Assessment of the effectiveness of implemented measures regarding combating soil degradation and to restore soil functions and ecosystem services.

Authors: Keizer J.J., Hessel R. and case study partners
### Project Information

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### Report Information

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Assessment of the effectiveness of the tested measures to combat soil degradation or restore soil functions

Keizer J.J., Hessel R. and case study partners

dd. 2018-06-29
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Appendix I. Contributions of the individual case study partners to this Deliverable

Appendix II. Template for the case study contributions to this Deliverable
1. INTRODUCTION

The present deliverable has as overarching aim to report on the results obtained in the field and glasshouse experiments carried out in the framework of the RECARE’s WP6 in the project’s 17 case study sites to test the prevention, remediation or restoration measures that had been selected/validated by stakeholders through a formal workshop-based procedure developed in WP4. As is common in experimental research and especially for field trials, however, for a variety of reasons it proved impossible to test all measures that had been foreseen in deliverable D6.1, to implement all experiments according to the set-up envisaged in deliverable D6.1, or to obtain sufficient data to duly evaluate all measures. Therefore, the next section will provide an overview of the measures that could, in fact, be evaluated successfully (whether as ineffective, negatively or positively) by the WP6 experiments.

To guide the actual evaluation of the measures, a distinction was proposed between the measures’ effectiveness in terms of targeted variables as well as principal soil threat, on the one hand, and, on the other, their impacts (or, side effects) on non-targeted variables as well as additional soil threats. This distinction was also the basis for the proposed structure of the contributions by the case study partners to this deliverable (see Appendix I). An example of the case studies in which this distinction was particularly useful is that of Portugal. Mulching with forest logging residues aimed to reduce soil erosion by water through increasing the protective litter cover but, at the same time, could be expected to decrease soil organic matter losses, increase soil moisture content or affect the abundance and/or diversity of ground-dwelling macro-invertebrates. Although the proposed structure was not followed in the contributions of all case study partners, the separate impacts of the measures on targeted and non-targeted variables, and on principal and additional soil threats and will be addressed here in sections 3 to 6, respectively.

The contributions of the individual case study partners to this deliverable are listed in Table 1 and included Appendix II. The majority of these contributions is in the form of scientific papers published (4), accepted (0), under revision by authors (6) and under.
review (5, of which 4 under 1st review and 1 under 3rd review) in/for/to a dedicated, virtual special issue of CATENA (https://www.sciencedirect.com/journal/catena/special-issue/1063L2HD49J). CATENA was selected for being a well-reputed interdisciplinary journal of soil science - hydrology - geomorphology focusing on geo-ecology and landscape evolution (www.journals.elsevier.com/catena). This special issue is being guest-edited by the first two authors of the present document. Because of author rights transference to the journal, Appendix II includes the versions of the papers that were originally submitted. However, links to the papers that have already been published (online) are listed in Table 1. Since the whole process from submitting to publishing papers in scientific journals with peer review typically takes considerable time, the final, publishable version of this deliverable will not be available till all submitted papers have been either published or rejected.

Table 1. Overview of the contributions of the case study partners to this deliverable.

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2. OVERVIEW OF THE EXPERIMENTS

Table 2 gives an overview of the 19 WP6 experiments that were reported by the case study partners in the contributions listed in Table 1. In the majority of experiments (11), two up to seven prevention, mitigation or restoration were tested, in accordance with the overall strategy as envisaged in RECARE’s DOW. In one of the other cases (cs5), additional measures were in fact tested but the findings are being reported in a separate article (Pulido-Moncada et al., under review). In the remaining cases, either only one
measure had been foreseen from the start, or the measures foreseen in deliverable D6.1 could not be (duly) tested, for a variety of case study-specific reasons. The latter can be exemplified by the second measure that was selected by the Portuguese stakeholders, i.e. post-fire contour plowing. Within the entire burnt area of some 700 ha, no ploughing was observed during the entire first post-fire year. Towards the end of that year, one of the landowners could be persuaded to plough a small part of one of his terrains, just for the sake of setting up a second WP6 experiment. However, since the second post-fire year was relatively dry, the obtained results were considered not to be sufficiently representative for assessing the measure’s effectiveness.

