
Hemp cultivation in soils polluted by Cd, Pb and Zn in the Mediterranean area: sites characterization and phytoremediation in real scale settlement

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Supplementary Materials: Soil description and chemical characteristics

The soil of the SITE 1 (39°32'52.74"N – 8°46'16.43"E, 46 m a.s.l.) was classified as fine loamy, mixed, superactive, thermic Vertic Haploxerept, with Ap, Bss1, Bss2, C horizons

Table S1. Profile horizons description of Site 1

Ap 0-50 cm	humid; humid matrix color very dark gray (10 YR 3/1); coarse / thick sub angle polyhedral structure, moderately developed, crumble when humid; slightly adhesive and plastic; 1% skeleton consisting of 1% fine and medium gravel (2–20 mm); very small pores (<0.5 mm) common (0,5%–2%); moderately well drained; linear clear limit
Bss1 50-75 cm	humid; humid matrix color dark gray (10 YR 4/1); medium angular polyhedral structure, weakly developed, hard when dry, slightly adhesive, plastic; common (2-20%) 8 mm soft concentrations of Calcium carbonate and common (20%) iron manganese nodules; few very small pores (<0.5 mm) (0.1%–0.5%); many (15-40%) slickensides; weakly calcareous, rather poorly drained; linear gradual limit
Bss2 75-90 cm	humid; humid matrix color dark gray (10 YR 4/1); 30% of streaks of yellowish brown color (10 YR 5/8), all dimension with distinct contrast; medium angular structure, weakly developed, hard when dry; slightly adhesive and plastic; common (2-20%) 8 mm soft concentrations of Calcium carbonate and common (20%) iron manganese nodules; 2% skeleton consisting of 2% fine and medium gravel (2-20 mm); few very small pores (<0.5 mm) (0.1%–0.5%); common (5-15%) slickensides; weakly calcareous; rather poorly drained; linear gradual limit
C 90-150 cm	humid; humid matrix color gray (10 YR 5/1); 75% of streaks of yellowish brown color (10 YR 5/8), all dimension with distinct contrast; 20% skeleton made up of 20% coarse gravel (20–75 mm); very small pores (<0.5 mm) few (0.1%–0.5%); weakly calcareous; rather poorly drained

Table S2. Chemical characterization of soil samples collected from each horizon of Site 1

Horizon Code		Ap	Bss1	Bss2	C
Depth	cm	0–50	50–75	75–90	90–150
Total sand	g·kg ⁻¹	331	279	262	436
Total Silt	g·kg ⁻¹	390	305	341	317
Clay	g·kg ⁻¹	279	416	397	247
Texture class		CL	C	CL	L
pH H ₂ O		7.3	8.9	9.6	9.3
pH KCl		5.7	7	7.4	7.4
Total CaCO ₃		0.0001	7	7.4	0.0001
Organic carbon	g·kg ⁻¹	12.7	5.07	2.82	0.53
Organic matter	g·kg ⁻¹	21.9	8.74	4.86	0.91
Total nitrogen	g·kg ⁻¹	2	1.19	1.02	0.65
C/N		6.4	4.3	2.8	0.8
Exchangeable Ca	mg·kg ⁻¹	2494	2489	1213	224
Exchangeable Mg	mg·kg ⁻¹	445	1076	1247.7	303
Exchangeable Na	mg·kg ⁻¹	136	984	2016.5	1326
Exchangeable K	mg·kg ⁻¹	288	194	149	39.6
CEC	meq·100 g ⁻¹	23.8	26.9	26.2	11
Base saturation	%	73.27	96.85	97.23	86.19
Zn	mg·kg ⁻¹	125	120	113	112
Pb	mg·kg ⁻¹	147	23.9	20.6	26.9
Cd	mg·kg ⁻¹	2.4	0.62	0.49	0.93

SITE 2 (39°37'5.65"N - 8°38'2.93"E, 33 m a.s.l.) was located just 150 meters outside to the areas amenable to the law for contaminated Sites of National Interest. The entire area was interested by the flooding of Sitzzerri river that deposited in their floodplain high amounts of mining wastes from Montevecchio.

