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Improving the stability of soil aggregates using soil additives and revegetation by grassland

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Abstract: Soil aggregate stability (SAS) is an important factor for soil quality and fertility. There are limited possibilities to influence this soil property, but one investigated method is the application of additives which have the potential to improve SAS. We established a four-year field experiment on a clay-loam Luvisol with poor soil structure to monitor SAS following the application of additives and grassland revegetation. Treatments included: (1) the untreated control; (2) compost; (3) biochar; (4) liming; (5) cattle manure; (6) woodchips; (7) woodchips + fungi inoculation; (8) pellets; (9) pellets + fungi; (10) hydrogel and (11) the change of arable land to grassland. The lowest 23.39% average SAS value was recorded for the untreated control, and then 23.92% for lime treatment, and the highest 27.69% average value was for hydrogel treatment, followed by woodchips with 27.22% and woodchips + fungi with 27.02%. A significant SAS increase of more than 200% was evident on the grassland two years after the trial's establishment, and this was also associated with other improved physical and chemical soil properties. Finally, while most of our applied soil additives were relatively ineffective in agricultural practice, grassland revegetation is highly recommended for its rapid increase in soil aggregate stability.

Keywords: climate condition; soil porosity; glomalin; fertilisers; soil amendments

Soil structure has both direct and indirect impacts on all soil processes. It especially affects the soil quality and fertility, water movement and retention, erosion and crusting (Bronick and Lal 2005). Quantitative data on soil structure are often acquired *via* soil aggregate stability (SAS) testing. This provides the soil's ability to resist the destructive flooding effects and raindrop kinetic energy, which causes its disintegration. Moreover, decreased SAS and changes in soil physical properties reduce water infiltration and crop production and also increase the risk of erosion (Barthés and Roose 2002).

The formation and stability of soil aggregates depend on many factors. These include the site's soil and climate conditions and the agricultural management techniques (Amézketa 1999). While the site conditions and soil mineral characteristics are beyond influence, the soil's chemical and hydro-physical properties can be improved by suitable intervention. The literature cites many articles on this topic; examples include the application of organic fertilisers (Zhou et al. 2013) and soil conservation technology (Carter 1992, Topa et al. 2021).

Additives which potentially improve soil physical properties have also recently been investigated, and these include the use of synthetic polymers such as polyacrylic acid. Buchman et al. (2015) demonstrated that hydrogel swelling directly affects soil micro-structural stability. Buchman and Schaumann (2017) concluded that the positive contribution of hydrogel structures to soil micro-structural stability depends on the hydrogel viscosity between soil particles and polymer-clay interactions.

The greatest disadvantage of synthetic hydrogels is their prolonged or zero biodegradation. It is,

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therefore, appropriate to use additives that decompose more easily in the soil. These include biochar (Ouyang et al. 2013), digestate (Pastorelli et al. 2021) and woodchips (Li et al. 2020). For example, Blanco-Canqui (2017) indicated that biochar application generally improved soil physical properties, especially by reducing soil bulk density and increasing soil porosity. Although the author found no obvious effect on soil aggregate stability, the reasons for this could include differences in the biochar source, or clay mineralogy or the local climate. Finally, An et al. (2013) and Ma et al. (2021) suggested grassland or afforestation as possible options to improve soil structure due to increased soil aggregate stability and hydrophobicity of soil organic carbon.

There were no long-term field studies in available literature which conclusively proved the extent of soil additive effects, so herein we established a field experiment on a clay-loam Luvisol with a poor structure to monitor changes in soil properties after applying eight soil additives and converting part of the arable land to grassland.

The study objectives were: (1) to investigate soil aggregate stability changes after a four-year trial of the various soil treatments; (2) to compare the effects of soil additives and grassland replacement, and (3) to determine the most suitable way to increase the soil aggregate stability on a clay-loam soil with poor structure.

MATERIAL AND METHODS

Site description and experimental design. The field experiment was established in November 2018 at the Hněvčeves experimental station of the Crop Research Institute in the Czech Republic. Table 1 lists the soil analysis results at the beginning of the experiment.

