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1 **Potential use of biochar, compost and iron grit associated with** 2 ***Trifolium repens* to stabilize Pb and As on a multi-contaminated** 3 **technosol**

4

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11

12 **Abstract**

13 Vegetation cover can be used in the phytomanagement of polluted areas by adding
14 value to abandoned sites and reducing the dispersion of pollutants by erosion. Appropriate
15 amendments, that allow both efficient plant growth and the immobilization of contaminants in
16 the soil must be chosen in order to optimize the efficiency of this process. We used a mining
17 technosol mainly contaminated by arsenic (1068 mg.kg⁻¹) and lead (23387 mg.kg⁻¹) to study
18 the effect of three amendments (biochar, compost and iron grit) on (i) physico-chemical
19 properties of the soil and soil pore water, (ii) metal(loid) mobility, bioavailability and
20 bioaccessibility (CaCl₂ and Simple Bioaccessibility Extraction Test (SBET)), and (iii) the
21 capability of *Trifolium repens* to germinate and grow. All the amendments used increased the
22 pH and electrical conductivity of the SPW, resulting in a 90% decrease in the concentration of
23 lead in the soil pore water (SPW). We also demonstrated a decrease in Pb phytoavailability.
24 The amendments allowed the establishment of a plant cover, although the addition of iron grit
25 alone did not allow any clover germination. For the Pontgibaud technosol, the combination of
26 the three amendments resulted in a significant decrease in As and Pb concentrations in clover
27 tissues, mainly in the aerial organs. The amendments also made it possible for some of them
28 to halve the phytoavailable fraction of arsenic. However, for compost, both the As
29 concentrations in the SPW, and the bioavailable fraction of As increased. All the amendments
30 used had contrasting effects on the bioaccessible fractions of metal(loid)s. The most efficient
31 amendment combination was the addition of 5 % biochar and 5 % compost.

32

33

34 **Keywords**

35 Phytomanagement, Biochar, Compost, Iron grit, metal(loid)s, *Trifolium*

36

37 **Highlights**

38 -Biochar and compost amendments, alone or combined, improved soil fertility and plant
39 growth

40 -Amendments decreased Pb concentration in soil pore water

41 -The dose application of iron grit had negative effects on plant growth

42 -Lead was more bioaccessible on amended soils

43

44 **Introduction**

45

46 After more than 200 years of industrialization, the European Union now faces a major
47 problem with metal and organic contaminated soils (EEA, 2007). It was estimated that
48 approximately 342,000 sites are currently contaminated, and that industrial activities,
49 including mining, are among the main sources, representing 33% of the contamination
50 (Panagos et al., 2013).

51 To the extent that this industrial waste contain organic and inorganic pollutants, they
52 participate as source of pollution for soil, water and air. Thus, these wastes can have negative
53 health consequences through direct ingestion or inhalation (Uzu et al., 2011) or by entering
54 the food chain (Schreck et al., 2012).

55 To reduce these risks, remediation methods such as controlled backfilling, soil
56 fixation, or leaching can be very useful. However, these methods are generally expensive, and
57 some may even have negative effects on the biodiversity, biological activities, soil structure,
58 or fertility (Ali et al., 2013). In contrast, environment-friendly remediation options, such as
59 “aided phytostabilisation”, could improve soil functionality and allow a vegetation cover to be
60 established, at the same time as reducing the mobility and availability of pollutants (Cundy et
61 al., 2013, 2016). Plant cover may also reduce contaminant leaching (Houben et al. 2012), as
62 well as stabilizing soils, and it controls water and wind erosion (Reubens et al. 2007). The
63 implementation of plants will stabilize contaminants by adsorption or accumulation in roots
64 (Vangronsveld et al. 2009). However, the translocation to the shoot system should remain

65 limited to avoid the transfer of contaminants into the food chain through grazing (Henry et al.,
66 2013; Pérez-de-Mora et al., 2011; Kidd et al. 2009).

67 The selection of an appropriate metal tolerant vegetation cover is critical, as it affects
68 the efficiency of the phytoremediation process.

69 *Trifolium repens* has characteristics which have led to it being selected for restoring
70 plant cover. Clover mainly stores metals and metal(loid)s in its roots (Bidar et al., 2009), and
71 it enriches poor soils by fixing atmospheric nitrogen, which allows the development of other
72 plant species. In addition, it has a high germination rate and good resistance to environmental
73 stress conditions. It appears that its stoloniferous growth makes *Trifolium repens* able to
74 colonize bare spaces in lawns and it can therefore be used in various revegetation strategies
75 (Bidar et al., 2007). Previous studies using *Trifolium repens* in contaminated zones have
76 focused on metal uptake and remediation (Bidar et al., 2007, 2009; Lopareva-Pohu et al.,
77 2011), and have shown that *Trifolium repens* could therefore play a positive role in the metal
78 phytoremediation strategy.

79 However, the extreme conditions encountered on polluted sites, i.e the high
80 concentrations of toxic elements, the low pH, and the low organic matter content, do not
81 usually allow plant growth. It is therefore essential to add mineral and organic amendments
82 that could reduce the mobility of soil pollutants, and therefore their (phyto)availability
83 (Houben et al., 2012; Kumpiene et al., 2008; Lambrechts et al., 2011; Mench et al., 2003), at
84 the same time as increasing soil fertility in order to improve plant development (Lopareva-
85 Pohu et al., 2011).

86 Biochar, used as an organic amendment, has received increasing attention in recent
87 years. It is a calcined carbon material produced by heating biomass in a closed system with a
88 limited oxygen supply, using thermochemical technologies such as pyrolysis, gasification, or
89 hydrothermal technologies (Xu et al., 2013). In degraded soils it is used for its potentially
90 beneficial effects on the environment. This includes increased soil fertility through
91 improvement of the soil microbial activity, and reduction of pollutant mobility. It can also
92 help reduce the greenhouse effect by long-term sequestration of carbon in the soil (Inyang et
93 al., 2016). Biochar can adsorb pollutants from the soil due to its microporous structure, high
94 pH, cation exchange capacity, and its surface functional groups (Jiang et al., 2012; Ding et al.,
95 2017).

96 However, biochar does not generally contain enough nutrients to allow plant growth
97 on polluted soils, which are often characterized by low nutrient content (Fischer and Glaser,
98 2012). Extra nutrients, such as those found in compost must therefore be added alongside the

99 biochar. The addition of compost will allow plant growth as it contains N, P, K, Ca, Mg, and
100 S, as well as humus and different kinds of microorganisms (Fischer and Glaser, 2012; Gil-
101 Loaiza et al., 2016). Moreover, it can reduce the phytoavailability of metal(loid)s due to their
102 association with organic matter (OM), carbonates, or metal oxides (Mench et al., 2000),
103 resulting in a reduction in the plant uptake of metals. But the effect of compost on metal
104 bioavailability depends on the nature of the organic matter, the mineral species content, the
105 potential degradability by microbiota, the pH and redox potential of the soil, and the soil type
106 and metal(loid)s concerned (Walker et al., 2003).

