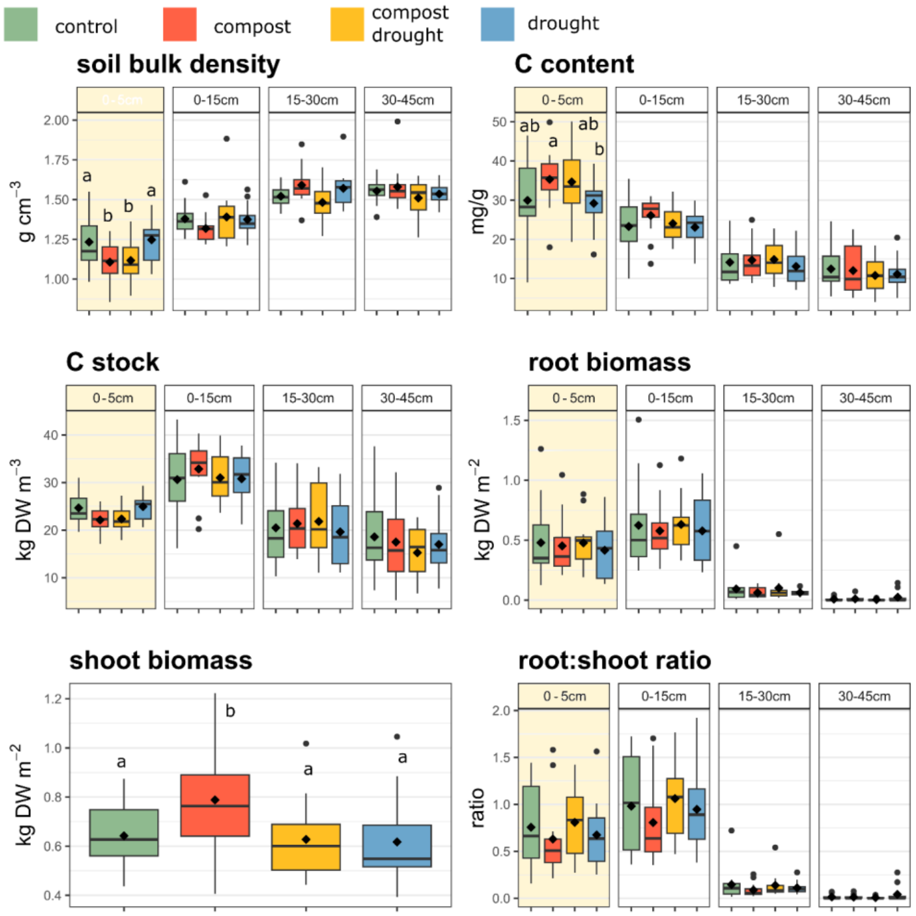


Fig. 2. Values of soil bulk density, ~~total~~ soil carbon (C) contents, soil C stocks, root biomass, shoot biomass and root-shoot ratio, at different sampling depths in 2022 (n = 12). Values are averages of all sites. ~~White~~ Green = control, red = compost, yellow = compost×drought, blue = drought. ~~Bars~~ Boxes show mean (~~dot~~ diamond inside the ~~bar~~box), median (horizontal line) and interquantile range (IQR, colored ~~bar~~box); whiskers extend to 1.5×IQR; dots in the graph are outliers. Different letters indicate statistically significant differences between means (P < 0.05). The yellow squares indicate the top layer (0-5 cm).