The Montevecchio mineral district activity, starting in 1848 and closed definitively in 1991, was dedicated to extract and process PbS and ZnS. This experimental site is actually situated into irrigated lands and it is usually grazed or cultivated.

The soil of the Site 2 was classified as coarse loamy, mixed, superactive, thermic Fluventic Haploxerept, with Ap1, Ap2, 2Bw, 3C1, 4C2, 5C3, 5C4, 6C5 horizons

Table S3. Profile horizons description of Site 2

Ap1 0–10 cm	dry; dry matrix color pale brown (10 YR 6/3); medium sub angle polyhedral structure, strongly developed, hard when dry; slightly adhesive and plastic; 7% skeleton consisting of 5% fine and medium gravel (2–20 mm) and 2% coarse gravel (20–75mm); very small pores (<0.5 mm) abundant (2–5%); not calcareous, well drained;
Ap2 10–45 cm	dry; dry matrix color pale brown (10 YR 6/3); structure absent, massive, slightly adhesive and plastic; 7% skeleton consisting of 5% fine and medium gravel (2–20 mm) and 2% coarse gravel (20–75mm); very small pores (<0.5 mm) common (2–5%); not calcareous, well drained;
2Bw 45–80 cm	humid; humid matrix color dark brown (7.5 YR 3/3); structure absent, massive, crumble when humid; slightly adhesive and not plastic; common (2–20%) 9 mm soft concentrations of iron manganese; 3% skeleton consisting of 3% fine and medium gravel (2–20 mm); few very small pores (<0.5 mm) (0.1%–0.5%); not calcareous; moderately well drained; linear abrupt limit
3C1 80–100 cm	humid; humid matrix color dark brown (7.5 YR 3/2); 20% of streaks of yellowish brown color (10 YR 5/8) and 2% of streaks of very dark gray color (10 YR 3/1); structure absent, massive, strong when humid; slightly adhesive and very plastic; few (<2%) 5 mm soft concentrations of iron manganese; 2% skeleton made up of 2% medium and fine gravel (2–20 mm); very small pores (<0.5 mm) common (0.5%–2%); not calcareous; moderately well drained; linear abrupt limit
4C2 100–120 cm	humid; humid matrix color dark gray (7.5 YR 4/1); 25% of streaks of dark brown color (7.5 YR 3/2) and 5% of streaks of dark reddish brown color (5 YR 3/3); structure absent, massive, very crumble when humid; slightly adhesive and not plastic; few (<2%) 2 mm soft concentrations of iron manganese; very small pores (<0.5 mm) common (0.5%–2%); not calcareous; moderately well drained; linear abrupt limit
5C3 120–145 cm	humid; humid matrix color dark gray (7.5 YR 4/1); 6% of streaks of very dark gray color (7.5 YR 3/1) and 5% of streaks of strong brown color (7.5 YR 5/8); structure absent, massive, strong when humid; very adhesive and plastic; few (<2%) 2 mm soft concentrations of iron manganese; very small pores (<0.5 mm) few (0.1%–0.5%); not calcareous; moderately well drained; linear abrupt limit
5C4 145–170 cm	humid; humid matrix color dark gray (10 YR 4/1); 20% of streaks of strong brown color (7.5 YR 4/6) and 3% of streaks of very dark gray color (10 YR 3/1); structure absent, massive, very crumble when humid; adhesive and very plastic; few (<2%) 2 mm soft concentrations of iron manganese; very small pores (<0.5 mm) few (0.1%–0.5%); not calcareous; moderately well drained; linear abrupt limit
6C5	wet; humid matrix color dark greenish gray (10 Y 4/1); 20% of streaks of color (7.5 Y 4/6) and 3% of streaks of very dark gray color (10 YR 3/1); structure absent, loose or inconsistent, loose when humid; slightly adhesive and not plastic; very small pores (<0.5 mm) common (0.5%–2%); not calcareous moderately well drained

