Supplementary material of

Opportunities for mitigating soil compaction in Europe – Case studies from the SoilCare project using soil improving cropping systems

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Table S1. Study site, climate and soil information for each country involved in the present study.

		Norway	Sweden	The U.K.	Italy	Romania
Study site	**Location**	Solør, near Kongsvinger	Orup, Skåne county	Loddington, Leicestershire	Legnaro	Drăgănești-Vlașca, Teleorman county
	Institution	NIBIO	SLU	GWCT	UNIPD	ICPA
	Latitude (DD), longitude (DD) and altitude (m a.s.l.)	60.25, 12.08, 172	55.49, 13.3, 75	52.36, 0.5, 186	45.2, 11.57, 7	44.07, 25.56, 26
	Starting year	2017	2018	2017	2018	2018
Climate	**Climate (Koppen-Geiger)**	Dfc	Cfc	Cfc	Cfb	Cfb
	Average annual precipitation (mm)	656	666	707	834	543
	Average annual temperature (C)	3.85	8.1	9.15	11.7	11.3
Soil	**WRB Reference Groups**	Stagnosol	Phaeozem	Stagnosol	Cambisol	Chernozem
	Soil texture class (USDA)	Silty[a]	Sandy loam[a]	Clay[b]	Silty loam[b]	Clay loam[a]
	SOC (g 100 g^{-1})	0.74[c]	2.11[d]	2.88[d]	0.76[d]	2.23[e]
	Total N (g 100 g^{-1})	na	0.20[d]	na	0.099[d]	na
	pH	4.95[f]	6.90[g]	6.64[f]	7.36[f]	6.20[g]
	Plant available K^+ (mg kg^{-1})[h]	na	74	125	94	13
	Plant available P (mg kg^{-1})[h]	na	100	41.8	35.6	44.7

na: not available; [a]pipette method, [b]laser diffraction method, [c]ignition loss, [d]dry combustion, [e]Walkley-Black method; [f]in KCl, [g]in water, [h]plant-available K and P were obtained accordingly with standard ISO methods.

Table S2. Depth of topsoil and subsoil sampling for chemical-physical analysis at each study site.

Study site	Topsoil sampling layer (cm)	Subsoil sampling layer (cm)
Norway-NIBIO	10-20	30-40
Sweden-SLU	10-15	28-33
U.K.-GWCT	0-10	30-40
Italy-UNIPD	0-20	40-60
Romania-ICPA	10-20	40-50

Table S3. Topsoil (10-20 cm) bulk density (BD), total pore volume (TPV), air capacity (AC), saturated hydraulic conductivity (Ks) and air permeability (Air perm) in the un-compacted reference plots at the Norwegian study site in 2015 and in treatment 3 (barley monoculture) and treatment 4 (alfalfa monoculture) plots in 2020.

	BD ($g\ cm^{-3}$)	TPV (%)	AC (%)	Ks ($m\ day^{-1}$)	Air perm (um^2)
2015					
Reference plot	1.34 ± 0.08	49.1 ± 2.8	8.02 ± 2.94	11.43 ± 4.05	419.0 ± 326.5
2020					
Reference plot					
Treatment 3*	1.30 ± 0.09 ns	49.4 ± 2.6 ns	17.50 ± 31.19 ns	2.38 ± 3.09 ns ¶	12.6 ± 15.6 ns ¶
Treatment 4	1.40 ± 0.14 ns	44.3 ± 8.6 ns	6.80 ± 2.77 ns	$1.0\times10^{-2} \pm 1.29\times10^{-2}$ ns ¶	0.2 ± 0.2 ns ¶

Mean ± standard deviation (2015 n = 5, 2020 n = 4). For 2020, ¶ indicates a significant difference between 2020 and the value in 2015 for each treatment. ns= not significant at $p<0.05$.

*Except for treatment 4 with alfalfa, all plots with annual crops (treatments 1-3) were ploughed to 25 cm depth every year. Consequently, in 2020, only barley monoculture plots (treatment 3) were subject to topsoil sampling for comparison with the alfalfa plots, assuming no differences in topsoil physical properties would have occurred between the treatments with annual crops.

Table S4. Results from soil profile descriptions in 2019, maximum penetrometer depth and analysis of undisturbed soil cylinders from two depths in 2020, for all three treatments at the Swedish study site.