The inclusion of target or reference – i.e. unthreatened or non-degraded - conditions in the WP6 experiments proved impossible in almost all experiments, except that of case studies 6 and 17. This reflected the fact that the bulk of the experiments were carried out on agricultural lands without nearby (semi-)natural ecosystems with comparable physical-environmental conditions. The only case study dealing with forest concerned planted forest with an exotic fast-growing species (eucalypt), without native forest in the wide vicinity. The ensuing sections will therefore not address the comparison with target or reference conditions.

3. TREATMENT EFFECTIVENESS IN TERMS OF TARGETED VARIABLES

Table 3 gives a summary of the impacts that the different measures had on the variables that these measures aimed to change directly or, as termed here, that these measures targeted. The concept of targeted variables was introduced to make sure that a measure’s lack of effectiveness in terms of principal soil threat could not be explained by its lack of impact on the targeted variable. The concept’s relevance can be illustrated by a well-known case in which post-fire mulching with straw in the USA was not effective because the straw had largely been blown away before the start of an extreme erosion event. Admittedly, however, the concept is not (easily) applicable to all WP6 experiments, as exemplified by the experiments of cs1 and cs5.

Targeted variables were defined and quantified for 14 of the RECARE WP6 experiments. In three of these experiments (cs4, cs7, cs10), the experimenters had full control over the target variable, or, in other words, could select its (approximate) value during the course of experiment. In five of the remaining 11 experiments, one or more treatments
seemed to have produced a significant as well as noticeable difference in the targeted variable compared to under threatened or degraded conditions. Three of these five cases concerned soil amendments targeting soil pH, with treatments aiming to either increase it (cs15 – amending; cs16) or decrease it (cs17). In contrast, three experiments revealed either insignificant (cs15 – treeing) or unsubstantial (cs12, cs13) differences in the target variables between the control and the treatment(s). Worth stressing, however, is that in the case of the cs13 experiment this lack of marked differences indicated that the two mitigation measures were, in fact, successful.

4. TREATMENT EFFECTIVENESS IN TERMS OF PRINCIPAL SOIL THREATS

Table 4 gives a summary of the impacts that the different measures had on the principal soil threats, i.e. the soil threats that these measures were aimed to prevent, mitigate or restore from. In almost all experiments, these impacts could be quantified through one or more key indicators of the state of the soil threat for the threatened/degraded conditions as well as for one or more treatments. In three case studies, this proved impossible during the execution of WP6, either because of measurement problems (cs1 and cs8) or, first and foremost, because of a lack of control over the experimental design and the measurement of the principal soil threat indicator, both being in the hands of the landowners and rather than the scientists (cs13).

Worth stressing is that from the 29 different indicators listed in Table 4, only two were directly comparable in the sense of having been measured with equivalent methods. In cs1 as well as cs3, soil erosion by water was measured with sediment fences under natural rainfall conditions and over a period of at least one hydrological year. In contrast, soil erosion was measured in cs7 under simulated rainfall conditions of 1h duration. Besides in cs7, runoff coefficient was measured in cs10 through field rainfall simulation experiments. Arguably, however, the results of both cs’s are not directly comparable due to the marked differences in rainfall intensity and duration, as indicated in Table 4, as well as in the size of the runoff plots (cs7: 0.28 m2; cs10: 0.625 m2). As further detailed in deliverable D6.1, a lack of harmonization across case studies assessing the same soil threats was due to various reasons. The main reasons were the advantages of sticking to methods and techniques that cs partners had been applying till RE CARE, on
the one hand, and, on the other, the nature of assessing measures’ effectiveness, in essence involving paired comparisons with untreated but otherwise (presumably) identical conditions.

In roughly half of the experiments (7 out of 17), the principal soil threat indicator differed significantly between one of more of the tested measures and the untreated conditions. In only one of these cases (cs12), these significant differences did not correspond to an improvement compared to the current, threatened situation, as CO2 emissions by soil respiration were significantly higher for the alternative grass species (reed canary and tall fescue) than for the control grass species (timothy). Even so, these differences in CO2 emissions were considered to be too small to be of much relevance for organic matter losses in organic soils, while both reed canary and tall fescue were regarded as promising alternatives to timothy in terms of yield, nutrient removal and carbon capture efficiency.