Table S4. Chemical characterization of soil samples collected from each horizon of Site 2

Horizon Code		Ap1	Ap2	2Bw	3C1	4C2	5C3	5C4
Depth	cm	0–10	10–45	45–80	80–100	100–120	120–145	145–170
Total sand	g·kg ⁻¹	592	567	701	379	771	413	397
Total Silt	g·kg ⁻¹	284	289	137	371	81	384	337
Clay	g·kg ⁻¹	124	144	162	250	148	203	266
Texture class		SL	SL	SL	L	SL	L	L
pH H ₂ O		5.9	5.9	6.6	6.7	7.2	7.3	7.2
pH KCl		4.8	4.4	4.6	5	5.2	5.4	5.3
Total CaCO ₃		0	0	0	0	0	0	0
Organic carbon	g·kg ⁻¹	11.8	6.63	1.59	2.71	1.73	2.35	1.17
Organic matter	g·kg ⁻¹	20.4	11.4	2.74	4.67	2.98	4.06	2.01
Total nitrogen	g·kg ⁻¹	1.27	0.91	0.47	0.62	0.3	0.39	0.38
C/N		9.3	7.3	3.4	4.4	5.8	6	3.1
Exchangeable Ca	mg·kg ⁻¹	650	539	684	1458	728	1517	1619
Exchangeable Mg	mg·kg ⁻¹	180	161	253	566	320	646	765
Exchangeable Na	mg·kg ⁻¹	76.9	39.7	53	124	74.2	161	194
Exchangeable K	mg·kg ⁻¹	269	168	108	121	72.2	104	108
CEC	meq·100 g ⁻¹	15.9	14.9	14.9	20.6	16.2	24.5	25.7
Base saturation	%	36.15	30.99	40.28	62.04	41.82	56.54	60.29
Zn	mg·kg ⁻¹	441	519	521	333	196	3	276
Pb	mg·kg ⁻¹	422	492	1038	69.4	47.9	62.8	70.9
Cd	mg·kg ⁻¹	3.7	4.3	4.3	1.39	0.85	0.98	1.19

SITE 3 (39°37'8.76"N - 8°38'6.48"E, 32 m a.s.l.) was located in the same area of site 2. The main characteristics and management of the area are close to those described for Site 2.

The soil of the Site 3 was classified as Humic Haploxerept fine-loamy, mixed, superactive, thermic with Ap1, Ap2, Bw, C, 2C, 3C horizons.

Table S5. Profile horizons description of Site 3

Ap1 0–10 cm	dry; dry matrix color dark grayish brown (10 YR 4/2); medium sub angle polyhedral structure, moderately developed, very hard when dry; 10% skeleton consisting of 10% fine and medium gravel (2–20 mm); very small pores (<0.5 mm) common (0.5–2%); not calcareous, well drained; linear abrupt limit
Ap2 10–40 cm	dry; dry matrix color very dark grayish brown (10 YR 3/2); thin sub angle polyhedral structure, moderately developed, very hard when dry; 10% skeleton consisting of 5% fine and medium gravel (2–20 mm) and 5% coarse gravel (20–75mm); very small pores (<0.5 mm) common (2–5%); not calcareous, well drained; linear abrupt limit
Bw 40–95 cm	humid; humid matrix color dark brown (10 YR 3/3); structure absent, massive, extremely resistant when humid; 4% skeleton consisting of 2% fine and medium gravel (2–20 mm) and 2% of pebbles (76–250 mm); very small pores (<0.5 mm), common(0.5%–2%); not calcareous; moderately well drained; linear clear limit
C 95–110 cm	humid; humid matrix color dark grayish brown (10 YR 4/2); 20% of streaks of strong brown color (7.5 YR 4/6) small (<5 mm) with distinct contrast; medium sub angle polyhedral structure, moderately developed, strong when humid; very small pores (<0.5 mm) common (0.5%–2%); not calcareous; rather excessively drained; linear abrupt limit
2C 110–140 cm	wet; humid matrix color dark grayish brown (10 YR 4/2); 40% of streaks of strong brown color (7.5 YR 4/6) all the dimensions; structure absent, loose, loose when humid; 40% skeleton consisting of 20% fine and medium gravel (2–20 mm) and 20% coarse gravel (20–75mm); not calcareous; excessively drained; linear abrupt limit
3C 140–150 cm	wet; humid matrix color dark grayish brown (10 YR 4/2); 50% of streaks of strong brown color (7.5 YR 4/6) all the dimension; structure absent, loose, loose when humid; not calcareous