Measurement	Control	Subsoiling	Subsoiling + straw
Soil profile description			
Number of roots at three depths[x]			
10 cm	31	32	63
20 cm	22	54	64
30 cm	3	19	16
Maximum penetration into the subsoil (cm)[y]	4 ± 1.2	10.9 ± 3.0	11.1 ± 2.6
Soil cylinders			
BD (g cm^{-3})			
10-15 cm depth	1.39ab	1.47b	1.36ac
28-33 cm depth	1.51a	1.58b	1.55ab
BD_fine soil (g cm^{-3})			
10-15 cm depth	1.35a	1.42a	1.32a
28-33 cm depth	1.46a	1.54a	1.49a
Gravel and stones (weight %)			
10-15 cm depth	6.7a	6.5a	6.1a
28-33 cm depth	6.3a	6.4a	8.3a
C (%)			
10-15 cm depth	2.10a	2.01b	2.09a
28-33 cm depth	1.81a	1.70a	1.64a
C/N			
10-15 cm depth	10.3a	10.4a	10.4a
28-33 cm depth	10.3a	10.3a	10.5a
pH			
10-15 cm depth	5.9a	5.9a	5.8a
28-33 cm depth	6.1a	6.1a	6.1a

[x]In one plot per treatment the number of roots was counted along a 10 cm line in the control, subsoiling and subsoiling + straw rows. [y]Means and standard deviations of maximum penetration into the subsoil (>24 cm) from six penetrometer measurements made in all plots for each treatment. BD = dry soil bulk density. BD_fine soil = dry soil bulk density of the fine soil fraction corrected for mass and volume of gravel and stones, where the volume was calculated using a measured mean rock density of 2.6 g cm^{-3}. For the 10-15 cm depth, BD, BD_fine soil, gravel and stones, C, C/N and pH were from measurements in all cylinders. For the 28-33 cm depth, C, C/N and pH were from measurements on pooled soil samples from the six cylinders taken in each plot. Values with different letters within each row for the 10-15 and 28-33 cm depths are significantly different.

Table S5. Comparison of significance level among the linear mixed-effect models analysis of bulk density (BD), penetration resistance (PR), volumetric water content (VWC), soil organic carbon concentration (SOC), maize yield and soil hydraulic parameters (S, A and Ks) at the Italian study site. Significant effect (p<0.05) are highlighted in bold.

	Effect	**BD**	**PR**	**VWC**	**SOC**	**Yield**	**S**	**A**	**K_s**
Topsoil	Intercept	**0.01**	**0.08**	**0.03**	**0.03**	**0.01**	0.16	0.19	0.19
	Soil cover (SC)	0.96	**0.02**	0.34	0.72	0.47	0.17	0.48	0.48
	Tillage (T)	0.14	**<0.01**	0.43	0.56	0.98	**0.05**	0.16	0.16
	S × T	0.47	0.54	0.28	0.95	0.79	0.12	0.35	0.35
Subsoil	Intercept	**0.01**	**0.03**	**0.02**	**0.04**				
	Soil cover (SC)	0.14	0.12	0.21	0.63				
	Tillage (T)	0.55	0.92	0.91	0.60				
	S × T	0.21	0.16	0.62	0.85				