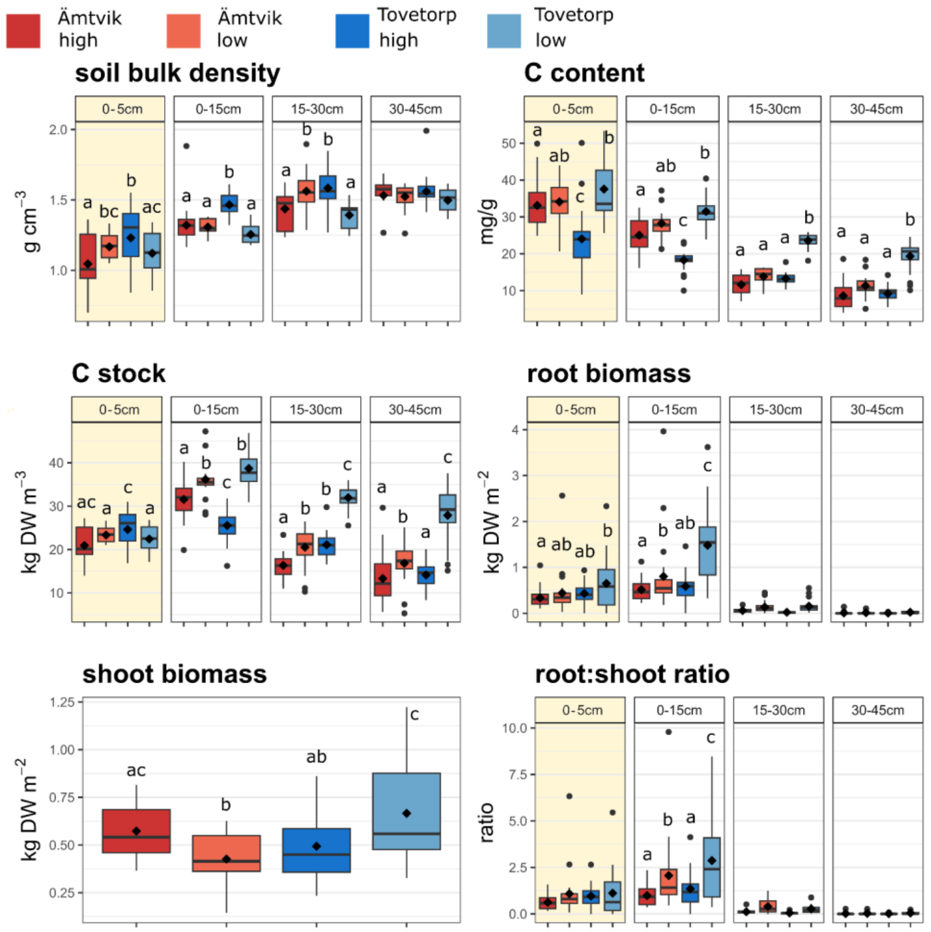
Root traits

~~Drought led to~~In all drought-treated plots we observed an increase in root tissue density ($P = 0.048$), in specific root length of fine roots ($P = 0.049$), and in average root diameter ($P = 0.045$). If only roots in the ~~topsoil~~ top layer (0-5 cm) were considered, in addition to these patterns~~ above~~, specific root length of coarse roots decreased under drought ($P = 0.04$), while root tissue density ($P = 0.02$) and specific root length of all roots increased after compost addition ($P = 0.01$).

In all control plots, soil C and root biomass was positively correlated both in the ~~topsoil~~ top 5-15 cm (5-10 cm, $r = 0.42$, $P = 0.04$; 10-15 cm, $r = 0.5$, $P = 0.01$) and in the whole 0-30 cm layer (0-30 cm, $r = 0.63$, $P < 0.01$). Soil C content was also positively correlated to the root:shoot ratio (5-10 cm, $r = 0.44$, $P = 0.03$; 10-15 cm, $r = 0.4$, $P = 0.052$; 0-30 cm, $r = 0.43$, $P = 0.04$). In the compost-~~-~~treated plots, the only significant correlation was between soil C and root biomass when considering the whole 0-30 cm layer (0-30 cm, $r = 0.55$, $P < 0.01$). The strength of the correlation did not differ between control and compost-treated plots ~~The correlation between soil C and aboveground biomass remained constant in both control and compost-treated plots~~ ($r = 0.22$, $P < 0.01$ in control and compost-treated plots~~both groups~~). ~~This indicates that the compost treatments affected soil C in the topsoil and aboveground biomass more than they affected roots and deeper soil.~~

~~Landscape S~~Spatial variability at the landscape scale

Soil C contents, total C stocks, bulk density, root biomass and root:shoot ratio ~~all~~ showed ~~statistically~~ significant ($P < 0.05$) differences between catenary positions and depths, and soil C content and bulk density also differed significantly between grasslands (Fig. 3, ~~Table T3~~table S8). Grassland identity and the interaction between grasslands and catenary positions were the only significant predictors of aboveground biomass (Fig. 3)~~, suggesting this variable is most likely related to land use history and plant community composition~~.


Ämtvik high
Ämtvik low
Tovetorp high
Tovetorp low
soil bulk density
g cm^{-3}
0-5cm
0-15cm
15-30cm
30-45cm
C content
mg/g
C stock
kg DW m^{-3}
root biomass
kg DW m^{-2}
shoot biomass
kg DW m^{-2}
ac
b
ab
c
root:shoot ratio
ratio