Table S6. Chemical characterization of soil samples collected from each horizon of Site 3

Horizon Code		Ap1	Ap2	Bw	C	2C	3C
Depth	cm	0–10	10–40	40–95	95–110	110–140	140–150
Total sand	g·kg ⁻¹	528	495	473	769	872	934
Total-Silt	g·kg ⁻¹	259	266	258	110	43	12
Clay	g·kg ⁻¹	213	239	269	121	85	54
Texture class		SCL	SCL	SCL	SL	LS	S
pH H ₂ O		6.4	6.4	7.3	7.7	7.4	7.3
pH KCl		5.2	5	6	5.6	5.3	5.7
Total CaCO ₃		0	0.5	0.5	0.5	0.5	0.5
Organic carbon	g·kg ⁻¹	14.5	9.21	4.57	1.49	0.85	0.35
Organic matter	g·kg ⁻¹	25.1	15.9	7.88	2.57	1.47	0.6
Total nitrogen	g·kg ⁻¹	1.5	1.03	1.12	0.21	0.24	
C/N		9.7	8.9	4.1	7.1	3.5	
Exchangeable Ca	mg·kg ⁻¹	1561	1491	1926	983	529	432
Exchangeable Mg	mg·kg ⁻¹	391	408	592	328	216	172
Exchangeable Na	mg·kg ⁻¹	64.6	52.4	87.6	84.1	58.2	50.9
Exchangeable K	mg·kg ⁻¹	325	154	71.1	30.3	42.3	51.7
CEC	meq·100 g ⁻¹	24	22.5	22.8	18.7	13.5	12.4
Base saturation	%	50.5	50.76	65.99	43.04	35.4	31.65
Zn	mg·kg ⁻¹	1076	1093	429	270	184	151
Pb	mg·kg ⁻¹	999	1063	373	280	88.9	198
Cd	mg·kg ⁻¹	9.2	8.8	3.7	1.73	0.39	0.39

SITE 4 (39°38'50.87"N - 8°40'53.13"E, 21 m a.s.l.) is located in agricultural land irrigated from decennals and it is usually cultivated with feed crops such as alfalfa, corn, sorghum. Public irrigation infrastructure serves this land.

The soil of the Site 4 was classified as coarse loamy, mixed, superactive, thermic Fluventic Haploxerept, with Ap, C, 2Bw, 2C, 3C horizons.