107 Although the application of biochar and compost has been shown to improve soil
108 agronomic characteristics, as well as its ability to sorb and reduce metal cation availability
109 such as Pb in soil, neither amendment is effective in decreasing the mobility of metal anions,
110 such as arsenic. They even tend to increase anion soil mobility due to the rise in soil pH
111 (Beesley et al., 2011). This can cause problems in soils polluted with both cationic and
112 anionic metal(loid)s. In such polluted sites, one possible strategy would be to combine
113 compost and biochar with iron-rich amendments, or Mn oxides for metal(loid) immobilization
114 (Ruttens et al., 2006). Among these amendments, zero-valent iron, in the form of iron grit, is
115 the most relevant type of iron (Kumpiene et al., 2006), because its high adsorption potential
116 has proved valuable in immobilizing inorganic contaminants (Liu and Zhao, 2007;
117 Satapanajaru et al., 2008; O'day and Vlassopoulos, 2010). In soil, iron grit is known to be
118 transformed to reactive iron (hydr)oxydes (e.g. ferrihydrite) (Komárek et al., 2013).
119 Moreover, iron (hydr)oxydes capacity to sorb ions is modulated according to soil pH. A
120 strong sorption of anions as arsenic is implemented at low pH due to a higher net positive
121 surface charge on iron, whereas at high pH a stronger sorption of cations will be possible. In
122 addition to sorption reactions, co-precipitation of metals and metalloids with iron oxides is
123 another important mechanism for stabilizing metal and metalloid elements in amended soils
124 (Komárek et al., 2013). Thus, it has been shown that the formation of relatively insoluble
125 mineral precipitates Fe(II/III)-As (e.g. $\text{FeAsO}_4 \cdot \text{H}_2\text{O}$, $\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$ and $\text{Fe}_3(\text{AsO}_4)_2$)
126 influences the immobilization of arsenic and its bioavailability in soils (Kumpiene et al.,
127 2008; Drahotá and Filippi 2009).

128 Thus, to demonstrate the effectiveness of amendments and revegetation, it is essential
129 to study the metal(loid) concentrations in the soil, soil pore water and plants *continuum*.
130 However, as Lebrun et al. (2018a) observed, the metal(loid) concentration in soil pore water
131 did not always reflect the amount available for plants. It is therefore interesting to measure
132 this phytoavailable quantity by simple extraction tests. These plant availability tests can be

133 performed using extractant salts to determine the more or less mobile fraction of metal(loid)s,
134 to understand their availability for plants (Qasim et al., 2015; Black et al., 2011).

135 However, the metal(loid) phytoavailability is not the only parameter to be measured,
136 as human exposure to pollutants must also be taken into account. This exposure can include
137 inhalation, oral ingestion or dermal absorption. One of the most common exposure pathways
138 is the accidental ingestion of polluted soils (Luo et al., 2012). Such risk of metal(loid)
139 exposure is often evaluated by a conservative approach in which the total metal(loid) content
140 of the soil is measured. However, it is often pointed out that the risk for the exposed
141 individual is only related to a small fraction of the total metal(loid)s, which is referred to as
142 the bioaccessible fraction. To measure the bioaccessible fraction, various *in vitro* methods
143 have been developed. They are usually simple and quick to manage, relatively inexpensive
144 and do not raise ethical concerns (Deshommes et al., 2012). Some of these methods evaluate
145 the fraction of ingested metal(loid)s that are soluble in the gastrointestinal tract (Mendoza et
146 al., 2017; Wijayawardena et al., 2017) and therefore available in the blood flow. The Simple
147 Bioaccessibility Extraction Test (SBET) procedure consists of an acid extraction that imitates
148 the gastric compartment where the bioaccessibility is the strongest (Ruby et al., 1996; Casteel
149 et al., 1997).

150 The objectives of this study were to evaluate: (1) the capacity of biochar, compost and
151 iron grit to reduce As and Pb phytoavailability when added to a multi-contaminated technosol
152 by measuring their concentrations in soil pore water and by using a CaCl₂ neutral salt
153 extractant; (2) whether clover can be used to set up a vegetative cover and (3) the
154 bioaccessibility of Pb and As in soil and in the aerial part of clover plants grown on amended
155 soil, using the SBET approach.

156

157 **Materials and methods**

158

159 **Origin of contaminated soil (Pontgibaud site)**

160 The studied site in Roure-les-Rosiers (France) is a former silver-lead extraction mine,
161 located in the Massif Central near Clermont-Ferrand (Saint-Pierre-le-Chastel (63)), in the
162 Pontgibaud mining district (P_s), Lambert II coordinates are: X: 638147.54 Y: 2087962.79.
163 The mine has been in operation since Gallo-Roman times, and was industrially exploited only
164 during the 19th century and ceased in 1897, with a resumption of activities during the Second
165 World War. Mining activities stopped definitively in 1947.

166 The old mining site is subject to a semi-continental climate, with snowy winters, and
167 hot summers, which can be marked by severe and localized thunderstorms. On average, the
168 Roure-les-Rosiers sector receives about 770 mm of rainfall per year, and is located at around
169 700 meters above sea level.

170

171 **Preparation of amended soils - Seed sowing and plant biomass**

172 The soil chosen for this study came from the slag heaps of the former Pontgibaud mine
173 site. Six different soil samples were tested: polluted soil (P_s), (P_s) amended with 5 % (w/w) of
174 hardwood-derived biochar (P_sB), (P_s) amended with 5 % (w/w) of compost (P_sC), (P_s)
175 amended with 1.5 % (w/w) of iron grit (P_sI); (P_s) amended with 5 % (w/w) of hardwood-
176 derived biochar and 5 % (w/w) of compost (P_sBC) and (P_s) amended with 5 % (w/w) of
177 hardwood-derived biochar and 1.5 % (w/w) of iron grit (P_sBI). Biochar, was provided by La
178 Carbonerie (Crissey, France). It was obtained by the slow pyrolysis of hardwood biomass (*Quercus*
179 *sp.*, *Carpinus sp.* and *Fagus sp.*) at 500 °C (residence time: 3 h, heating rate: 2.5 °C.min⁻¹), followed
180 by a sieving to obtain a particle size between 0.2 and 0.4 mm. Physico-chemical properties of
181 amendments including biochar is provided in table 1 SM.

182 Three replicates of the different mixtures were placed in rectangular pots with a
183 capacity of 5 liters, and a surface area of 360cm² (24cm x 15cm). The bases of the pots were
184 covered with clay beads to keep the soil mixture in the pots when watering. Each pot was
185 divided into 2 compartments: one non-vegetated (NV), and the other vegetated (V), with 500
186 clover seeds, which had a measured germination rate of 91%. The experiment was carried out
187 in a controlled growth chamber under the following conditions: day/night temperatures
188 (25°C/16°C), 16 hours of light/8 hours of darkness and with a light intensity of 800 $\mu\text{mol.m}^{-2}.\text{s}^{-1}$.

190 The experiment lasted 30 days. The plants were then separated from the soil. The roots
191 were washed thoroughly with tap water and rinsed with distilled water to remove soil particles
192 attached to the roots. Next, the plants were divided into two: the root system and the aerial
193 parts (shoots and leaves). Finally, the plant organs were dried in an oven at 55 °C (until they
194 were a constant weight), and the dry weight of the organs (DW) was determined.