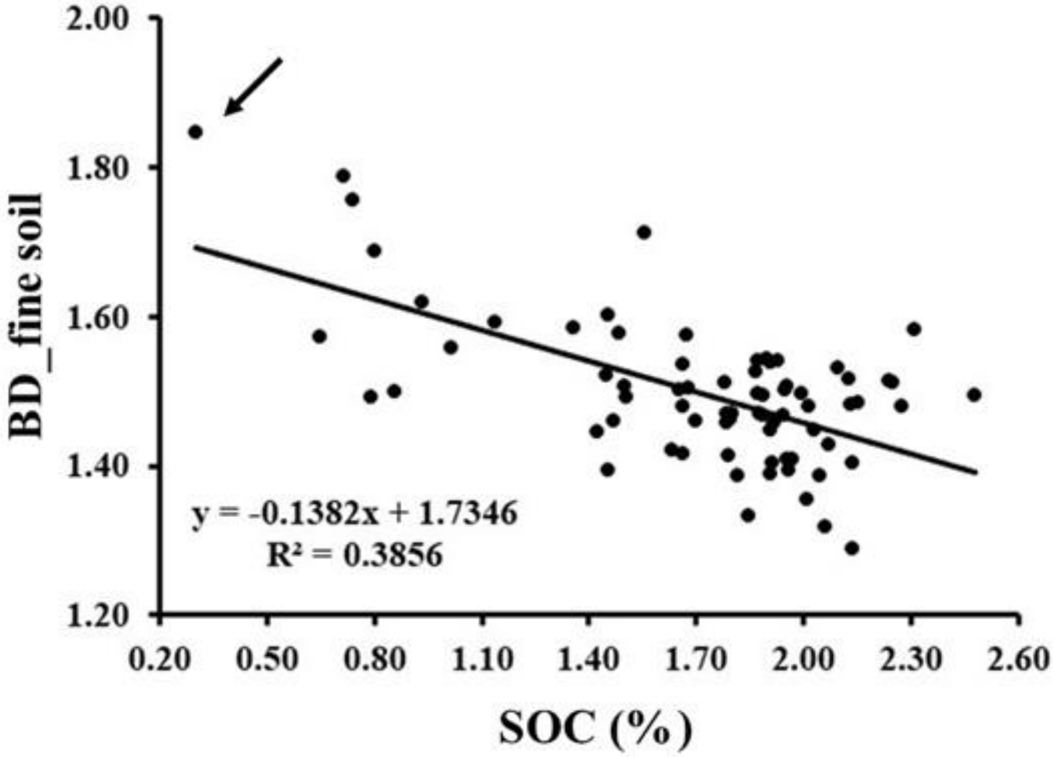

Figure S1. Relationship between soil organic carbon (SOC) content and dry soil bulk density of the fine soil fraction (BD_fine soil) measured with all soil cylinders taken from 28-33 cm depth at the Swedish study site in 2020 (N = 72). The relationship excluding the point with the lowest SOC content (indicated with the arrow) was BD_fine soil = -01199 x 1.7007 (R^2 = 0.3118).

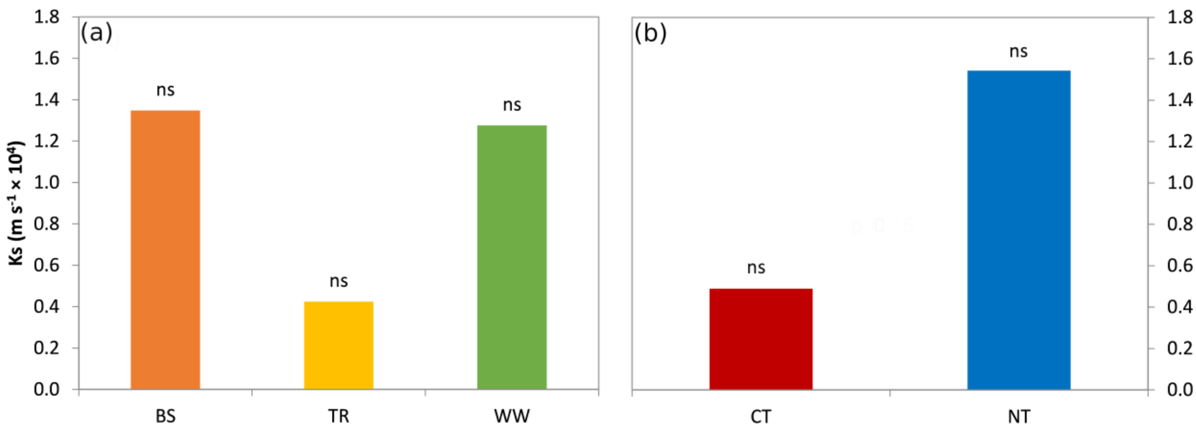

Figure S2. Topsoil (0-20 cm) saturated hydraulic conductivity (Ks) as affected by soil cover (a) and tillage (b) at the Italian study site. ns=not significant at $p<0.05$. BS: bare soil; TR: tillage radish; WW: winter wheat; CT: conventional tillage; NT: no-tillage.

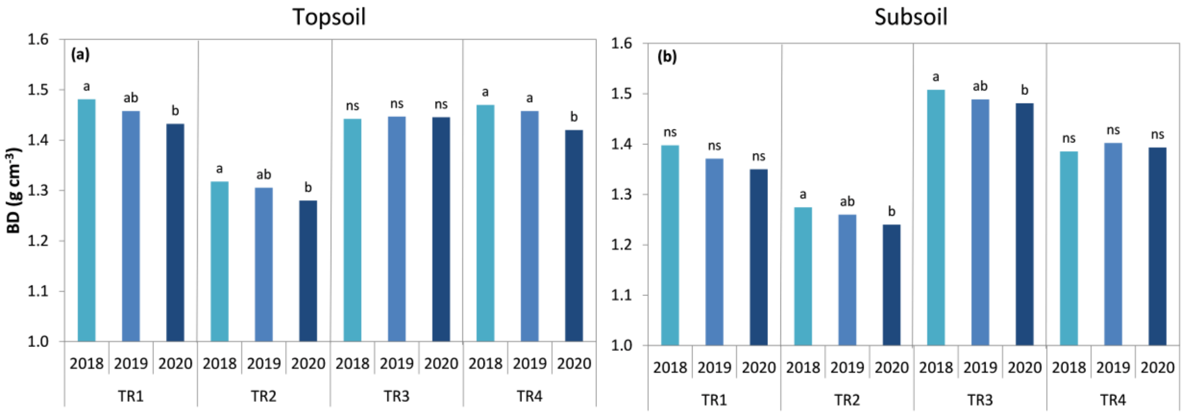

Figure S3. Topsoil (10-20 cm) (a) and subsoil (40-50 cm) (b) bulk density (BD) as affected by different years during three years of the experiment at the Romanian study site. Different letters represent significant differences according to Tukey post-hoc test at $p<0.05$. ns=not significant at $p<0.05$. TR1: mouldboard ploughing with furrow inversion to 25 cm depth; TR2: subsoiling to 60 cm + disking to 12 cm depth; TR3: control treatment with 2-times disking; TR4: chiselling to 25 cm depth with furrow inversion.