The following additives were applied in autumn 2018 to improve soil aggregate stability potentially; (1) 4 t/ha biochar from woodchips; (2) 80 t/ha cattle manure; (3) 40 t/ha compost; (4) 40 t/ha pellets with 50% straw and 50% separated from the biogas plant; (5) 40 t/ha pellets and 0.008 t/ha fungal inoculation; (6) 46 t/ha apple tree woodchips; (7) 46 t/ha woodchips and 0.008 t/ha fungal inoculation; (8) 5 t/ha lime and (9) 200 kg/ha hydrogel from nanotechnology-modified potassium carbonate (https://hydrogel.cz). The supporting "Polymix" fungal preparation contained *Botryotrichum*, *Isaria*, *Clonostachys* and *Talaromyces* conidia genera produced by Fytovita Inc. (http://www.fytovita.cz/polymix.htm).

These soil additives were applied evenly to the selected plots and ploughed to 10 cm depth with a disc cultivator. Part of the arable land beside the experimental plots was transformed into grassland by sowing a clover-grass mixture and cutting it once or twice annually. The addition of untreated control and transformed grassland provided a total of 11 experimental treatments.

The fertilised experimental area was divided into thirty 3 × 5 m plots, with three replicates for each application, and each plot was separated on all sides by isolation strips of 1.5 m on the longitudinal aspects and 2.5 m on the horizontal aspects.

The field trial management included conventional tillage to 20 cm depth with mouldboard; the following crops were cultivated in 2019–2022; spring wheat, winter wheat, maize and spring barley. Mineral fertiliser and pesticide applications met crop requirements. The average mineral nitrogen application over 4 years was 120 kg N/ha. Maize was fertilised with a dose of 50 kg P/ha. Straw was removed from the field after harvest.

Soil sampling and sample processing. Soil samples were taken from all treatments and repetitions after crop harvesting in 2019–2022. Disturbed soil samples were taken by field shovel from the 0–7 cm upper soil layer, and these were air-dried, homogenised and divided into two portions. The first part contained fine soil by sieving through a 2 mm sieve. This was used for the measurement of pH; hot wa-

Table 1. Experimental site characteristics with available nutrients measured by Mehlich III extraction, as in Carter and Gregorich (2007)

Longitude	15.72°E
Latitude	50.31°N
Altitude (m a.s.l.)	265
FAO Classification	Haplic Luvisol on loess, clay-loam
Average annual temperature (°C)	8.2
Average annual rainfall total (mm)	573
pH_{H_2O}	6.9
pH_{KCL}	6.04
P_{avail} (mg/kg)	98.9
K_{avail} (mg/kg)	284.2
Mg_{avail} (mg/kg)	251.1
Ca_{avail} (mg/kg	2 529.7
Soil organic carbon content (%)	1.36
Clay content (%)	20

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ter extractable carbon (HWC); soil organic carbon (SOC), total nitrogen (total N), and for spectroscopic examination of soil organic matter. A 1–2 mm grain-size soil fraction was obtained by sieving the soil through an appropriate sieve system. This was used to analyse easily extractable glomalin and the soil aggregate water stability.

The total soil organic carbon and total organic nitrogen content were evaluated by Vario/CNS analyser (Elementar Analysensysteme GmbH, Langenselbold, Germany). Hot water extractable labile carbon was determined by Körschens et al. (1990). FTIR spectra were measured by Thermo Nicolet Avatar 320 FTIR spectrometer (Nicolet, Madison, USA) in a homogeneous mixture of bulk soil and FTIR grade KBr (Sigma-Aldrich, Darmstadt, Germany). This was then analysed at the following functional group absorption bands; aliphatic hydrophobic CH_2 and CH_3 (3 000–2 800/cm), aromatic COO-, C=C (1 660–1 580/cm) and hydrophilic (1 740–1 600/cm) (Demyan et al. 2012). The decomposition index (DI), which determines the intensity of FTIR spectra for C=C/C-H functional groups, and the hydrophobicity index (HI), which establishes the intensity of FTIR spectra for a ratio of hydrophobic to hydrophilic functional groups, were calculated (Ellerbrock et al. 2005, Margenot et al. 2015).

The proportion of water-stable aggregates determined soil aggregate stability. This was assessed by Kandeler's (1996) wet-sieving method and HERZOG laboratory equipment (Adolf Herzog GmbH, Vienna, Austria). The sieving time was 5 min, with 3 repetitions for each sample. Glomalins were extracted from the soil by autoclaving in neutral or alkaline citrate solution to yield easily extractable fractions, as in Wright and Upadhyaya (1996).