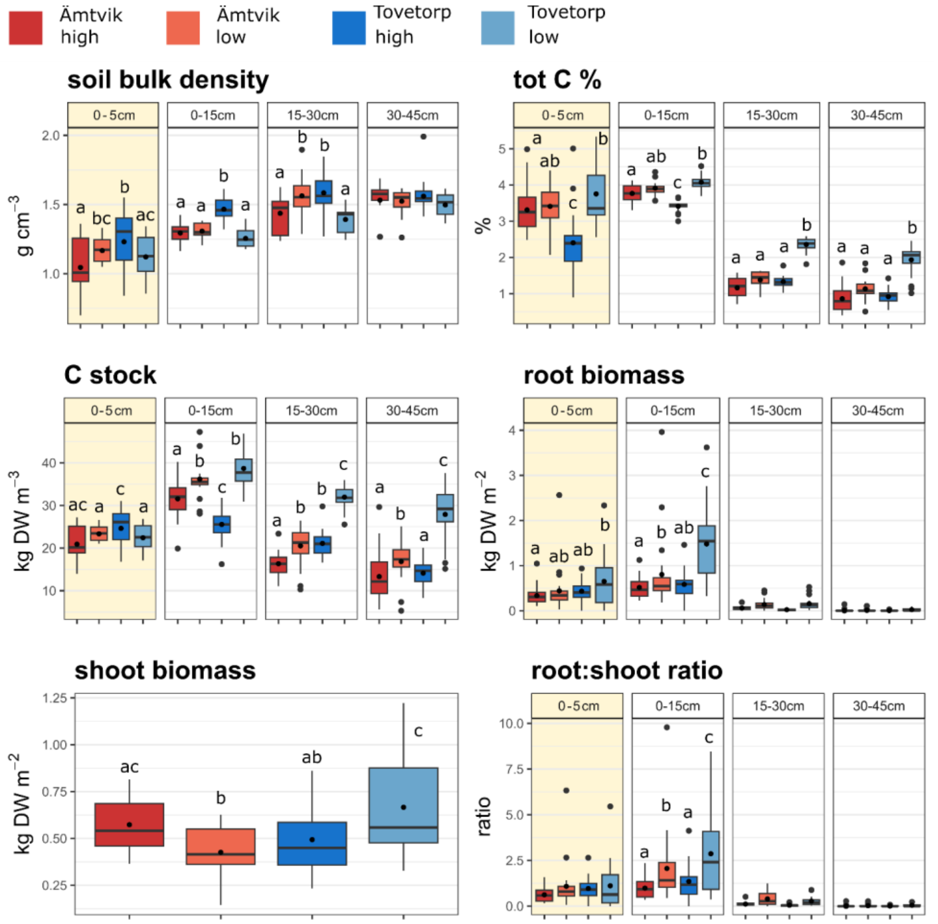
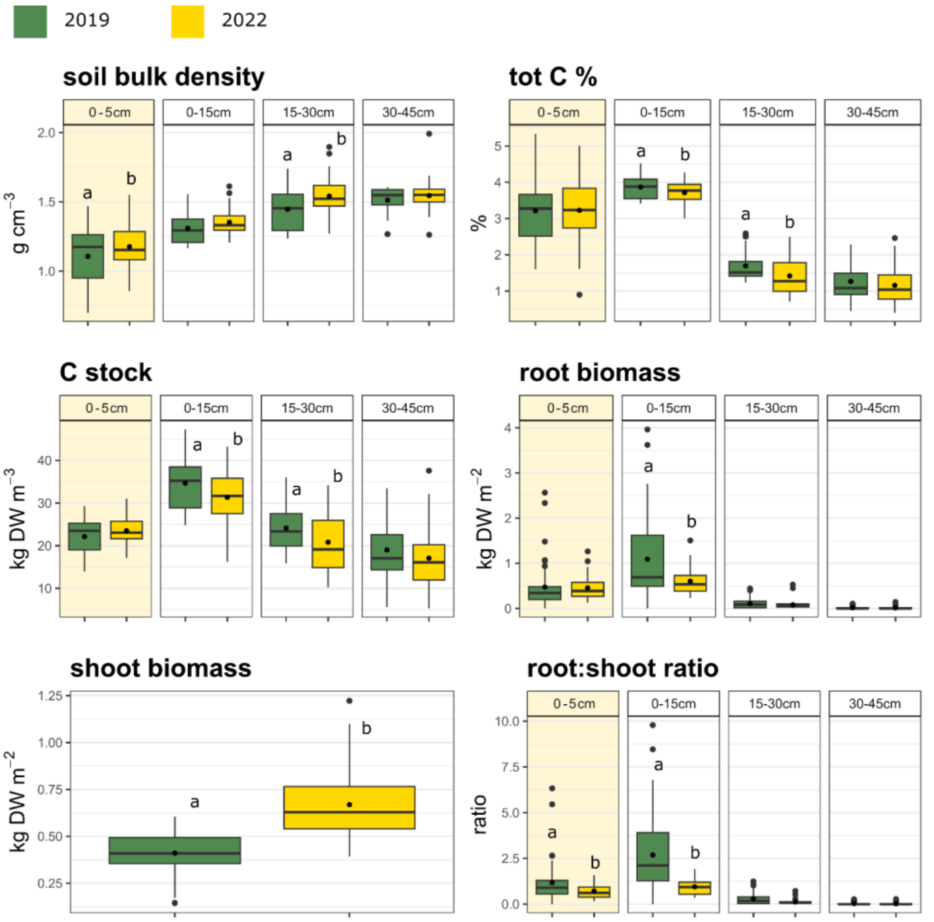