Besides the experiment of cs12, two more experiments revealed just minor differences in the indicator or any of the multiple indicators of the principal soil threat between the selected measures and the threatened/degraded conditions. In cs10, neither planting shrubs nor trees seemed to markedly change stream bank instability, at least under the experimental conditions. Even so, model simulations did suggested relevant impacts of the proposed measures for steeper stream banks. In the case of the tree planting experiment of cs15, a marked reduction in soil contamination levels apparently depended more on individual tree specimens than on tree species per se and, in particular, on their capacity to change soil pH.

The two types of measures that were tested in more than one case study site appeared to be highly effective in both cases. Mulching strongly reduced soil erosion by water in a recently burnt eucalypt plantation (cs2) as well as in an intensively managed clementine orchard (cs7), in spite different types of mulch were used (logging residues and straw, respectively). Likewise, inorganic soil amendments that effectively changed soil pH levels, were highly effective in immobilizing metals in contaminated soils in cs15 as well as cs16, in spite different types of amendments were applied.
5. TREATMENT IMPACTS ON ADDITIONAL SOIL THREATS

Table 5 gives a summary of the impacts that the different measures had on other than the principal soil threats, i.e. soil threats that these measures were not (necessarily) aimed to prevent, mitigate or restore from. Five experiments could, in fact, address a second soil threat, covering five distinct threats.

In all five experiments, the impacts on the additional soil threat closely matched those on the principal one. As such, four experiments gave evidence for synergistic effects. Post-fire mulching not only reduced soil erosion by water but also organic matter losses (cs2). Cover crops not only reduced the rainfall-runoff response but also soil erosion by water (cs10). Conservation farming not only increased topsoil organic carbon sequestration but also decreased nitrate concentration in subsoil water (cs14). Applying organic as well as inorganic amendments not only reduced available metal contents but also increased total soil organic carbon contents (cs15). In contrast, alternative grass species neither impacted soil respiration nor susceptibility to soil compaction to an important degree (cs12), while tree species did not have a clear-cut effect on the topsoil content of either available metals or total organic carbon (cs15).
Table 2. Overview of the field and greenhouse experiments testing selected prevention, mitigation and restoration measures ("treatments") for threatened or degraded soils, as reported by the RECARE case study partners as contribution to this deliverable.