Determination of the soil's hydro-physical properties required sampling the undisturbed soil to 7 cm depth. Three samples were collected annually from each trial plot, and these were placed in 100 cm^3 steel cylinders for determinations of the following selected hydro-physical parameters; as recorded by Zbíral et al. (2011) and Pospíšilová et al. (2016); bulk density (BD); total porosity (P) consisting of capillary porosity, non-capillary porosity, and semi-capillary porosity.

Statistical analyses. Analysis of variance (ANOVA) was performed using Statistica 14.0.0.14 software (TIBCO Software Inc., Palo Alto, USA). The treatment and year were fixed, and the monitored soil characteristics were dependent variables. The Tukey *HSD* (honestly significant difference) test at $\alpha = 0.05$ then determined homogenous groups; each treatment combination's mean values and standard errors are presented.

RESULTS AND DISCUSSION

The soil aggregate stability and other monitored soil properties were significantly affected by the treatment, year, and interaction (Table 2). Figure 1A highlights the differences between treatments in SAS. The low-

Table 2. Significance of the effects of treatment and year and their interaction on the following soil properties revealed by multi-factorial ANOVA

Dependent variable	Statistic	Treatment	Year	Treatment × year
Soil aggregate stability	*P*	0.0000	0.0000	0.0000
	F-value	84.32	244.29	43.03
Soil bulk density	*P*	0.00000	0.0000	0.00281
	F-value	7.47	63.8	1.93
Porosity	*P*	0.00000	0.0000	0.003547
	F-value	6.0	63.8	1.9
Glomalin	*P*	0.41142	0.0000	0.00368
	F-value	1.0584	196.3	3.1279
Soil organic carbon	*P*	0.0000	0.00000	0.0000
	F-value	73.8	23.522	25.05
Total nitrogen	*P*	0.0000	0.0000	0.0000
	F-value	70.58	43.815	19.158
Hot water extractable carbon	*P*	0.0000	0.0000	0.0000
	F-value	73.244	49.597	21.803

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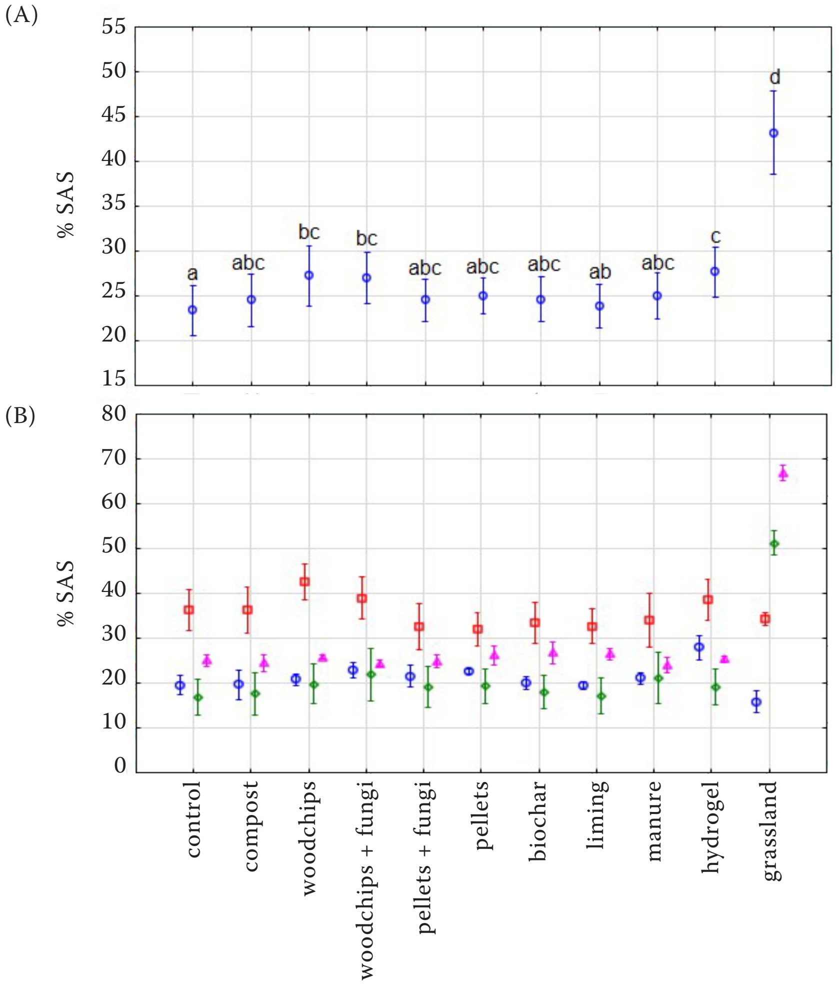