Fig. 3. Values of soil bulk density, ~~total~~ soil carbon (C) content, soil C stocks, root biomass, shoot biomass and root-shoot ratio, at different sampling depths at the four sites, excluding treatments. The data consists of average values from 2019 (all plots, $n = 48$) and 2022 (only control plots, $n = 12$). Red = Amtvik High catenary position, orange = Ämtvik Low catenary position, blue = Tovetorp High catenary position, light blue = Tovetorp Low catenary position. ~~Bars~~ Boxes show mean (~~dot~~ diamond inside the ~~bar~~box), median (horizontal line) and interquantile range (IQR, colored ~~bar~~box); whiskers extend to 1.5×IQR; dots in the graph are outliers. Different letters indicate statistically significant differences between means ($P < 0.05$). The yellow squares indicate the top layer (0-5 cm).

Natural changes during the 2019-2022 period

~~From 2019 to 2022, we observed large changes in soil C and plant biomass in the control plots. Soil C contents, total C stocks, bulk density, root biomass and root:shoot ratio all showed statistically significant ($P < 0.05$) differences between 2019 and 2022 and between depths (Fig. 4, Table T4).~~ Aboveground biomass also differed significantly between sampling years. Between 2019 and 2022 (Fig. 4, table S9) total soil C contents and root biomass in the first 5 cm of the control plots decreased by 10.7% (from 3~~.~~3.5~~%~~ mg/g~~ ±~~, SD = 1.05 to 2~~.~~.99~~%~~ mg/g~~ ±~~, SD = 1.03) and 8.4% (from 522.96 g m^{-2}~~ ±~~, SD = 626.48 to 479.25 g m^{-2}~~ ±~~, SD = 320.75), respectively. In the first 15 cm, ~~, in the first 5 cm, and~~they decreased by ~~27.1~~21.5% (from 2~~.77~~9.7~~%~~ mg/g~~ ±~~, SD = 0.~~78~~73 to 2~~.02~~3.3~~%~~ mg/g~~ ±~~, SD = 0.~~61~~71) and ~~67.4~~38.7% (from ~~477.26~~1017.95 g m^{-2}~~ ±~~, SD = ~~252.49~~955.16 to ~~155.81~~623.65 g m^{-2}~~ ±~~, SD = ~~51.62~~65.19), respectively~~, in the first 15 cm~~. Aboveground biomass instead increased by 53% (from 419.68 g m^{-2}~~ ±~~, SD = 137.45 to 642.23 g m^{-2}~~ ±~~, SD = 129.23).


2019
2022
soil bulk density
0-5cm
0-15cm
15-30cm
30-45cm
g cm^{-3}
2.0
1.5
1.0
a
b
a
b
tot C %
%
5
4
3
2
1
a
b
a
b
C stock
kg DW m^{-3}
40
30
20
10
a
b
a
b
root biomass
kg DW m^{-2}
4
3
2
1
0
a
b
shoot biomass
kg DW m^{-2}
1.25
1.00
0.75
0.50
0.25
a
b
root:shoot ratio
ratio
10.0
7.5
5.0
2.5
0.0
a
b
a
b