Table S7. Profile horizons description of Site 4

Ap 0–45 cm	humid; humid matrix color dark brown (10 YR 3/3); coarse sub angle polyhedral structure, strongly developed, crumble when humid; not adhesive and plastic; 10% skeleton consisting of 5% pebbles (76-250 mm) and 5% coarse gravel (20-75 mm); small pores (0.5-2 mm) plenty (2–5%); not calcareous, well drained; linear abrupt limit
C 45–55 cm	humid; humid matrix color brown (7.5 YR 4/3); 35% of streaks of strong brown color (7.5 YR 4/6) all the dimension with distinct contrast; medium sub angle polyhedral structure, strongly developed, crumble when humid; slightly adhesive and plastic; few (<2%) 5 mm Calcium carbonate nodules; 20% skeleton consisting of 10% fine and medium gravel (2–20 mm) and 10% coarse gravel (20-75mm); very small pores (<0.5 mm) few (0.1–0.5%); not calcareous, moderately well drained; linear abrupt limit
2Bw 55–80 cm	humid; humid matrix color very strong grayish brown (10 YR 3/2); medium sub angle polyhedral structure, moderately developed, very crumble when humid; not adhesive nor plastic; 8% skeleton consisting of 5% fine and medium gravel (2-20 mm) and 3% of coarse gravel (20-75 mm); small pores (0.5-2 mm), common(0.5%–2%); not calcareous; well drained; linear clear limit
2C 80–100 cm	humid; humid matrix color grayish brown (2.5 YR 5/2); 30% of streaks of strong brown color (7.5 YR 4/6) all the dimension with marked contrast; coarse sub angle polyhedral structure, weakly developed, very crumble when humid; not adhesive nor plastic; few (<2%) 5 mm soft concentrations of Calcium carbonate; 5% skeleton consisting of 5% fine and medium gravel (2-20 mm); small pores (0.5-2 mm) plenty (2%–5%); not calcareous; rather excessively drained; linear abrupt limit
3C 100–150 cm	wet; humid matrix color dark gray (2.5 YR 4/1); 35% of streaks of strong brown color (7.5 YR 5/8) all the dimensions with marked contrast; structure absent, loose, loose when humid; not adhesive nor plastic; common films (5-15%) of clay; 35% skeleton consisting of 15% pebbles (76–250 mm) and 20% coarse gravel (20-75mm); very small pores (<0.5 mm) few (0.1–0.5%); not calcareous; rather poorly drained

Table S8. Chemical characterization of soil samples collected from each horizon of Site 4

Horizon Code		Ap	C	2Bw	2C	3C
Depth	cm	0–45	45–55	55–80	80–100	100–150
Total sand	g·kg ⁻¹	546	426	657	767	532
Total-Silt	g·kg ⁻¹	237	215	246	169	177
Clay	g·kg ⁻¹	217	359	97	64	291
Texture class		SCL	CL	LS	SL	LCS
pH H ₂ O		7.8	7.7	7.8	8.2	8.1
pH KCl		6.4	6.9	6.4	6.1	5.8
Total CaCO ₃		2.86	26	2.03	1.07	6.51
Organic carbon	g·kg ⁻¹	6.06	2.53	6.7	0.8	2.08
Organic matter	g·kg ⁻¹	10.4	4.37	11.6	1.38	3.58
Total nitrogen	g·kg ⁻¹	0.72	1.21	0.54	0.88	1.18
C/N		8.4	2.1	12.4	0.9	1.8
Exchangeable Ca	mg·kg ⁻¹	2165	3358	1187	458	1483
Exchangeable Mg	mg·kg ⁻¹	379	614	179	117	659
Exchangeable Na	mg·kg ⁻¹	57.2	103	54.2	32.3	99.2
Exchangeable K	mg·kg ⁻¹	168	153	38.1	32.5	52.1
CEC	meq·100 g ⁻¹	18.1	14.7	10.1	5.42	14.6
Base saturation	%	80.67	100	76.53	64.04	91.7
Zn	mg·kg ⁻¹	2.51	134	105	77.3	144
Pb	mg·kg ⁻¹	5.20	29.8	44	26.8	35.4
Cd	mg·kg ⁻¹	0.21	1.17	0.45	0.2	0.52

SITE 5 (39° 5'49.42"N - 8°32'15.62"E, 5 m a.s.l.) is an agricultural area, served by a public irrigation system from long time and was usually cultivated by irrigated feed crops typically in the area, such as corn and alfalfa.