Figure 1. The effects of (A) treatment and (B) year and treatment interaction on soil aggregate stability (SAS). Vertical columns show the 0.95 confidence interval, and different letters indicate significant differences at α = 0.05 by the Tukey *HSD* (honestly significant difference) test

est 23.39% average SAS values were recorded for the untreated control and 23.92% for lime treatment, while hydrogel provided the highest 27.69% average SAS values. This is supported by Guilherme et al. (2015), who recorded improved soil physical properties after hydrogel application into the soil. In addition, woodchip application positively influenced SAS, with 27.22% average SAS values for woodchips and 27.02% for woodchips + fungi. Although the woodchip effects on soil are under-researched, some work indicates that they improve soil properties. For example, Holtz et al. (2004) found increasing total organic carbon and soil organic matter after almond brush woodchip addition to the soil, Li et al. (2020) recorded improved soil physical properties and accelerated microbial activity when woodchips were added to the corn straw.

However, grassland treatment results were different from all other treatments; Figure 1B highlights progressive grassland SAS increase over time. This trend is independent of the year-to-year variability noted in the other treatments. Moreover, many investigations have confirmed very high soil aggregate stability in non-grazed grassland soil compared to crop-land soil, as in An et al. (2013) and Ma et al. (2021).

The highest year-to-year differences were recorded for hydrogel treatment. This follows the principles of hydrogel action. For example, hydrogel-soil contact is broken due to shrinkage when hydrogel completely dries out, and this increases rehydration time (Guilherme et al. 2015, Crous 2017).

Figure 2 compares the average values of the SAS increase/decrease in the fertilised treatments and control for 2019 to 2022; this provides a better indication of the individual additive effects. The highest 42.66% increase was recorded for hydrogel in the first year, followed by a 16% increase for woodchips + fungi and 14.8% for pellets. The positive effect of hydrogel decreased in the following years to 5.1% in 2022. In contrast, the positive effect of the manure was evident, with a 24.8% and 11% increase in SAS in the last two experimental years. This is supported by Wang et al. (2013), who reported that cattle manure added to the NPK mineral fertilisers significantly improved soil aggregate stability.

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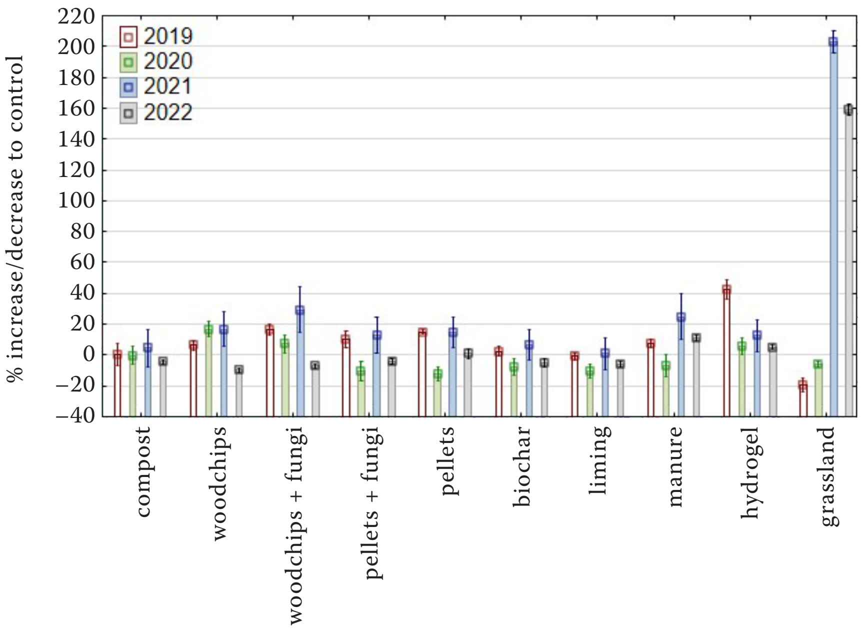

Figure 2. Soil aggregate stability percentage increase/decrease for individual treatments compared to the control, with the mean for each year ± standard error

However, we did not find the expected positive effects of compost application presented by other authors. For example, Rivier et al. (2022) confirmed that compost application to sandy and loam soils affected pore-size distribution and reduced bulk density in their pot-plant experiments. The different results