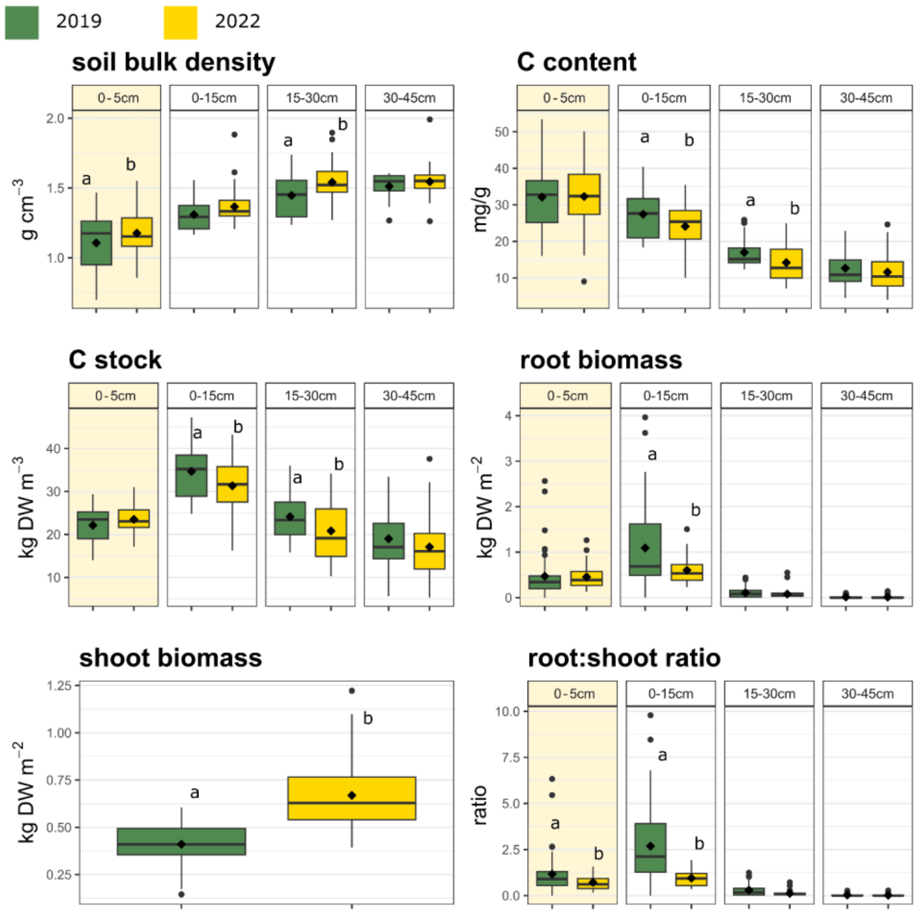


Fig. 4. Values of soil bulk density, ~~total~~ soil carbon (C) contents, soil C stocks, root biomass, shoot biomass and root-shoot ratio, at different sampling depths in 2019 and 2022 (~~excluding treatment~~control plots, n = 12). Values are means for all plots. Green = 2019, yellow = 2022. ~~Bars~~ Boxes show mean (~~dot~~ diamond inside the ~~bar~~box), median (horizontal line) and interquantile range (IQR, colored ~~bar~~box); whiskers extend to 1.5×IQR; dots in the graph are outliers. Different letters indicate statistically significant differences between means ($P < 0.05$). The yellow squares indicate the top layer (0-5 cm).

~~Table 1. Effect sizes (Cohen's d) of the differences between sites, years and treatments for each soil depth. Effect sizes can be regarded as small (absolute value <0.2, black), medium (0.2-0.8, orange)~~

Discussion

Compost effects on soil C and plant growth

Total soil C contents increased after compost application, but because bulk density was also reduced, there was no significant increase in soil C stocks (partly confirming our first hypothesis), despite higher mean ~~values of~~ soil C ~~per m^2~~stocks in the compost treated plots in the first 15 cm of soil. This difference was lower than the ~~estimated~~ C addition (~0.54 kg C m^{-2}) and thus lower than expected, but is~~,~~ likely due to respiration loss. Compost is partly decomposed organic matter, and thus more chemically recalcitrant than fresh grass residues. As a result, its ~~Compost can be considered a recalcitrant type of organic amendment,~~ effects on SOC accrual can be persistent over several years ~~with initially slow but persistent effects expected to be observed years after the first application~~ (Sarker et al. 2022) even after a single application (Ryals et al. 2013). ~~Therefore~~Despite ~~there being~~ evidence that compost amendments can lead to SOC accumulation already within two years after application (Gravuer et al. 2023), it is ~~un~~likely that ~~an~~ the effect of ~~the~~ our treatment on soil properties and soil C ~~had occurred before our~~will persist beyond the 2022 sampling~~, and that such an effect was somewhat transient and undetectable at the time of the sampling~~. This ~~conclusion~~ is also supported by the isotope tracing (Fig. 1), indicating that at least a fraction of the compost-derived C is still present in the soil after three growing seasons. T~~In addition,~~he significant increase in aboveground biomass three years after the compost application could partly be explained by the persistence of favorable plant growing conditions, such as increased N in the soil. This mechanism was invoked by Oladeji et al (2020), and may interact with precipitation-related interannual variability in plant growth (Sala et al. 2012)~~the significant increase in aboveground biomass three years after the compost application indicate the persistence of favorable plant growing conditions, such as increased N in the soil~~. Our results suggest that compost treatments might benefit the ecosystem C balance indirectly through increased biomass production, such as in this case, or by extending the growing season, such as in Fenster et al. (2023). ~~These results are in accordance with Fenster et al. (2023), who found that the benefits of compost treatments on the ecosystem C balance of grasslands one year after application were manifested as extended growing season, and thus potentially higher plant productivity, rather~~

~~than as an increase in net soil C.~~ Th~~i~~ese interactions between land management, vegetation growth and plant-derived C inputs also ~~stresses~~ underline the importance of including vegetation dynamics when assessing the effectiveness of C management. Our compost addition treatment did not lead to an increase in soil C accumulation, but resulted ~~however~~ in a lower net C loss from the grassland. In fact, soil C in a given layer increased more than the amount of compost-derived C remaining in that layer. This suggests that the increase in soil C is not only derived from the amendment itself, but also from increased plant C inputs. However, longer-term studies are necessary to understand whether SOC saturation limits the effectiveness of compost amendments in sustaining these gains over time (Moinet et al. 2023).