195

196 **Soil pore water (SPW) sampling and analysis**

197 SPW was collected using Rhizon® (Rhizosphere Research Product, Wageningen, The
198 Netherlands), from each pot. 20mL of SPW was sampled to determine the pH (pH meter,

199 FE20/EL20, Mettler-Toledo AG 2007), electrical conductivity (EC) (conductimeter, SOLEA,
200 Tacussel électronique, Lyon, France), dissolved organic carbon (DOC) concentration (Pastel
201 UV spectrophotometer, SECOMAM, Ales, France) and metal(loid) concentrations (ICP-AES,
202 ULTIMA 2, HORIBA, Labcompare, San Francisco, USA), according to Bart et al. (2016).
203 The sampling was done before sowing the clover seeds (T0) and at the end of the greenhouse
204 experiment (TF) (30 days).

205

206 **Metal(loid) quantification in tested soils and in plant organs**

207 Metal(loid) contents (As, Fe and Pb) of soil samples and plant organs were determined
208 by aqua regia digestion treatment (HNO₃ (65%) : HCl (37%), 1:3 v/v) (Zhang and Selim
209 2008), with a solid/liquid ratio of 1/45. The digestion program consisted of a gradual increase
210 in temperature to 180°C in 15 minutes, a 15 minutes digestion step at 180°C followed by a 15
211 minutes cooling step. The mineralized samples were then adjusted to a volume of 50 mL with
212 ultrapure water (18 MΩ.cm⁻¹) and filtered through a nitrocellulose membrane at 0.45 µm.
213 Arsenic, iron and lead concentration were measured by Inductively Coupled Plasma Atomic
214 Emission Spectroscopy (ICP-AES, Ultima 2, HORIBA, Labcompare, San-Francisco, USA).
215 The accuracy of the assay technique was verified by enriching the samples analyzed with a
216 solution whose concentration of the element to be assayed was known.

217

218 **Soil metal(loid) simple extraction procedures (CaCl₂ treatment)**

219 The phytoavailable fractions of As and Pb were obtained as described by Qasim et al
220 (2015), using CaCl₂ extractant at 0.01M with a solid: liquid ratio 1: 10. Metal(loid)
221 concentrations were determined by ICP-AES (ULTIMA 2, HORIBA, Labcompare, San
222 Francisco, USA).

223

224 **Metal(loid) bioaccessibility test for soil samples (SBET) and plant organs**

225 According to the method developed by Mendoza et al. 2017, crushed dry material from
226 tested soils or plant upper parts were put in a glycine solution 0.4 mol.L⁻¹ adjusted to pH 1.5
227 at a concentration of 1%. The suspension was shaken for 1 h at 37 ± 1 °C, then filtered
228 through a 0.45 µm pore size membrane with syringe filter and stored at 4 °C until analysis.
229 Metal(loid) concentrations were determined by ICP-AES (ULTIMA 2, HORIBA,
230 Labcompare, San Francisco, USA).

231

232 **Data processing and statistical analysis**

233 Data was analyzed using R statistical software Version 3.1.2 (R Development Core
234 Team, 2009). The normality and homogeneity were tested using Shapiro and Bartlett tests,
235 and the means were compared using a parametric Anova test for normal data and the non-
236 parametric Kruskal-Wallis test for non-normal data. Differences were considered significant
237 when $p < 0.05$.

238

239 **Results and discussions**

240

241 **Effect of amendments on soil characteristics**

242 All tested amendments apart from iron induced an increase in WHC, averaging 10% for
243 compost, and 30% for biochar when added alone at 5% (w/w) to Pontgibaud soil. Biochar
244 showed real efficiency in retaining water due to its porous structure, its hydrophobicity and
245 high surface area (Pietikäinen et al., 2000; Warnock et al., 2007; Molnar et al., 2016).
246 However, these results are inconsistent with those obtained when measuring water holding
247 capacity (WHC) on isolated compost and biochar, which were 299% and 183% respectively
248 (Table 1SM). This difference is certainly related to the fact that the compost is compressed
249 when it is added to Pontgibaud soil, meaning it is no longer able to expand in order to retain
250 such a large quantity of water. Biochar is less subject to compressive stress when added to the
251 Pontgibaud soil due to its porous and rigid structure, and therefore maintains its water
252 retention characteristics.

253 None of the treatments affected the As pseudo-total concentrations compared to Ps. The
254 iron concentration in Pontgibaud soil was 6325 mg kg^{-1} , and the addition of amendments,
255 apart the iron grit, did not induce a significant change in iron soil concentration. The iron grit
256 addition in PsI and PsBI caused the pseudo-total Fe soil concentration to increase by
257 approximately 3 times. Lastly, the pseudo-total Pb soil concentrations in the different tested
258 soils were the same for Ps, PsI, PsC, PsB and PsBI, whereas for PsBC, Pb concentration
259 decreased by 30% compared to Ps due to a dilution effect produced by the addition of
260 compost and biochar (Table 1).

261

262 **Effect of amendments and clover plants on SPW characteristics**

263 At the beginning of the experiment, neither time nor the presence of clover significantly
264 modified the SPW pH of Pontgibaud soil (Ps) which was approximately 4.08 (Table 2).

265 Iron grit application to P_s allowed a 0.5 unit increase in SPW pH, whereas time and
266 clover growth induced a significant decrease in SPW pH (0.5 units). Compost (C), biochar
267 (B), biochar + iron grit in combination (BI) and biochar + compost in combination (BC)
268 increased P_s SPW pH by 2.3 units, 2.7 units, 2.6 units and 3.3 units, respectively. It is noted
269 that clover growth impacted SPW pH for P_sB and P_sBC by 0.45 units, whereas for these
270 treatments on non-vegetated pots, time did not allow any significant pH modification. The
271 alkalization of SPW due to the addition of biochar has already been demonstrated by
272 Lebrun et al. (2018a) when 5% pinewood biochar was added to Pontgibaud soil, inducing a
273 2.7 pH unit increase. Moreover, Beesley et al. (2014) showed that the SPW pH of a
274 contaminated soil increased by more than three units when compost combined with biochar
275 was added. The improvement in pH following the application of biochar or compost can be
276 attributed to: (i) the alkalinity of the biochar (Table 1SM) which induced a liming effect
277 (Lebrun et al., 2017); (ii) the dissolution or addition of alkali metals, and (iii) the presence of
278 functional groups on the surface of the biochar, such as carbonyls, phenols, carboxyls and
279 pyrones (Marks et al., 2014; Lebrun et al., 2018a).

280 Finally, for P_sBI the pH decreased by two units over the time period of the treatment.
281 This can be explained by the fact that the iron was oxidized during the experiment thus
282 inducing the SPW pH decrease.