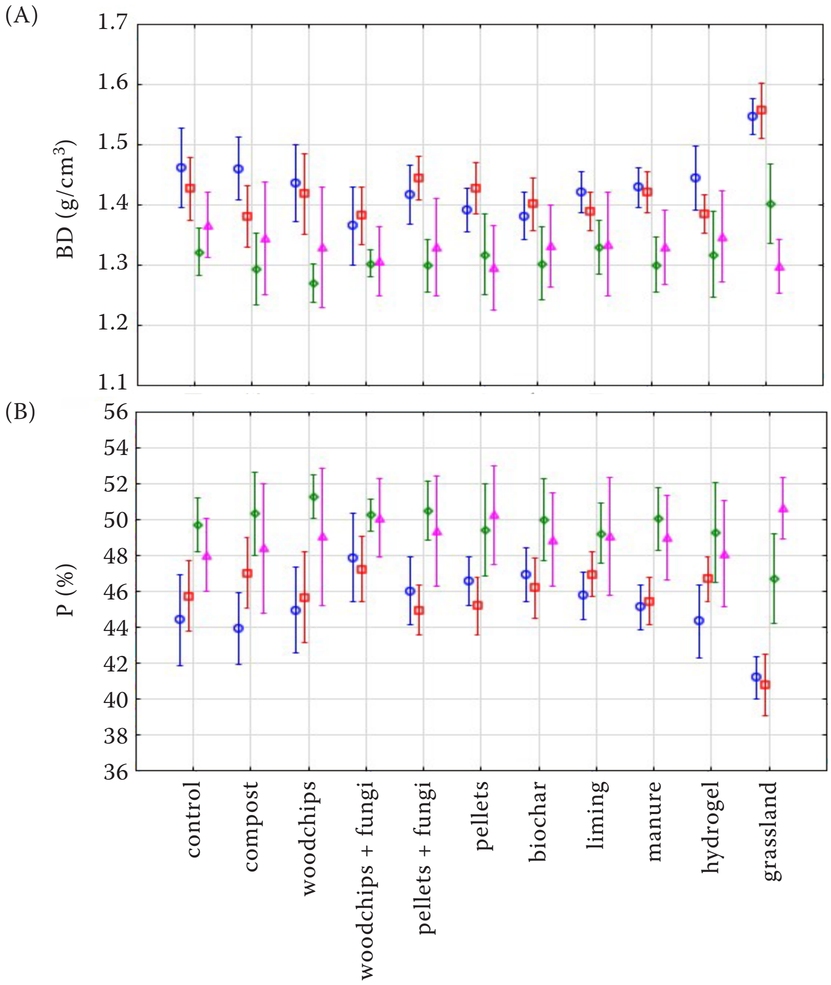

Figure 3. The effect of year and treatment interaction on (A) soil bulk density (BD) and (B) soil porosity (P). Vertical columns show the 0.95 confidence interval

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Table 3. Contents of soil organic carbon (SOC), total nitrogen (total N) and hot water extractable carbon (HWC); mean ± standard error