Compost enhanced aboveground biomass growth, but not root growth~~, thereby only partly confirming our first hypothesis~~, possibly in response to the increased nutrient supply (Bloom et al. 1985; Poorter and Nagel 2000), thereby only partly confirming our first hypothesis. ~~and suggesting the presence of a tradeoff between root and shoot investment. This was already observed in Garbowski et al. (2020) and is in line with the expectation that plants in nutrient-rich environments can allocate to aboveground tissue growth the resources that would otherwise be allocated to nutrient acquisition belowground (Bloom et al. 1985; Poorter and Nagel 2000).~~ In broader terms, this suggests that the compost treatment led plants to preferentially allocate to aboveground organs the resources that would otherwise be allocated to nutrient acquisition belowground (Cleland et al. 2017)~~this suggests that the compost treatment shifted the C balance between soil pool and vegetation pool, and moved the plant C allocation from belowground to aboveground organs~~. Nevertheless, increased root tissue density and specific root length in the ~~topsoil~~ top 5 cm layer suggest that root response to organic amendments is manifested in more subtle changes in root traits related to nutrient acquisition (Bardgett et al. 2014), rather than in net root biomass production.

Microbial activity and microbial biomass can be higher after~~as a result of~~ compost addition (Sarker et al. 2022; Gravuer et al. 2019). Here, the limited effects ~~Our experimental setup did not allow us to test whether microbial activity and microbial biomass increased as a result of compost addition, as was reported by previous studies (Sarker et al. 2022; Gravuer et al. 2019). However, the limited effects~~ of the compost treatment on soil C stocks suggest that the potential C accrual brought by the increased plant productivity ~~the C sequestration benefits in the form of increased plant growth~~ might have been offset by increased microbial respiration (promoted by either compost or enhanced rhizodeposition of more productive plants) (Borken et al. 2002). Finally, the significant spatial and temporal variability in both soil C and vegetation biomass observed in the control dataset suggests that treatment effects might be site-specific (Garbowsi et al. 2020), and management plans seeking to ~~optimize soil C sequestration~~increase C accrual should consider the potentially interactive effects of several biotic and abiotic factors, such as plant community composition, soil type and climate. For instance, in our experiment, aboveground biomass increase was highest at the site with the greatest abundance of grasses (table S4)~~the increase in aboveground plant biomass after compost application was mostly driven by the grass-rich plots in the Tovetorp grassland (Roth, 2023), suggesting that plant community composition might be important in determining the effects of soil amendments on grasslands~~.

Drought effects on soil moisture, soil C and plant growth

Drought treatments reduced soil moisture and aboveground plant biomass, but did not significantly decrease root biomass (~~Table ~~table ~~T2~~S7), indicating preferential biomass allocation and resource investment to belowground organs under precipitation reduction~~a tradeoff between above- and belowground biomass investment~~. Plant growth is very sensitive to yearly fluctuations and even intra-annual distribution of precipitation (Knapp and Smith 2001, Porporato et al. 2006). Because our analyses are based on only two temporal datapoints (2019 and 2022), it is difficult to assess whether drought reduced plant turnover, defined as the ratio of standing biomass to net primary productivity (NPP).~~Because plant growth is very sensitive to yearly fluctuations and even intra-annual distribution of precipitation (Knapp and Smith 2001, Porporato et al. 2006), and because our analyses are based on only two temporal datapoints (2019 and 2022), it is difficult to assess whether drought reduced plant turnover, defined as the ratio of standing biomass to net primary productivity (NPP)~~. ~~We note that while the precipitation in the growing seasons 2019 and 2022 (April through August) was roughly the same (157 mm and 156 mm, respectively), the 2019 sampling followed an extremely dry summer in 2018, when the study area received only 77 mm of precipitation, about half of the precipitation compared to the average 1961-1990 (historical data from SMHI, 2021). Conversely, the 2022 sampling followed the very wet 2021, when the area received almost 140% of the normal precipitation over the same time period (250 mm).~~ As there was some natural variability in the annual precipitation (see methods section), ~~I~~it is possible that a legacy effect of ~~these two precipitation extremes~~this variability may have affected plant growth (Sala et al. 2012)~~,~~ particularly aboveground (Fig. 4), where growth is more sensitive than root biomass to yearly fluctuations in water availability (Zhang et al. 2021). In particular, l~~L~~egacy effects of the 2018 drought could have hampered growth in 2019, as aboveground vegetation in the control plots increased by more than 50% between 2019 and 2022. Conversely, the high summer precipitation in 2021 could have buffered the effects of the experimental drought in 2022, leading to overall weak drought effects (Sala et al. 2012).