283 At T₀, the SPW electrical conductivity (EC) for P_s and P_sI was 0.220 mS.cm⁻¹ and 0.315
284 mS.cm⁻¹ respectively. For the other treatments, at T₀, EC value was approximately 1.1
285 mS.cm⁻¹. At the end of the experiment, an increase in EC was observed compared to T₀ on all
286 tested non-vegetated soils, and corresponded to 4.2 fold, 2.5 fold, 2 fold, 2.4 fold, 3 fold and
287 2.1 fold for P_s, P_sI, P_sC, P_sB, P_sBI, P_sBC, respectively. The presence of clover had no effect
288 on P_s, P_sI and P_sBC, while for P_sC, P_sB and P_sBI it caused a 1.3 fold EC decrease when
289 compared to the corresponding non-vegetated pots. Overall, biochar and compost
290 significantly increased SPW EC (p <0.05), which is consistent with previous studies (Lebrun
291 et al., 2017, 2018a). Indeed, organic matter and mineral compounds such as Ca²⁺, Mg²⁺, K⁺ or
292 inorganic carbonates present on biochar and compost can be released into the soil and thus
293 increase SPW electrical conductivity (Chintala et al., 2013). Kloss et al. (2014) demonstrated
294 an increase in EC from 0.04 dS.cm⁻¹ to 0.19 dS.cm⁻¹ when 3% straw biochar was applied to a
295 planosol. Finally, iron grit must be solubilized and mostly precipitated in the form of iron
296 oxide on soil particulates, which is why it did not induce a large increase in the specific EC
297 value.

298 The DOC content of SPW at T0 (Table 2) for P_s was 5.7 mg.L⁻¹, which is identical to that of
299 P_sBI. Moreover, the DOCs for P_sB and P_sBI were 2.8 fold and 1.2 fold smaller than P_s. On the
300 contrary, DOC for P_sC and P_sBC were 3.7 and 1.9 fold higher than for P_s. It should be noted
301 that neither the time nor the presence of clover modified the DOC.

302 A decrease in DOC was observed in previous studies when biochar was added to
303 various soils (Lu et al. 2014; Kloss et al., 2014; Jain et al., 2014). This has been explained by
304 the structure of the biochar, which contains sorption sites able to bind soluble organic
305 compounds (Hass et al., 2012). Treatments containing compost (i.e P_sC and P_sBC) showed
306 higher levels of DOC, which could be explained by the fact that even though the compost is
307 composed of refractory humified material, labile fresh organic matter is also present (Lefevre,
308 2015).

309

310 **SPW metal(loid) concentrations and phytoavailable metal(loid)s**

311 At T0 (Table 2), no As content was detected for P_s, P_sI, P_sB and P_sBI SPW whereas
312 for P_sC and P_sBC, As concentrations were 0.09 mg.L⁻¹ and 0.06 mg.L⁻¹, respectively. Both the
313 passage of time, and the presence of clover plants increased As SPW for these last two
314 treatments, by 2 fold and 4 fold respectively. For P_s, at TF, As SPW concentration could be
315 quantified, and corresponded to 0.03 mg.L⁻¹ and 0.02 mg.L⁻¹, for TF-NV and TF-V,
316 respectively. The As soil phytoavailable fractions (CaCl₂-extractable fraction) for P_s and P_sC
317 at T0 were not significantly different, and corresponded on average to 0.11 % of the total soil
318 As concentration (Table 1). Whereas for the other treatments P_sI, P_sB, P_sBI and P_sBC, As
319 phytoavailability was 1.9 times smaller than P_s. Arsenic is usually found as an oxyanion in
320 solutions, and presents specific challenges to sanitation, because its mobility increases when
321 pH increases (Beesley et al., 2011, Nandillon et al., 2019). It was shown that the addition of
322 compost may increase the mobility and leacheability of metal(loid)s, particularly arsenic
323 (Mench et al., 2003). In the present study, a significant increase in arsenic SPW concentration
324 was observed when compost was added to soils, probably because DOC competed with
325 arsenic for sorption sites, such as those present in iron oxides, resulting in its increased
326 mobility (Bolan et al., 2014). Compost with a high degradable organic matter content,
327 associated to a neutral pH, present an active microbial activity which uses the organic matter
328 as energy source (Balasoiu et al., 2001). This means that compost and its microbiota could
329 reduce the soil redox potential, and consequently support the transformation of As(V) to
330 As(III), which is more mobile (Kim et al., 2003). This high mobility could also be explained
331 by the presence of phosphorus. Indeed, Fresno et al. (2018) showed that phosphorus-Olsen

332 had a significant effect on mobilizable As, as phosphate and arsenate have similar chemical
333 properties, and they compete for organic and inorganic binding sites (Bolan et al., 2014;
334 Moreno-Jiménez et al., 2013; Adriano, 2001). Other authors (Clemente et al., 2012; Moreno-
335 Jiménez et al., 2013; Beesley et al., 2014) have already reported that competition for mineral
336 sorption sites between these anions can be expected, which will lead to arsenic mobilization
337 from less labile soil fractions and increase its availability. It is important to note that the
338 phytoavailable fraction of arsenic was identical for the P_s and P_sC treatments, suggesting that
339 compost influenced the easily mobilizable fraction found in pore water, but not the CaCl₂
340 extractable fraction. Moreover, the decrease in As concentration observed between P_sB and
341 P_sBC both at T₀ and at T_F (Table 2) could be explained by: (i) the mobile part of arsenic
342 potentially being trapped in the biochar structure; (ii) DOC decrease after biochar addition
343 resulting in less competition between dissolved organic matter and arsenate; and (iii) the
344 calcite present in the biochar could form stable spherical compounds with arsenate anions on
345 the biochar's surface (Alexandratos et al., 2007; Yin et al., 2016).

346

347 At T₀, the SPW iron concentration (Table 2) for P_s was 0.05 mg.L⁻¹. No soluble Fe was
348 quantified in SPW for P_sC, P_sC and P_sBC. As expected, Fe concentration in P_sI and P_sBI
349 treatments were 450 times and 50 times higher than P_s, respectively. Moreover, for P_sI and
350 P_sBI, no significant difference in SPW Fe concentration was observed at T_F between non-
351 vegetated and vegetated pots. Although at T_F, SPW Fe concentration increased by 2.4 fold for
352 P_sI and 38 fold for P_sBI. The values for the Fe-CaCl₂-extractable fraction (Table 1) for P_s, P_sI
353 and P_sBI, were not significantly different, and were all between 0.06 % and 0.08 %. Finally,
354 compost or biochar added to P_s soil, alone or in combination (P_sB, P_sC and P_sBC), led to a
355 significant decrease in the Fe-CaCl₂-extractable fraction (3.5 fold).

356 As expected, lead was the most prevalent ion in Pontgibaud SPW (11.2 mg.L⁻¹), at T₀,
357 and on top of that, no significant difference was measured between T₀ and T_F for P_s, or any of
358 the other studied treatments. The SPW Pb concentrations for P_sI, P_sC, P_sB, P_sBI and P_sBC
359 were 4.8 mg.L⁻¹, 0.3 mg.L⁻¹, 0.6 mg.L⁻¹, 1.4 mg.L⁻¹ and 0.12 mg.L⁻¹, respectively. For the
360 Pb-CaCl₂-extractable fraction (Table 1) four different significant groups were identified P_sI
361 2.75 %; P_s 2.15 %; P_sB and P_sBI 1.6 %; and P_sC and P_sBC 0.15 %.