Treatment	Year	SOC (%)	Total N (%)	HWC (mg C/g)
Grassland	2019	1.23 ± 0.02^{a}	0.17 ± 0.00^{a}	0.45 ± 0.01$^{f–k}$
	2020	nd	nd	0.89 ± 0.02^{l}
	2021	1.79 ± 0.08^{b}	0.21 ± 0.01^{b}	0.98 ± 0.02^{l}
	2022	2.72 ± 0.11^{c}	0.28 ± 0.01^{c}	0.98 ± 0.04^{l}
Control	2019	1.15 ± 0.01^{a}	0.15 ± 0.00^{a}	0.49 ± 0.05^{ijk}
	2020	nd	nd	0.35 ± 0.02$^{a–j}$
	2021	1.17 ± 0.01^{a}	0.16 ± 0.00^{a}	0.22 ± 0.05^{a}
	2022	1.23 ± 0.02^{a}	0.16 ± 0.00^{a}	0.34 ± 0.01$^{a–j}$
Compost	2019	1.25 ± 0.07^{a}	0.16 ± 0.00^{a}	0.49 ± 0.01^{ijk}
	2020	nd	nd	0.36 ± 0.01$^{a–j}$
	2021	1.24 ± 0.04^{a}	0.16 ± 0.00^{a}	0.26 ± 0.05$^{a–d}$
	2022	1.28 ± 0.00^{a}	0.17 ± 0.00^{a}	0.34 ± 0.02$^{a–j}$
Woodchips	2019	1.19 ± 0.01^{a}	0.15 ± 0.00^{a}	0.46 ± 0.04$^{f–k}$
	2020	nd	nd	0.43 ± 0.01$^{e–k}$
	2021	1.18 ± 0.01^{a}	0.16 ± 0.00^{a}	0.24 ± 0.05^{ab}
	2022	1.26 ± 0.05^{a}	0.17 ± 0.01^{a}	0.36 ± 0.00$^{a–j}$
Woodchips + fungi	2019	1.23 ± 0.03^{a}	0.16 ± 0.00^{a}	0.49 ± 0.04$^{h–k}$
	2020	nd	nd	0.40 ± 0.01$^{b–k}$
	2021	1.17 ± 0.03^{a}	0.16 ± 0.00^{a}	0.25 ± 0.05^{abc}
	2022	1.19 ± 0.04^{a}	0.17 ± 0.00^{a}	0.35 ± 0.01$^{a–j}$
Pellets + fungi	2019	1.24 ± 0.01^{a}	0.16 ± 0.00^{a}	0.51 ± 0.02^{k}
	2020	nd	nd	0.41 ± 0.01$^{b–k}$
	2021	1.21 ± 0.01^{a}	0.16 ± 0.00^{a}	0.31 ± 0.04$^{a–f}$
	2022	1.21 ± 0.02^{a}	0.16 ± 0.00^{a}	0.37 ± 0.01$^{a–j}$
Pellets	2019	1.20 ± 0.02^{a}	0.15 ± 0.00^{a}	0.51 ± 0.02^{k}
	2020	nd	nd	0.43 ± 0.01$^{e–k}$
	2021	1.12 ± 0.01^{a}	0.16 ± 0.00^{a}	0.33 ± 0.04$^{a–j}$
	2022	1.20 ± 0.01^{a}	0.17 ± 0.00^{a}	0.38 ± 0.02$^{a–j}$
Biochar	2019	1.16 ± 0.03^{a}	0.15 ± 0.00^{a}	0.47 ± 0.02$^{f–k}$
	2020	nd	nd	0.37 ± 0.01$^{a–j}$
	2021	1.10 ± 0.01^{a}	0.16 ± 0.00^{a}	0.29 ± 0.05$^{a–e}$
	2022	1.17 ± 0.01^{a}	0.16 ± 0.00^{a}	0.35 ± 0.00$^{a–j}$
Liming	2019	1.19 ± 0.03^{a}	0.16 ± 0.00^{a}	0.49 ± 002^{ijk}
	2020	nd	nd	0.40 ± 0.01$^{b–j}$
	2021	1.20 ± 0.01^{a}	0.16 ± 0.00^{a}	0.30 ± 0.05$^{a–e}$
	2022	1.26 ± 0.01^{a}	0.17 ± 0.00^{a}	0.35 ± 0.01$^{a–j}$
Manure	2019	1.12 ± 0.01^{a}	0.14 ± 0.00^{a}	0.5 ± 0.01^{jk}
	2020	nd	nd	0.42 ± 0.03$^{c–k}$
	2021	1.14 ± 0.02^{a}	0.15 ± 0.00^{a}	0.33 ± 0.06$^{a–g}$
	2022	1.18 ± 0.03^{a}	0.16 ± 0.00^{a}	0.37 ± 0.00$^{a–j}$
Hydrogel	2019	1.19 ± 0.05^{a}	0.16 ± 0.01^{a}	0.48 ± 0.01$^{h–k}$
	2020	nd	nd	0.37 ± 0.02$^{a–j}$
	2021	1.16 ± 0.04^{a}	0.16 ± 0.00^{a}	0.28 ± 0.05$^{a–e}$
	2022	1.18 ± 0.04^{a}	0.17 ± 0.01^{a}	0.34 ± 0.01$^{a–j}$

The letters in each column indicate significant differences between different fertiliser applications at α = 0.05 (Tukey *HSD* (honestly significant difference) test); nd – not detected

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Table 4. The mean values of soil organic matter components (SOM) identified by intensity FTIR spectra in fertiliser treatments for 2019–2022