The drought treatment had a relatively small impact on plant biomass and on r~~(Fig. 2). In addition to potential effects of interannual precipitation variation, this may be due to adaptation in the plant community during the treatment years (Basu et al. 2016), or that the drought was not intense enough. R~~oots in particular ~~where not significantly affected by drought~~ (Fig. 2).~~, but while we monitored the relative proportions of annuals and perennials, grasses and forbs in each plot, we do not know which plant species the sampled roots belong to. Therefore,~~ ~~)~~. Because we do not know which plant species the sampled roots belong to, we cannot make any conclusions related to belowground drought responses of different plant functional groups ~~the ecology of these plant groups, all of which can be expected to respond differently to drought~~ (Zhang et al. 2017; Mackie et al. 2019; Zhong et al. 2019). However, ~~since~~we note that- the magnitude of the drought did not differ between locations and ~~since~~ soil physical properties were similar across sites, ~~while~~but drought effects differed across locations (Fig. S4). Therefore, we can hypothesize that differences in the plant communities account for at least some of the spatial heterogeneity observed in our study, as was observed ~~in~~ by Garbowski et al. (2020). Also, while drought effects on root biomass were marginal, the drought treatment did increase both root tissue density and average root diameter. Climate is a strong predictor of root trait variation (Freschet et al. 2017), and higher root tissue density is correlated with resource-conservative acquisition strategies (Bardgett et al. 2014) and longer root life span (Ryser, 1996), suggesting ~~adaptation of root traits~~some degree of drought adaptation in ~~these~~ our plant communities.

Adopting a standardized ~~approach for the~~ drought experimental design ~~makes our findings easier to compare with others~~improves comparability, but partial rainout shelters will still allow for a substantial amount of precipitation to pass through, potentially raising soil moisture above the wilting point. ~~the roof sheets. If there is enough precipitation, even the small percentage of rain that reaches the ground might bring the soil moisture over the threshold of the permanent wilting point. It is also~~

~~possible that soil water retained in the soil from snowmelt or winter/spring precipitation could have sustained vegetation growth in the drought treatments.~~ Experimental droughts also fail to account ~~Finally, experimental droughts do not control~~ for reduced air humidity, which may underestimate negative responses of plant biomass to drought in field experiments (Kröel-Dulay et al. 2022), and for increased temperatures, which often occur in combination with natural droughts. ~~Drier and warmer air increases evaporative demand, causing stomatal closure and thus lower productivity for a given soil moisture level (Zhang et al. 2019).~~These methodological limitations might explain why we observed minor drought effects on vegetation.

To understand the ecosystem-level implications of drought, soil C changes need to be considered as well. Dry conditions decrease heterotrophic respiration because microbial activity is inhibited due to both physiological mechanisms, such as osmoregulation diverting efforts from resource acquisition to survival, and physical mechanisms, like the slower transport of substrates in dry soils (as the water films around soil particles shrink and pore connectivity is lost) (Moyano et al. 2013; Schimel 2018). However, heterotrophic respiration increases again after soil rewetting, leading to disproportionally large C emissions during the short post-rewetting period (Canarini et al. 2017; Barnard et al. 2020). Because the drought plots with added compost had a higher fraction of compost-labelled isotopes compared to the non-drought plots in the topsoil (Fig. 1), this would imply that any soil C emission pulses at rewetting were not sufficient to compensate for the possibly lowered microbial activity during the soil moisture dry-downs. As a result, in our experiment drought had no effects on soil C contents and stocks, as per our second hypothesis, although it slightly reduced soil bulk density (in a pre-treatment vs post-treatment comparison, data not shown), possibly in relation to shrinkage in dry soil.~~In our experiment, drought had no effects on soil C contents and stocks, as per our second hypothesis, but it slightly reduced soil bulk density (in a pre-treatment vs post-treatment comparison, data not shown), possibly in relation to shrinkage in dry soil. Because drought reduced plant productivity (and thus C inputs to soil), the lack of drought effect on soil C stocks can be explained by a reduction of microbial activity approximately of the same magnitude as the reduction in plant productivity. This is supported by the fact that in the topsoil, the drought plots with added compost had a higher fraction of compost-labelled isotopes compared to the non-drought plots. Therefore, any soil C emission pulses at rewetting were not sufficient to compensate for the lowered microbial activity during the soil moisture dry-downs.~~