362 Compost and biochar + compost appeared to be the treatments that decreased the
363 phytoavailable Pb fraction the most significantly, suggesting that the high pH and organic
364 content of these amendments reduce the lead mobility in the soil. As is well known, SPW

365 metal mobility is strongly influenced by organic carbon, which is brought to the soil by the
366 biochar and compost (Bolan et al., 2014). Furthermore, higher pH values are known to
367 increase the surface charges of soil particles including amendments, which induces the
368 retention of metal (Perez-Esteban et al., 2014; Boisson et al., 1999; Mench et al., 1998, 2000).
369 These amendments can immobilize metal(loid)s via three mechanisms (Mench et al., 2000):
370 (i) adsorption of metals to highly accessible sites on the surface of modified aluminosilicates,
371 soil components and of biochar or compost through interactions with oxygenated functional
372 groups (Lebrun et al. 2018b); (ii) precipitation with Al, Fe and Mn oxides (Oustrière et al.,
373 2017); (iii) formation of minerals (such as metal silicates) and diffusion through mineral
374 surfaces (Lee et al., 2013) and (iv) precipitation with phosphates and carbonates contained by
375 the biochar (Lomaglio et al. 2016).

376

377 **Metal(loid) bioaccessibility in soil**

378 The SBET was used to assess the oral bioaccessibility of As, Fe and Pb in soil samples
379 (Mendoza et al., 2017). This method simulates the human gastric phase, and was validated by
380 the EPA (USEPA, 2012). The results for the present study are presented in Table 3.

381 The bioaccessible arsenic concentration for P_s was 3.2% and decreased for P_sI and
382 P_sBI treatments by 2.1 and 1.8 times respectively, compared to P_s. This is because the iron
383 oxide formed strongly adsorbed As. Many studies (Martin and Ruby 2003; Subacz et al.,
384 2007) have shown that use of Fe-rich amendments (FeCl₃, FeCl₂.4H₂O, Ferrihydrite, Fe⁰ and
385 FeBr₃) could be an effective strategy for reducing bioavailability and bioaccessibility, and for
386 remediating soils contaminated with As. Cui et al. (2010) demonstrated that the addition of
387 FeSO₄ to a mining technosol decreased gastric and intestinal bioaccessibility of arsenic in all
388 treatments. Finally, the bioaccessible arsenic fraction for P_sC, P_sB and P_sBC treatments was
389 almost 1.4 times higher than for P_s. This could be explained by the fact that anions such as
390 bicarbonate, phosphate, silicate, and organic acids present in the soil solution due to the
391 addition of compost and biochar to P_s could compete with As for chemisorption sites, and
392 thus mobilize As to the aqueous phase. The links between biochar and arsenic, and between
393 compost and arsenic are weak and therefore easily broken by the glycine present in SBET
394 solution. This would explain the greater As accessibility for P_sC, P_sB and P_sBC.

395 The iron bioaccessible fraction for P_s was 1.3 % , which demonstrates its high stability
396 in soil. When compost and biochar were added to P_s (P_sC and P_sB), Fe accessibility was
397 unchanged. As expected, the addition of iron to P_s or P_sB led to an increase in accessible-Fe,
398 by 1.9 and 3.1 fold, respectively. Interestingly, for P_sBC, the iron bioaccessible fraction was

399 almost twice the value measured for P_s. This was probably due to the destabilization of iron
400 oxides by the increase in organic ligands following the addition of biochar and compost.

401

402 Finally, the bioaccessible Pb proportion was high regardless of the treatment. For the
403 P_s treatment, just over half of the total lead (51 %) was bioaccessible, which shows its low
404 stability in soil. This could be explained by the low pH (pH = 1.5) and the presence of organic
405 ligands in the gastric solution which may have favored the dissolution and desorption of the
406 minerals containing lead (Cui et al., 2010). Iron did not affect the Pb accessible fraction when
407 added to P_s or P_sB. Similarly, a recent study showed that a highly adsorbent Mn oxide added
408 in large quantities (10% by weight) to a Pb polluted soil produced no change to the Pb
409 bioaccessible fraction (McCann et al., 2015). When compost or biochar were added to P_s,
410 whether alone or in combination, the Pb accessible fraction increased between 1.2 and 1.4
411 times . This result was probably due to the establishment of even weaker links between the
412 lead and compost and lead and biochar than those that may exist between lead and soil
413 particles in the technosol P_s.

414

415 **Plant growth and metal(loid) uptake**

416 After 30 days of growth, the clover dry weight (DW) and the metal(loid) concentrations
417 in the roots and aerial parts were measured for the different treatments. Firstly, it was noted
418 that when iron was added alone to P_s the seeds could not germinate. This was probably due to
419 the high iron concentration in the soil pore water at T0. Indeed, when just iron grit was added
420 to P_s the concentration of Fe in the SPW was 22.5 mg L⁻¹, whereas when iron grit was added
421 to P_s at the same time as biochar (P_sBI), the Fe SPW concentration was 2.5 mg L⁻¹ due to the
422 biochar's physico-chemical characteristics. Iron alone seemed to have an acidifying effect,
423 certainly due to the oxidation of Fe(II) followed by the precipitation of Fe(OH)₃. Thus, the
424 combination of high Fe supply and acidity induced a high solubility and Fe availability. In the
425 presence of biochar, the pH effect was attenuated. However, it was noted that the smallest
426 increase in the biomass of aerial parts was observed for P_sBI treatment (0.623 g). For the P_s
427 treatment, the dry weights of the roots and aerial parts were smaller, and corresponded to
428 0.124 g and 0.170 g, respectively. For the roots, P_sC, P_sB and P_sBC DW were not
429 significantly different and corresponded to four times the value for P_s.

430 For P_sC, P_sB and P_sBC, the average DW of the aerial parts was 1.24 g, i.e. 7 times the
431 value measured in P_s pots. The same beneficial effect for the DW of *Salix viminalis* and
432 *Populus euramericana* cuttings was obtained by Lebrun et al. (2018a) when adding biochar

433 produced from different feedstocks (hardwood, lightwood and pinewood, at 2% and 5% w/w)
434 to Pontgibaud technosol. Fresno et al., (2018) showed that iron combined with bio-char on an
435 As and Cu contaminated technosol slightly increased lupine shoot biomass. In our case, even
436 though biochar allowed a better biomass production of clover aerial parts, the compost
437 addition to biochar improved DW production by 30%. Indeed, organic matter, provided by the
438 compost improved the N, P, K nutrient cycle (Marques et al., 2008, Abbas et al., 2018),
439 allowing better plant growth, as observed by Marques et al. 2008 on *Solanum nigrum* and
440 Gregory et al. (2014) on *Lolium perenne* grown on polluted soils