Treatment	Year	SOM components			DI	HI
		aliphatic	aromatic	hydrophilic		
Grassland	2019	1.12^{bc}	3.60^{b}	6.04^{a}	3.58^{ab}	0.19^{a}
	2021	1.55^{c}	3.42^{b}	6.75^{a}	2.37^{a}	0.24^{a}
	2022	2.47^{d}	2.13^{a}	5.11^{a}	0.88^{a}	0.49^{b}
Control	2019	1.05^{abc}	3.66^{b}	6.10^{a}	3.64^{ab}	0.18^{a}
	2021	1.19^{abc}	3.60^{b}	5.51^{a}	3.47^{ab}	0.22^{a}
	2022	0.20^{a}	4.22^{b}	6.94^{a}	25.53^{c}	0.03^{a}
Compost	2019	1.10^{abc}	3.57^{b}	5.94^{a}	3.39^{ab}	0.19^{a}
	2021	1.06^{abc}	3.72^{b}	5.97^{a}	3.99^{ab}	0.18^{a}
	2022	1.14^{abc}	3.59^{b}	6.15^{a}	6.05^{ab}	0.26^{a}
Woodchips	2019	0.91^{abc}	3.58^{b}	6.10^{a}	3.95^{ab}	0.15^{a}
	2021	0.67^{abc}	4.00^{b}	6.32^{a}	6.41^{ab}	0.11^{a}
	2022	0.38^{ab}	3.78^{b}	6.66^{a}	13.07^{b}	0.06^{a}
Woodchips + fungi	2019	0.88^{abc}	3.54^{b}	5.66^{a}	4.10^{ab}	0.16^{a}
	2021	0.9^{abc}	3.60^{b}	6.33^{a}	4.52^{ab}	0.14^{a}
	2022	0.67^{abc}	3.87^{b}	7.00^{a}	7.30^{ab}	0.10^{a}
Pellets + fungi	2019	1.01^{abc}	3.39^{ab}	5.65^{a}	3.46^{ab}	0.18^{a}
	2021	0.91^{abc}	3.59^{b}	6.14^{a}	4.30^{ab}	0.15^{a}
	2022	0.51^{ab}	4.09^{b}	6.72^{a}	8.37^{ab}	0.08^{a}
Pellets	2019	1.11^{abc}	3.38^{ab}	5.91^{a}	3.09^{ab}	0.19^{a}
	2021	1.05^{abc}	3.60 ^{b}	5.97^{a}	3.73^{ab}	0.18^{a}
	2022	0.56^{ab}	4.10 ^{b}	7.07^{a}	7.39^{ab}	0.08^{a}
Biochar	2019	1.12^{abc}	3.59^{b}	5.92^{a}	3.25^{ab}	0.19^{a}
	2021	0.55^{ab}	3.99^{b}	6.61^{a}	10.43	0.08^{a}
	2022	0.85^{abc}	3.67^{b}	6.69^{a}	6.63^{ab}	0.13^{a}
Liming	2019	0.93^{abc}	3.64^{b}	6.11^{a}	4.37^{ab}	0.15^{a}
	2021	0.65^{ab}	4.28^{b}	6.75^{a}	9.31^{ab}	0.10^{a}
	2022	0.91^{abc}	3.46^{ab}	6.06^{a}	3.96^{ab}	0.15^{a}
Manure	2019	1.05^{abc}	3.54^{b}	6.00^{a}	3.59^{ab}	0.18^{a}
	2021	1.14^{abc}	3.45^{ab}	5.87^{a}	3.38^{ab}	0.20^{a}
	2022	0.84^{abc}	3.67^{b}	6.44^{a}	4.95^{ab}	0.14^{a}
Hydrogel	2019	1.07^{abc}	3.56^{b}	6.11	3.44^{ab}	0.17^{a}
	2021	1.07^{abc}	3.76^{b}	6.22	4.03^{ab}	0.18^{a}
	2022	0.54^{ab}	3.66^{b}	6.33	8.19^{ab}	0.09^{a}

The different letters in each column indicate significant differences between different fertiliser applications at α = 0.05 (Tukey *HSD* (honestly significant difference) test). DI – decomposition index; HI – hydrophobicity index

can be explained by the lower amount of compost applied in our work and the different soil structure. Differences between the control and the lime and biochar treatments were minimal. We did not confirm biochar improvement in the clay-loam soil's physical properties. Ouyang et al. (2013) also recorded that biochar application increased soil aggregate stability more in sandy-loam soil than in silty-clay soil. Finally, there was a significantly rapid SAS increase of over 200% in the grassland area after the first two trial years.