Interactive effects of compost and drought

~~The effects of soil amendments on water retention capacity are modulated by soil texture, by the quantity and quality of soil organic matter (Rawls et al. 2003; Yang et al. 2014; Franco-Andreu et al. 2017; Sarker et al. 2022) and by the chemical composition of the compost (Franco-Andreu et al. 2017).~~ While previous studies indicated increased soil water retention after soil amendments ~~In our study, soil moisture did not differ between the drought plots and the ones with drought and compost, which indicates that the soil amendment did not increase soil moisture, in contrast with previous findings~~ (Franco-Andreu et al. 2017; Ali et al. 2017), in our study compost-treated drought plots did not have higher soil moisture than the untreated drought plots three~~3~~ years after compost application (Fig. S3), which leads us to reject our third hypothesis~~and leads us to reject our third hypothesis~~. As the negative effects of drought on aboveground biomass were weak, they were not visibly compensated for by the compost addition. On the contrary, the experimental precipitation reduction obliterated the biomass increase detected in the compost-treated plots in ambient rainfall, overriding the positive effects of the increased C and N provided through the compost. This suggests that the vegetation response in our experiment does not only depend on nutrient addition and interannual variability in precipitation, but likely also on plant physiological processes related to water availability (Bista et al. 2018) and on the ability of soil microbes to render the nutrients available for plant uptake. Interestingly however, while both compost and drought ~~slightly reduced~~tended to reduce root biomass, there was a tendency for higher root:shoot ratio in the plots with combined compost and drought treatment ~~the compost applied on the drought plots led to an increase in root:shoot ratio~~ (Fig. ~~4~~2). While our results from the compost-treated plots show that plants may reduce their belowground biomass investment relative to aboveground growth when adding organic matter, this mechanism ~~appears~~ appeared to work differently under drought conditions, when plants may ~~and the observed~~ shift ~~in~~ C allocation belowground ~~may serve~~ to aid in water acquisition (Eziz et al. 2017; Guswa et al. 2010). This~~, in turn, could lead to increased evapotranspiration, and this~~ improved capacity for soil water absorption could potentially offset any compost-induced increase in soil water retention capacity~~mask any increase in soil water retention capacity in the compost x drought plots~~. However, since our experiment did not include drought recovery, it is not known if this change would persist after the end of the experimental drought.

Conclusions

~~The goal of this study was to~~We explored how drought and compost amendment affect~~ provide an overview of the changes in~~ soil properties and~~,~~ above- and belowground plant ~~biomass vegetation C content and~~ biomass within a grassland ecosystem~~, through a multifactorial drought and compost amendment field trial~~. Compost amendment and drought had distinct effects on plant shoot and root growth, revealing the presence of trade-offs in their responses to environmental change. The compost treatment led to an increase in biomass in shoots but not in roots, and ultimately did not result in an increase in soil C stocks. Drought did not significantly affect plant biomass, but led to changes in root traits and stunted the compost-induced increase in plant growth measured in plots under ambient precipitation. ~~The compost treatment revealed contrasting responses of shoots and roots, but it~~ ultimately ~~did ultimately not result in an increase in soil C stocks. Drought decreased aboveground biomass, but root response was limited to shifts in root traits. Compost amendment and drought had distinct effects on plant C allocation, revealing the presence of trade-offs in their responses to environmental change.~~ These findings improve our understanding of C dynamics in grasslands by illustrating the different components of plants and soil properties affected by ~~the~~land management~~, offering potential contributions to ecosystem C modelling~~. We also observed significant spatial and temporal variability in vegetation and soil C dynamics over the study period, which may be driven by differences in topography, land use and plant community composition, as well as temporal variability in precipitation. ~~This suggests that ecosystem C dynamics can be influenced by multiple biotic and abiotic factors, which can be revealed by field observations and multifactorial experiments.~~

Author contributions

Conceptualization and methodology: SC, DG, GH, SM, NR; Field investigation and lab work: DG, NR; Statistical analysis: DG; Writing – original draft: DG; Writing – review & editing: DG, SC, GH, SM, NR.

Acknowledgements

The authors wish to thank Tovetorp Research Station and the land owners of Ämtvik for allowing us to work on their grasslands, Linnea Ström, Louis Hunninck, Luca Durstevitz, Marie Förg, Olov Hammarström, Victor Eriksson and Willeke A'Campo for help in the sampling, and Lukas

Rimondini, Torge Gerwin and Sean Burke for help in the lab. Funding for this study was provided by the Bolin Centre for Climate Research and by the Mannerfelt Fund.

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