441 Concerning the concentrations of ions in clover organs (Fig 2), we noticed that the
442 amendments systematically decreased the As and Pb concentrations in aerial parts by about
443 1.8 times for arsenic and between 1.8 and 3.8 times for lead, whereas As and Pb
444 concentrations in P_s plants were 396 mg kg⁻¹ and 4577 mg kg⁻¹, respectively. In roots, As
445 concentrations were only decreased by P_sB and P_sBC treatments, and corresponded to 500 mg
446 kg⁻¹, whereas for P_s, P_sC and P_sBI, As concentrations were approximately 812 mg kg⁻¹. For Pb
447 concentrations in roots, P_s and P_sBI demonstrated the same accumulation i.e 13300 mg kg⁻¹,
448 whereas P_sC, P_sB and P_sBC decreased root Pb concentration by 2.4 fold. As expected, iron
449 concentration was highest in clover plants grown on the P_sBI soil, with concentrations of 5000
450 mg kg⁻¹ and 17000 mg kg⁻¹ in aerial parts and roots, respectively. Whereas for P_s, P_sC, P_sB and
451 P_sBC treatments Fe concentrations in aerial parts were 2500, 1200, 1300 and 800 mg kg⁻¹,
452 respectively. Finally, Fe concentrations in roots for P_s, P_sC, P_sB and P_sBC were not
453 significantly different, and corresponded to 3100 mg kg⁻¹, which was 5.5 times lower than the
454 Fe concentration measured in roots of plants grown on the P_sBI soil. In the present study, for
455 all treatments, As, Fe and Pb concentrations were higher in the roots than in the aerial parts of
456 clover. This is consistent with the results of Bidar et al., (2007, 2009) and Lopareva-Pohu et
457 al., 2011 for *Trifolium repens* growing on metal(loid) contaminated soil. However, it is
458 difficult to distinguish between the elements fixed to the root surface and those that are
459 absorbed. We observed, a significant As, Fe and Pb concentration decrease in the aerial parts
460 for all treatments, apart from for plant Fe accumulation levels on the P_sBI treatment. For Pb
461 and Fe, this decrease could be associated to a significant diminution of the two ions in the soil
462 pore water, correlated to the amendments. Interestingly we demonstrated that compost being
463 added to P_sC and P_sBC soils was associated with an increase in As concentrations in the soil
464 pore water, whereas As concentrations in the aerial parts decreased compared to P_s. Such
465 results could be associated to a probable change in the chemical form of As, which is certainly
466 less assimilable for clover plants. In fact, the plant metal(loid) absorption depends on different

467 parameters, relative both to the plant (such as root exudations), and to the soil characteristics
468 (such as oxidation-reduction processes in the soil, pH, cation exchange capacity, dissolved
469 oxygen, and temperature), which modify the metal(loid) speciation (Cheng, 2003).

470

471 The high concentration of As in the roots for the P_sBI treatment compared to the P_sB
472 and P_sBC treatments, which have similar biomasses and phytoavailable arsenic, could be due
473 the mobilization of As by root exudates in soils treated with iron (Fresno et al. 2017). Another
474 explanation could be that the precipitation of iron oxides on the roots causes an indirect
475 increase in arsenic on the roots. The SBET bioaccessible fraction (Table 4) was only
476 measured for the aerial parts of clover plants grown on amended soil. We were not able to do
477 these measurements for aerial parts of clover grown on Pontgibaud soil (P_s) due to poor plant
478 biomass.

479 The bioaccessible As fraction was significantly larger for clover plants grown on soils
480 containing compost (Table 4). Thus, the SBET bioaccessible As fraction for clover plants
481 collected on P_sC and P_sBC soils was 8.2 % and 9.5 %, respectively. These values were twice
482 as high as those calculated for clover aerial parts collected on P_sB and P_sBI soils. The P_sB and
483 P_sBI soils were the treatments with the lowest As SBET bioaccessible fraction. Finally, we
484 demonstrated that the P_sBI soil allowed the highest Fe and Pb bioaccessible fractions for
485 clover aerial organs. On average this increase was 6.6 and 1.7 times the average value
486 measured for the other amendments tested, respectively. It was also noted that lead was the
487 most accessible element measured in the clover aerial organs. Between 34 % and 64% of all
488 lead was part of the bioaccessible fraction and could therefore potentially be released into the
489 gastric tract. In addition, our results for lead were significantly higher (2 to 6 times higher),
490 than those obtained in the gastric phase for edible parts of spinach, lettuce, radish and carrot
491 plant grown on a poly-metallic polluted soil (Intawongse and Dean, 2008).

492 It has been explained that the SBET bioaccessible fraction of ions in plant organs is correlated
493 to the chemical form, location and concentration of the ion, as well as the compounds to
494 which it is potentially associated within the plant tissues, such as fibers, polyphenols and
495 phytates (Labronici-Bertin et al., 2016; Machado et al., 2017). These specific tissue locations
496 for As and Pb are linked to plant metal(loid) tolerance. Indeed, Chou and Shen (2007) and Fu
497 and Cui (2013) proposed that metal(loid)s are mainly found in the vacuole and cell wall,
498 which contains polysaccharides and proteins which are composed of many oxhydryl,
499 carboxyl, aldehyde and phosphate groups, which show affinity with metal(loid)s. Therefore,

500 these groups could form bonds to reduce metal(loid) activity, which could modify their
501 bioaccessible fraction.

502

503 **Conclusion**

504

505 In the present study, we demonstrated that the addition of amendments (compost,
506 biochar or iron grit, alone or combined) to an As and Pb polluted soil could be efficient in
507 reducing As and Pb soil mobility and availability. In addition, the amendments allowed the
508 establishment of a clover cover on a soil that had previously been resistant to any plant
509 development. The most appropriate treatment for the studied technosol was 5 % biochar
510 combined with 5 % compost. It resulted in a decrease in As and Pb concentrations in both
511 clover roots and aerial parts. However, while the Pb concentration in SPW decreased
512 significantly, the As concentration increased, although it did remain within environmentally
513 acceptable values. It should also be noted that the bioaccessible As and Pb soil fractions
514 increased significantly following the addition of amendments. In our case, the use of iron grit
515 did not give the expected positive results.

516 Finally, field tests using the selected combination of amendments are currently being
517 undertaken to demonstrate the role of clover leaf cover in stabilizing soil particles, and
518 preventing the dispersion of arsenic and lead into the environment by wind or surface runoff.

519

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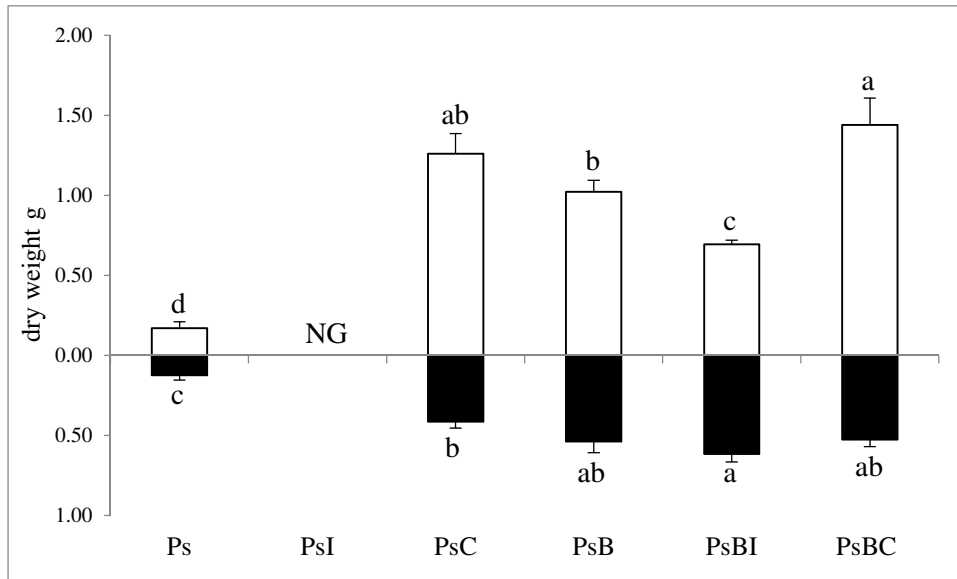


Figure 1: *Trifolium repens* dry weight (DW) (g) of organs collected at the end of the experiment (30 days); white columns: aerial parts, black columns: roots. Results are obtained from 500 seeds sown on tested soils. Ps: polluted soil, PsI: Ps + iron grit (I) 1.5%, PsC: Ps + compost (C) 5%, PsB: Ps + biochar (B) 5%, PsBI: Ps + B 5% + I 1.5%, PsBC: Ps + B 5% + C 5%. Results are expressed as the mean value and bars indicate standard error (n=5); letters indicate significant difference (p<0.05). NG: no germination.