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<td>erosion by water</td>
<td>terracing</td>
<td>-</td>
<td>collapsed t. walls</td>
<td>maintained t. walls</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>GR</td>
<td>salinization</td>
<td>irrigating</td>
<td>salinized water (sw)</td>
<td>-</td>
<td>sw + tomato inoculation</td>
<td>&quot;rain&quot; water (rw)</td>
<td>rw + tomato inoculation</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>DK</td>
<td>compaction</td>
<td>trafficking</td>
<td>using tires</td>
<td>-</td>
<td>using tracks</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>PL</td>
<td>sealing</td>
<td>feeing</td>
<td>without legal protection (2007/08-2017)</td>
<td>-</td>
<td>with legal protection (1992/94-2006/07)</td>
<td>-</td>
<td>-</td>
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<tr>
<td>7</td>
<td>ES_V</td>
<td>desertification</td>
<td>mulching</td>
<td>intensive orchard</td>
<td>-</td>
<td>straw mulching</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>IS</td>
<td>desertification</td>
<td>vegetating</td>
<td>-</td>
<td>eroded grassland</td>
<td>seeding (grass/leguminosae)</td>
<td>tree planting (birch/willow)</td>
<td>seeding + fertilizing</td>
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<tr>
<td>9</td>
<td>NO</td>
<td>floods &amp; land slides</td>
<td>banking</td>
<td>grass-cov. stream bank</td>
<td>-</td>
<td>shrub planting</td>
<td>tree planting</td>
<td>-</td>
<td></td>
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<tr>
<td>10</td>
<td>SK</td>
<td>floods &amp; land slides</td>
<td>covering</td>
<td>bare cropland</td>
<td>-</td>
<td>seeding winter crop</td>
<td>rapeseeding (3 stages)</td>
<td>-</td>
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<tr>
<td>11</td>
<td>NL_B</td>
<td>om losses org. soils</td>
<td>draining</td>
<td>permanent pasture</td>
<td>-</td>
<td>submerged winter crop</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>SE</td>
<td>om losses org. soils</td>
<td>grassing</td>
<td>timothy grassland</td>
<td>-</td>
<td>reed canary seeding</td>
<td>tall fescue seeding</td>
<td>-</td>
<td></td>
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<tr>
<td>13</td>
<td>NL_E</td>
<td>om losses min. soils</td>
<td>farming</td>
<td>-</td>
<td>grass+maize field</td>
<td>grass intercropping</td>
<td>separated manuring</td>
<td>biomass incorporation</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>IT</td>
<td>om losses min. soils</td>
<td>farming</td>
<td>conventional cropland</td>
<td>-</td>
<td>conservation farming</td>
<td>cover cropping</td>
<td>-</td>
<td></td>
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<tr>
<td>15</td>
<td>ES_G</td>
<td>contamination-CSIC</td>
<td>treeing</td>
<td>-</td>
<td>post-remediation &quot;control&quot;</td>
<td>everg. tree planting (4 spp)</td>
<td>decid. tree planting (3 spp)</td>
<td>-</td>
<td>biomass composting</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>amending</td>
<td>-</td>
<td>post-remediation &quot;control&quot;</td>
<td>sugar beet liming</td>
<td>biosolid composting</td>
<td>-</td>
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<td></td>
<td></td>
<td></td>
<td>amending</td>
<td>-</td>
<td>post-remediation &quot;control&quot;</td>
<td>sugar beet liming (sbl)</td>
<td>sbl + composting (co)</td>
<td>sbl + claying (dl)/sbl+co+cl</td>
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<tr>
<td>16</td>
<td>RO</td>
<td>contamination</td>
<td>amending</td>
<td>grassland</td>
<td>natural &quot;zeoliting&quot;</td>
<td>&quot;bentoniting&quot;</td>
<td>&quot;dolomiting&quot;; manuring</td>
<td>-</td>
<td></td>
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<tr>
<td>17</td>
<td>GB</td>
<td>soil biodiversity</td>
<td>amending</td>
<td>&quot;improved&quot; pasture</td>
<td>ferrous sulphating</td>
<td>elemental sulphuring</td>
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Table 3. Summary of the effectiveness of the selected treatments on the target variables as reported in the contributions of the case study partners to this deliverable. The underlined values indicate significant differences of the treatment with the control.

<table>
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<tr>
<th>cs</th>
<th>count principal soil threat</th>
<th>designation experiment</th>
<th>targeted variable</th>
<th>measurement unit</th>
<th>degrad./threat.</th>
<th>treatments</th>
<th>t1</th>
<th>t2</th>
<th>t3</th>
<th>t4</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>PT erosion by water</td>
<td>mulching</td>
<td>litter cover (incl. mulch)</td>
<td>%</td>
<td>2</td>
<td>79</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>GR salinization</td>
<td>irrigating</td>
<td>T. harzianum colonization</td>
<td>%</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>DK compaction</td>
<td>trafficking</td>
<td>vertical soil stress (at 0.35m)</td>
<td>kPa</td>
<td>228</td>
<td>139</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>ES_V desertification</td>
<td>mulching</td>
<td>mulch cover</td>
<td>%</td>
<td>0</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>IS desertification</td>
<td>vegetating</td>
<td>vegetation biomass</td>
<td>Mg ha-1</td>
<td>0-0.1</td>
<td>&lt;0.1/1.7</td>
<td>0.7/&lt;0.1</td>
<td>0.7-1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>SK floods &amp; land slides</td>
<td>banking</td>
<td>root cohesion</td>
<td>kPa</td>
<td>0.35</td>
<td>0.35-1.37</td>
<td>7.18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>SE floods &amp; land slides</td>
<td>covering</td>
<td>vegetation cover</td>
<td>%</td>
<td>0</td>
<td>80</td>
<td>40-50</td>
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<td></td>
<td></td>
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<tr>
<td>11</td>
<td>NL_B om losses org. soils</td>
<td>draining</td>
<td>groundwater level</td>
<td>mNAP</td>
<td>variable</td>
<td>dry period: t1 = t0+(10-15 cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>SE om losses org. soils</td>
<td>grassing</td>
<td>grass yields</td>
<td>Mg ha-1 y-1</td>
<td>11.7</td>
<td>14.3</td>
<td>13.5</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>13</td>
<td>NL_E om losses min. soils</td>
<td>farming</td>
<td>vegetation cover</td>
<td>NDVI</td>
<td>0.53-0.57</td>
<td>0.50-0.55</td>
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<td></td>
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<tr>
<td>15</td>
<td>ES_G contamination-CSIC</td>
<td>treeing</td>
<td>soil pH</td>
<td>1/2.5 KCl</td>
<td>4.0</td>
<td>3.4-4.0</td>
<td>4.1-4.9</td>
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<td></td>
<td></td>
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<tr>
<td>16</td>
<td>RO contamination</td>
<td>amending</td>
<td>soil pH</td>
<td>1/2.5 KCl</td>
<td>3.5</td>
<td>7.0</td>
<td>5.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>GB soil biodiversity</td>
<td>amending</td>
<td>soil pH</td>
<td>1/2.5 H2O</td>
<td>5.5</td>
<td>6.1</td>
<td>6.8</td>
<td>7.2</td>
<td>6.1</td>
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</table>