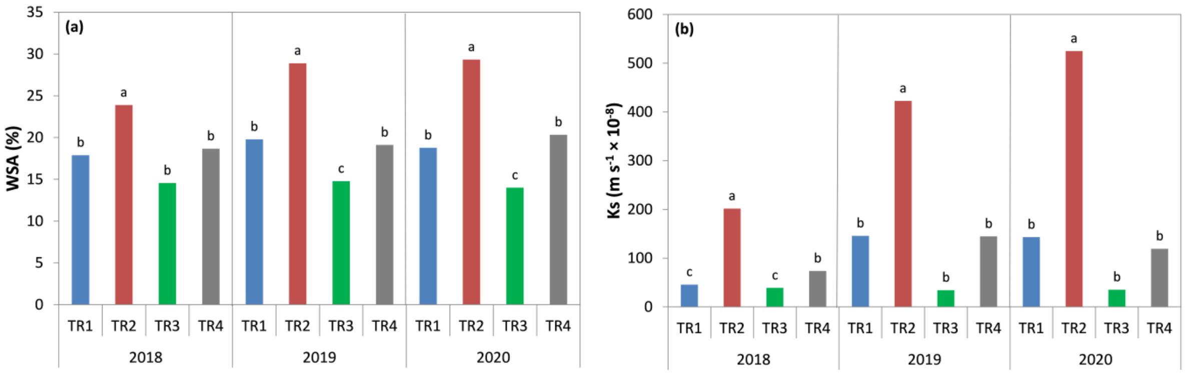

Figure S4. Content of water-stable aggregates (WSA) (a) and saturated hydraulic conductivity (Ks) (b) in the topsoil (10-20 cm) layer as affected by different tillage systems during three years of the Romanian experiment. Different letters represent significant differences according to Tukey post-hoc test at $p<0.05$. TR1: mouldboard ploughing with furrow inversion to 25 cm depth; TR2: subsoiling to 60 cm + disking to 12 cm depth; TR3: control treatment with 2-times disking; TR4: chiseling to 25 cm depth with furrow inversion.

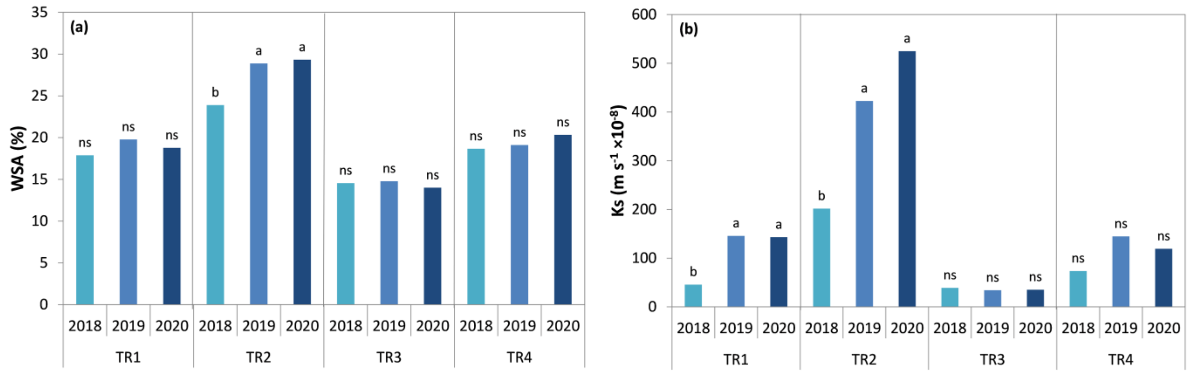

Figure S5. Content of water-stable aggregates (WSA) (a) and saturated hydraulic conductivity (Ks) (b) in the topsoil layer as affected by different years during three years of the experiment at the Romanian study site. Different letters represent significant differences according to Tukey post-hoc test at $p<0.05$. ns=not significant at $p<0.05$. TR1: mouldboard ploughing with furrow inversion to 25 cm depth; TR2: subsoiling to 60 cm + disking to 12 cm depth; TR3: control treatment with 2-times disking; TR4: chiselling to 25 cm depth with furrow inversion.