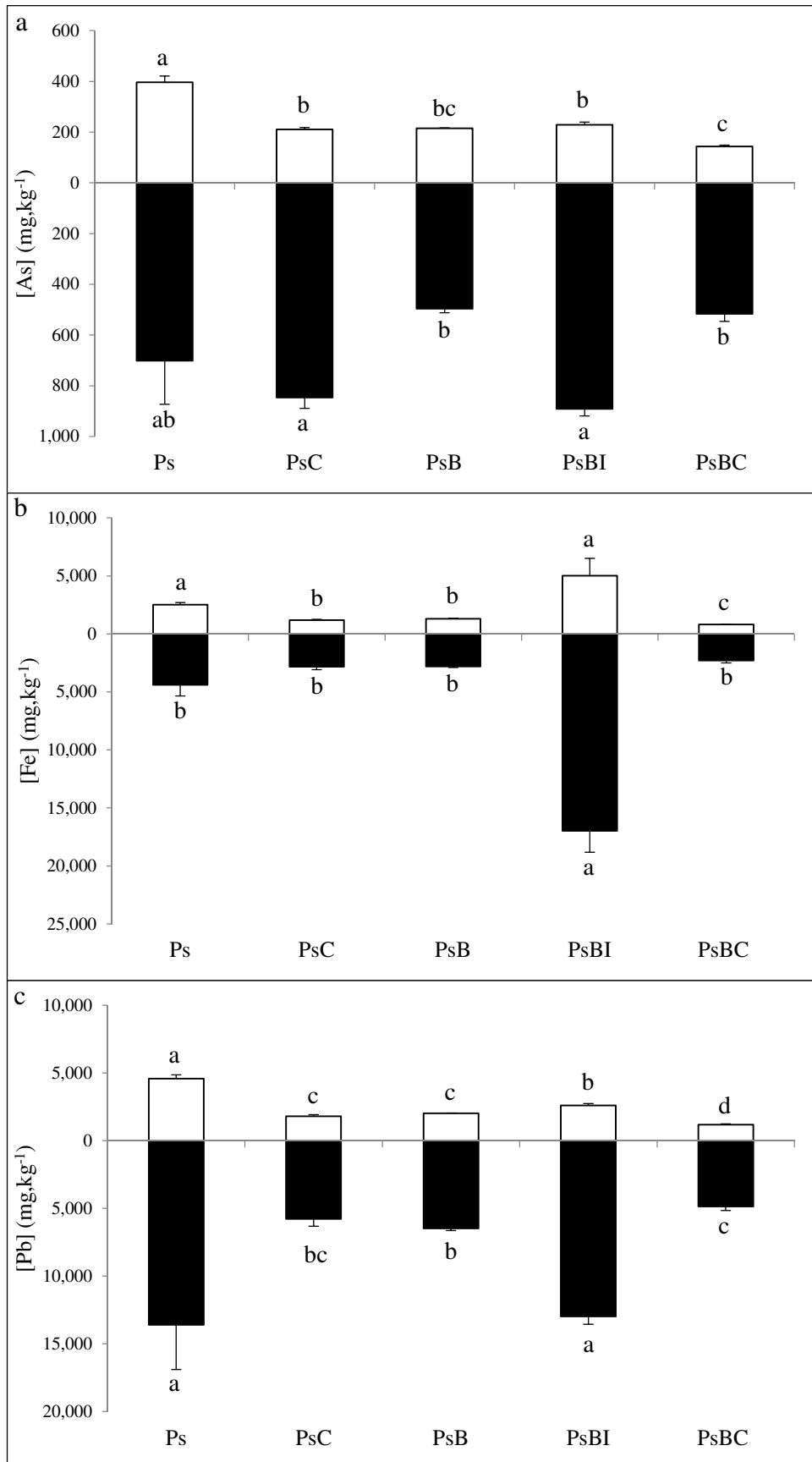


Figure 2 : Arsenic (a), iron (b) and lead (c) concentration (mg.kg⁻¹) in the different *Trifolium repens* organs collected at the end of the experiment (30 days); white columns: aerial parts, black columns: roots. Results are obtained from 500 seeds sown on tested soils. Ps: polluted soil, PsI: Ps + iron grit (I) 1.5%, PsC: Ps + compost (C) 5%, PsB: Ps + biochar (B) 5%, PsBI: Ps + B 5% + I 1.5%, PsBC: Ps + B 5% + C 5%. Results are expressed as the mean value and bars indicate standard error (n=5); letters indicate significant difference (p<0.05).

Table 1: Physico-chemical characteristics of tested soils at the beginning of the experiment (T0). WHC: water holding capacity (% mass), TOC: total organic carbon (% mass) and soil As, Fe and Pb concentrations (mg.kg^{-1}) and CaCl_2 -extractable fraction (%). Ps: polluted soil, PsI: Ps + iron grit (I) 1.5%, PsC: Ps + compost (C) 5%, PsB: Ps + biochar (B) 5%, PsBI: Ps + B 5% + I 1.5%, PsBC: Ps + B 5% + C 5%. Results are expressed as the mean value \pm standard error (n = 5). Letters indicate treatment significant difference ($p < 0.05$).

treatments	WHC (%)	TOC (%)	Pseudo-total concentrations (mg.kg^{-1})			CaCl ₂ -extractable fraction (%)		
			[As]	[Fe]	[Pb]	[As]	[Fe]	[Pb]
Ps	29.80 \pm 0.47 e	0.04	1068 \pm 20 a	6325 \pm 114 b	23387 \pm 1020 a	0.11 \pm 0.01 a	0.06 \pm 0.02 a	2.15 \pm 0.19 b
PsI	28.11 \pm 0.38 f	0.04	1007 \pm 52 a	23248 \pm 4341 a	18420 \pm 1422 ab	0.07 \pm 0.01 b	0.08 \pm 0.01 a	2.75 \pm 0.06 a
PsC	32.75 \pm 0.49 d	0.87	906 \pm 44 a	5407 \pm 205 b	18882 \pm 670 ab	0.13 \pm 0.01 a	0.02 \pm 0.01 b	0.12 \pm 0.03 d
PsB	40.11 \pm 0.48 b	3.28	1003 \pm 18 a	5960 \pm 103 b	18927 \pm 555 ab	0.05 \pm 0.01 b	0.01 \pm 0.00 b	1.59 \pm 0.06 c
PsBI	36.83 \pm 0.26 c	4.03	990 \pm 17 a	20090 \pm 2410 a	18903 \pm 435 ab	0.05 \pm 0.01 b	0.06 \pm 0.01 a	1.60 \pm 0.09 c
PsBC	44.55 \pm 2.06 a	3.89	842 \pm 41 a	4973 \pm 296 b	16419 \pm 295 b	0.06 \pm 0.01 b	0.02 \pm 0.01 b	0.17 \pm 0.04 d