The underlined values indicate significant differences of the treatment with the control.
Table 4. Summary of the impacts of the selected treatments on the indicators of the principal soil threats as reported in the contributions of the case study partners to this deliverable. Underlined values indicate significant differences of treatment with control.

<table>
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<tr>
<th>cs</th>
<th>country</th>
<th>principal soil threat designation</th>
<th>experiment</th>
<th>soil threat indicator</th>
<th>measurement unit</th>
<th>degrad./threat.</th>
<th>t1</th>
<th>t2</th>
<th>t3</th>
<th>t4</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>PT</td>
<td>erosion by water</td>
<td></td>
<td>mulching</td>
<td>sediment losses (1st post-fire year)</td>
<td>Mg ha-1 yr-1</td>
<td>8.0</td>
<td>0.3</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>CY</td>
<td>erosion by water</td>
<td></td>
<td>terracing</td>
<td>soil losses</td>
<td>Mg ha-1 yr-1</td>
<td>3.9</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>GR</td>
<td>salinization</td>
<td></td>
<td>irrigating</td>
<td>Δ soil pH</td>
<td>pH units</td>
<td>0.8</td>
<td>0.7</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Δ soil saturated extract EC</td>
<td>dS m-1</td>
<td>-7</td>
<td>-4</td>
<td>-14</td>
<td>-4</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Δ soil Sodium Adsorption Ratio</td>
<td>mmol L-1</td>
<td>22.2</td>
<td>14.4</td>
<td>6.8</td>
<td>4.8</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>salinity class (van Beek and Tóth, 2012)</td>
<td>nominal</td>
<td>sodic-saline (ss)</td>
<td>ss to saline</td>
<td>saline</td>
<td>saline</td>
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<tr>
<td>5</td>
<td>DK</td>
<td>compaction</td>
<td></td>
<td>trafficking</td>
<td>dry bulk density (0.33-0.37m depth)</td>
<td>g cm-3</td>
<td>1.56</td>
<td>1.55</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>air permeability (0.33-0.37m depth)</td>
<td>μm2</td>
<td>20.3</td>
<td>7.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>volumetric water content (0.33-0.37m depth)</td>
<td>m3 m-3</td>
<td>0.25</td>
<td>0.25</td>
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<tr>
<td>6</td>
<td>PL</td>
<td>sealing</td>
<td></td>
<td>feeing</td>
<td>Poznan - annual rate of agricultural land conversion</td>
<td>ha yr-1</td>
<td>101</td>
<td>216</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Wroclaw - annual rate of agricultural land conversion</td>
<td>ha yr-1</td>
<td>125</td>
<td>232</td>
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<tr>
<td>7</td>
<td>ES_V</td>
<td>desertification</td>
<td></td>
<td>mulching</td>
<td>runoff coefficient (1h 38mm h-1 simulated rain)</td>
<td>%</td>
<td>66</td>
<td>51</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>sediment losses (1h 38mm-h-1 simulated rain)</td>
<td>g m-2 mm-1</td>
<td>41.3</td>
<td>6.8</td>
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<tr>
<td>9</td>
<td>NO</td>
<td>floods &amp; land slides</td>
<td></td>
<td>banking</td>
<td>Δ x/y-position erosion pins (bank failure indicator)</td>
<td>m</td>
<td>0.01-0.09</td>
<td>0.01-0.06</td>
<td>0.01-0.07</td>
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<tr>
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<td></td>
<td></td>
<td>stream bank stability (BESTER simulated)</td>
<td>safety factor (Fs)</td>
<td>&gt;1.3</td>
<td>&gt;1.3</td>
<td>&gt;1.3</td>
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<tr>
<td>10</td>
<td>SK</td>
<td>floods &amp; land slides</td>
<td></td>
<td>covering</td>
<td>runoff coeff. (3min 3-7mm min-1 simulated rain)</td>
<td>%</td>
<td>0.30</td>
<td>0</td>
<td>5-15</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td>peak flow surface runoff (SMODERP simul. 10y rp)</td>