The grassland's increased soil aggregate stability is associated with a significant decrease in soil bulk density. The significantly highest bulk density was

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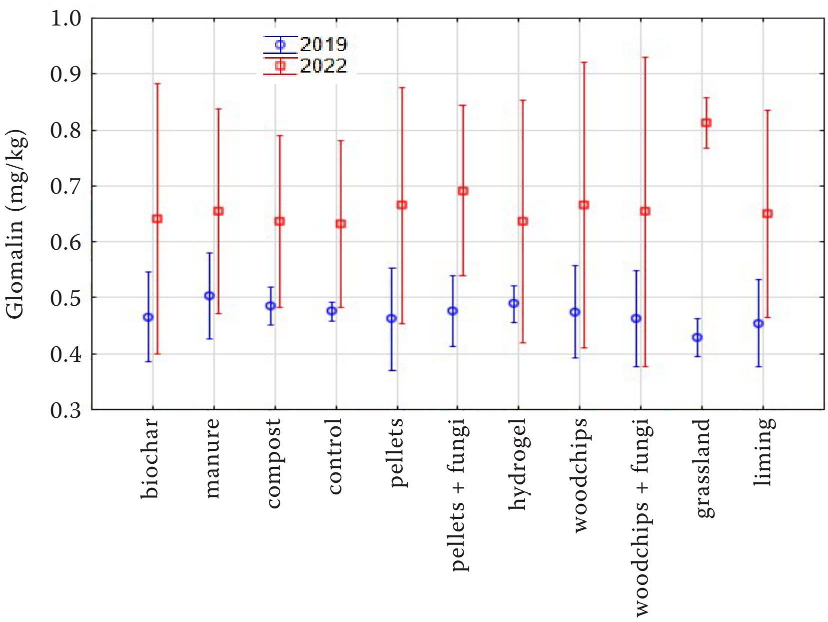

Figure 4. The effect of year and treatment interaction on easily extractable glomalin. Vertical columns show the 0.95 confidence interval

in 2019 and 2020, with an average 1.55 g/cm^3 value, but this reduced to 1.3 g/cm^3 in 2022 (Figure 3A). This contrasted with continuous porosity increases over the years. The 40.78% 2019/2020 average porosity values increased to 46.72% in 2021 and 50.71% in 2022 (Figure 3B).

Although there were no significant differences in the other treatments, lower bulk density and higher porosity values were observed for the woodchips + fungi and biochar plots, with opposing higher bulk density and lower porosity in control. However, the lower bulk density recorded above for biochar application did not increase aggregate stability.

The content of both soil organic carbon and hot water extractable carbon gradually increased in the grassland area from 2019, and the values doubled by 2022. Table 3 shows that the total nitrogen content also increased, but the differences between years were not significant for other treatments. However, there was decreasing HWC for most treatments. Our results are supported by Williams et al. (2005), who recorded a highly significant loss in total soil organic carbon, organic matter and aggregate stability in the cultivated fields compared to the grassland areas. We also noted that even the application of organic fertiliser did not significantly increase the amount of hot water extractable carbon over 4 years.

The grassland SAS increase is to the FTIR results in Table 4. The hydrophobic (aliphatic) component of organic matter in soils with more stable aggregates increased significantly from 1.12 in 2019 to 2.47 in 2022. In contrast, this component decreased for all other treatments except compost. Moreover, the hydrophobicity index increased in the grassland from 0.19 in 2019 to 0.49 in 2022; the decomposition index decreased from 3.58 in 2019 to 0.88 in 2022.

In addition, the rapid improvement in grassland soil properties is proven by the significant increase in easily extractable glomalin (EEG), whose value doubled in 2022 compared to 2018 (Figure 4). Higher EEG values were also found in the other treatments in 2022, but the significant differences noted in the grassland were not apparent in those treatments because of the high variability in experiment repetitions.

In conclusion, we established that soil aggregate stability could be temporarily increased by adding synthetic hydrogel to the clay-loam soil and that woodchip application also had a positive effect. However, most additives expected to improve soil aggregate stability proved ineffective in practice due to their short-term effect, technical problems in their application and higher costs. Finally, we highly recommend treatment by grassland revegetation for at least 3 years because this rapidly and significantly improved soil aggregate stability in poorly structured soil.

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