The soil of the Site 5 was classified as Pachic Calcixeroll coarsy-loamy, mixed, semiactive, thermic with Apk, 2Bk, 3Bw, 4Ab, 5Bwb horizons.

Table S9. Profile horizons description of Site 5

Apk 0–60 cm	humid; humid matrix color very dark grayish brown (10 YR 3/2); 5% of streaks of yellowish brown color (10 YR 5/6) small (<5 mm); very coarse sub angle polyhedral structure, moderately developed, crumble when humid; few (<2%) 15 mm Calcium carbonate concretions; 2% skeleton consisting of 2% all the dimension; small pores (0.5-2 mm) plenty (2–5%) and very small pores (<0.5 mm); extremely calcareous, well drained; linear abrupt limit
2Bk 60–80 cm	humid; humid matrix color pale brown (10 YR 6/3); coarse sub angle polyhedral structure, moderately developed, very crumble when humid; common (2-20%) 5 mm Calcium carbonate concretions; very small pores (<0.5 mm) common (0.5–2%) and small pores (0.5-2 mm); extremely calcareous, moderately well drained; linear abrupt limit
3Bw 80–95 cm	humid; humid matrix color almost dark grayish brown (10 YR 3.5/2); medium sub angle polyhedral structure, moderately developed, crumble when humid; very small pores (<0.5 mm) common (0.5–2%) and small pores (0.5-2 mm); weakly calcareous, moderately well drained; linear abrupt limit
4Ab 95–125 cm	humid; humid matrix color very dark brown (10 YR 2/2); coarse angular polyhedral structure, strongly developed, strong when humid; very small pores (<0.5 mm) few (0.1-0.5%); many (15-40%) slickensides; not calcareous; moderately well drained; linear clear limit
5Bwb 125–160 cm	humid; humid matrix color dark gray (10 YR 4/1); coarse angular polyhedral structure, moderately developed, strong when dry; medium pores (2-5 mm) common (0.5-2%) and small pores (0.5-2 mm); many (15-40%) slickensides; not calcareous; moderately well drained

Table S10. Chemical characterization of soil samples collected from each horizon of Site 5

Horizon Code		Apk	2Bk	3Bw	4Ab	5Bwb
Depth	cm	0–60	60–80	80–95	95–125	125–160
Total sand	g·kg ⁻¹	427	442	690	511	384
Total-Silt	g·kg ⁻¹	308	468	263	414	494
Clay	g·kg ⁻¹	265	90	47	75	122
Texture class		L	L	LS	L	L
pH H ₂ O		8	8.5	8.6	8.6	8.5
pH KCl		7.4	7.5	7.2	7.1	7.1
Total CaCO ₃		117	112	0.5	0.5	0.5
Organic carbon	g·kg ⁻¹	5.07	5.89	4.76	7.2	3.75
Organic matter	g·kg ⁻¹	8.74	10.2	8.2	12.4	6.47
Total nitrogen	g·kg ⁻¹	1.45	0.56	0.51	0.68	0.78
C/N		3.5	10.5	9.3	10.6	4.8
Exchangeable Ca	mg·kg ⁻¹	2940	2516	2860	3430	2299
Exchangeable Mg	mg·kg ⁻¹	536	809	1288	1424	1058
Exchangeable Na	mg·kg ⁻¹	288	673	888	1056	941
Exchangeable K	mg·kg ⁻¹	60.4	56.8	207	274	216
CEC	meq·100 g ⁻¹	24	23.3	30.7	34.5	30.1
Base saturation	%	85.38	95.64	95.32	98.93	82.48
Zn	mg·kg ⁻¹	61.8	38.1	54.3	48.3	40.5
Pb	mg·kg ⁻¹	24.1	9.1	8.9	7.0	7.3
Cd	mg·kg ⁻¹	0.40	0.2	0.2	0.2	0.2