<td>L sec-1</td>
<td>3.9</td>
<td>&lt;0.1</td>
<td>nq</td>
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<tr>
<td>11</td>
<td>NL_B</td>
<td>om losses org. soils</td>
<td></td>
<td>draining</td>
<td>Δ ground level (subsidence indicator)</td>
<td>mm y-1</td>
<td>3.0-5.2</td>
<td>0.9-2.5</td>
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<td></td>
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<td></td>
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<td></td>
<td>soil organic matter losses (Δ ground level derived)</td>
<td>Mg ha-1 yr-1</td>
<td>3.4-5.8</td>
<td>1.0-3.1</td>
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<tr>
<td>12</td>
<td>SE</td>
<td>om losses org. soils</td>
<td></td>
<td>grassing</td>
<td>soil respiration CO2 emissions (2h data snow-free season)</td>
<td>mg m-2 h-1</td>
<td>730</td>
<td>795</td>
<td>825</td>
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<tr>
<td>14</td>
<td>IT</td>
<td>om losses min. soils</td>
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<td>farming</td>
<td>Δ 0-5 cm soil organic carbon stocks t_start to t_end</td>
<td>Mg C ha-1 yr-1</td>
<td>0.3</td>
<td>4.4</td>
<td>-0.4</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Δ 5-50 cm soil organic carbon stocks t_start to t_end</td>
<td>Mg C ha-1 yr-1</td>
<td>12</td>
<td>11</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>Δ CO2 efflux-influx (DNC simulations 2018-2112 81 scenario)</td>
<td>kg C ha-1 yr-1</td>
<td>173</td>
<td>-309</td>
<td>-228</td>
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<tr>
<td>15</td>
<td>ES_G</td>
<td>contamination-CSIC</td>
<td></td>
<td>treeing</td>
<td>CaCl2-extractable soil cadmium (Cd) concentration</td>
<td>mg kg-1</td>
<td>?</td>
<td>?</td>
<td>?</td>
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<td></td>
<td></td>
<td>CaCl2-extractable soil copper (Cu) concentration</td>
<td>mg kg-1</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>amendment</td>
<td>CaCl2-extractable soil cadmium (Cd) concentration</td>
<td>mg kg-1</td>
<td>0.19</td>
<td>&lt;0.01</td>
<td>0.10</td>
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<td></td>
<td></td>
<td>CaCl2-extractable soil copper (Cu) concentration</td>
<td>mg kg-1</td>
<td>2.9</td>
<td>0.1</td>
<td>0.2</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>amendment</td>
<td>pseudototal soil cadmium (Cd) concentration</td>
<td>mg kg-1</td>
<td>3.33</td>
<td>0.97</td>
<td>0.81</td>
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<tr>
<td>16</td>
<td>RO</td>
<td>contamination</td>
<td></td>
<td>amending</td>
<td>DTPA-extractable soil cadmium (Cd) concentration</td>
<td>mg kg-1</td>
<td>11.2</td>
<td>10.0</td>
<td>9.9</td>
<td>8.3</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td>DTPA-extractable soil zinc (Zn) concentration</td>
<td>mg kg-1</td>
<td>280</td>
<td>180</td>
<td>150</td>
<td>80</td>
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<tr>
<td>17</td>
<td>GB</td>
<td>soil biodiversity</td>
<td></td>
<td>amending</td>
<td>fluorescein released (microbial activity indicator)</td>
<td>μg fluor. g-1 h-1</td>
<td>170</td>
<td>nq</td>
<td>90</td>
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<td></td>
<td></td>
<td></td>
<td>earthworm fresh biomass</td>
<td>g 8dm-3</td>
<td>2.6</td>
<td>2.2</td>
<td>1.3</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>nematodes abundance</td>
<td>nr individuals</td>
<td>770</td>
<td>500</td>
<td>250</td>
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</table>
Table 5. Summary of the impacts of the selected treatments on the indicators of the additional soil threats as reported in contributions of the case study partners to this deliverable. Underlined values indicate significant differences of treatment with control.