Table 2: Physico-chemical characteristics of the soil pore water of tested soils at the beginning of the experiment (T0) and after 30 days (TF). Non-vegetated soils corresponded to TF-NV and vegetated soils corresponded to TF-V. EC: Electrical Conductivity (mS.cm⁻¹), DOC: dissolved organic carbon (mg.L⁻¹) and As, Fe and Pb concentrations (mg.L⁻¹). Ps: polluted soil, PsI: Ps + iron grit (I) 1.5%, PsC: Ps + compost (C) 5%, PsB: Ps + biochar (B) 5%, PsBI: Ps + B 5% + I 1.5%, PsBC: Ps + B 5% + C 5%. Results are expressed as the mean value ± standard error (n = 5). For each treatment, letters indicate time and vegetation effect (p < 0.05). Amendments effect is represented by asterisk, **: p < 0.01, ***: p < 0.001.

treatments		pH	EC (mS.cm ⁻¹)	DOC (mg.L ⁻¹)	[As] (mg.L ⁻¹)	[Fe] (mg.L ⁻¹)	[Pb] (mg.L ⁻¹)
Ps	T0	3.98±0.20 a	0.220±0.09 a	5.7±0.3 a	0.00±0.00 a	0.05±0.02 a	11.25±0.41 a
	TF-NV	4.02±0.16 a	0.916±0.063 b	5.9±0.6 a	0.03±0.00 b	0.09±0.02 a	8.08±1.60 a
	TF-V	4.24±0.18 a	0.761±0.067 b	5.4±0.1 a	0.02±0.00 b	0.02±0.01 a	5.46±1.52a
PsI	T0	4.51±0.03 a	0.315±0.025 a	4.8±0.2 a	0.00±0.00 a	22.47±0.45 a	5.92±0.25 a
	TF-NV	4.02±0.03 b	0.797±0.044 b	4.9±0.4 a	0.00±0.00 a	59.03±6.04 b	5.06±0.51 a
	TF-V	4.09±0.06 b	0.822±0.039 b	4.8±0.5 a	0.00±0.00 a	50.16±14.61 b	3.46±0.52 a
PsC	T0	6.32±0.15 a	0.926±0.095 a	23.4±0.2 a	0.09±0.01 a	0.01±0.01 a	0.61±0.12 a
	TF-NV	6.97±0.19 a	1.824±0.085 b	21.9±6.8 a	0.43±0.09 b	0.00±0.00 a	0.18±0.06 a
	TF-V	6.95±0.11 a	1.295±0.134 a	24.9±6.7 a	0.34±0.11 b	0.01±0.01 a	0.15±0.07 a
PsB	T0	6.70±0.04 a	1.176±0.079 a	2.0±0.2 a	0.00±0.00 a	0.00±0.00 a	0.58±0.04 a
	TF-NV	7.04±0.13 ab	2.785±0.042 b	2.1±0.5 a	0.00±0.00 a	0.00±0.00 a	0.54±0.01 a
	TF-V	7.16±0.13 b	2.433±0.082 c	1.9±0.1 a	0.00±0.00 a	0.00±0.00 a	0.61±0.07 a
PsBI	T0	6.60±0.10 a	1.088±0.035 a	5.7±0.5 a	0.00±0.00 a	2.51±0.33 a	0.88±0.21 a
	TF-NV	4.53±0.09 b	3.196±0.047 b	5.8±0.4 a	0.00±0.00 a	107.64±16.24 b	1.78±0.18 a
	TF-V	4.47±0.04 b	2.634±0.064 c	5.6±0.4 a	0.00±0.00 a	83.09±23.34 b	1.44±0.13 a
PsBC	T0	7.31±0.09 a	1.232±0.094 a	10.7±0.2 a	0.06±0.01 a	0.00±0.00 a	0.15±0.02 a
	TF-NV	7.64±0.15 ab	2.573±0.019 b	10.6±0.9 a	0.15±0.06 b	0.00±0.00 a	0.06±0.01 a
	TF-V	7.75±0.13 b	2.255±0.199 b	10.8±0.8 a	0.12±0.05 b	0.00±0.00 a	0.15±0.04 a
amendments effect T0		***	***	***	***	***	***
amendments effect NV		***	***	***	***	***	***
amendments effect V		***	***	**	***	***	***

Table 3: As, Fe and Pb bioaccessible fractions (%) in tested soils using SBET (Simplified Bioaccessibility Extraction Test). Ps: polluted soil, PsI: Ps + iron grit (I) 1.5%, PsC: Ps + compost (C) 5%, PsB: Ps + biochar (B) 5%, PsBI: Ps + B 5% + I 1.5%, PsBC: Ps + B 5% + C 5%. Results are expressed as the mean value \pm standard error (n = 5). Letters indicate treatment significant difference ($p < 0.05$).

treatments	SBET bioaccessible fractions (%)		
	[As]	[Fe]	[Pb]
Ps	3.24 \pm 0.07 c	1.32 \pm 0.21 b	51.12 \pm 0.61 d
PsI	1.58 \pm 0.09 d	2.43 \pm 0.24 c	53.00 \pm 2.36 cd
PsC	4.38 \pm 0.20 b	2.12 \pm 0.14 bc	60.54 \pm 1.04 b
PsB	4.12 \pm 0.15 b	1.68 \pm 0.07 b	59.52 \pm 2.04 bc
PsBI	1.97 \pm 0.12 d	4.14 \pm 0.32 a	54.08 \pm 2.79 cd
PsBC	5.11 \pm 0.14 a	2.46 \pm 0.10 c	69.49 \pm 1.18 a

Table 4: As, Fe and Pb bioaccessible fractions (%) in *Trifolium repens* aerial parts collected at the end of the experiment (30 days) on amended soils. Results are obtained from 500 seeds sown on tested soils. PsC: Ps + compost (C) 5%, PsB: Ps + biochar (B) 5%, PsBI: Ps + B 5% + I 1.5%, PsBC: Ps + B 5% + C 5%. Results are expressed as the mean value \pm standard error (n=5); letters indicate significant difference ($p < 0.05$).

treatments	SBET bioaccessible fractions (%)		
	As	Fe	Pb
PsC	8.2 \pm 0.5 a	2.3 \pm 0.2 b	34.6 \pm 2.2 b
PsB	5.5 \pm 0.7 b	2.3 \pm 0.4 b	34.7 \pm 1.8 b
PsBI	3.6 \pm 0.2 b	16.4 \pm 3.0 a	64.2 \pm 3.7 a
PsBC	9.5 \pm 0.6 a	2.9 \pm 0.2 b	42.5 \pm 2.6 b