<table>
<thead>
<tr>
<th>cs</th>
<th>count additional soil threats</th>
<th>designation experiment</th>
<th>soil threat indicator</th>
<th>measurement unit</th>
<th>degrad./ threat.</th>
<th>treatments</th>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>PT</td>
<td>mulching</td>
<td>organic matter losses by runoff (1st post-fire year)</td>
<td>Mg ha-1 y-1</td>
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</table>
APPENDIX I.

Template for the case study contributions to this Deliverable
Case study number: xxx

Country: xxx

Author(s): family name, first name

Affiliation(s): xxx

Principal soil threat: xxx

Additional soil threats: xxx

Selected treatments for WP6 testing and demonstration:

1. xxx
2. xxx
3. xxx

CONTRIBUTION TO Deliverable 6.2

version: xxx

date: xxx
1. Introduction

2. Case Study area and monitoring sites

3. Materials and methods
   3.1. Experimental design and treatments
   3.2. Field data and sample collection
   3.3. Laboratory analyses
   3.4. Data analyses

4. Results
   4.1. Treatment effectiveness in terms of targeted variable(s)
   4.2. Treatment impacts on non-targeted variable(s)
4.3. Treatment effectiveness in terms of principal soil threat

A critical comparison of the treatment effectiveness, as identified in sections 4.1 and 4.2, was conducted for the ecological conservation and effective treatment rates of the principal threat (e.g., phosphorus flux, nutrient leaching).

4.4. Treatment impacts on additional soil threats

A critical comparison of the treatment impacts on additional soil threats (e.g., fire machinery, reforested areas) was conducted for the ecological effectiveness and treatment rates of these threats.

5. Discussion

5.1. Treatment effectiveness in terms of principal soil threat

Critical comparison of the treatment effectiveness, as identified in section 4.1, was conducted for the ecological conservation and effective treatment rates of the principal threat (e.g., phosphorus flux, nutrient leaching).

5.2. Treatment impacts on additional soil threats

Critical comparison of the treatment impacts on additional soil threats (e.g., fire machinery, reforested areas) was conducted for the ecological effectiveness and treatment rates of these threats.

5.3. Overall discussion

A critical discussion of the treatment effectiveness and impacts on additional soil threats was conducted for the ecological conservation and effective treatment rates of these threats.

6. Conclusions

(i)

(ii)

(iii)

(iv)

(v)

Acknowledgements
References

Books:

Articles:

Reports:

Technical reports:

Theses:

Proceedings:

Patents:

Mechanical equipment:

Other:

}
APPENDIX II.

Contributions of the individual case study partners to this Deliverable
Abstract: Tubers and root crops are a typical element of the crop rotation system widely practiced in the Swiss Plateau and especially prone to soil erosion by water, resulting in recurrent soil loss and considerable off-site damages. Thus, improved cultivation practices are needed to counteract and mitigate the erosion risk. This research evaluates the effectiveness of a device called the "Dyker", which was trialled during two cropping seasons. The Dyker consists of a set of wheels (three, in our case) with three inclined shovels each. It is attached to the rear end of a potato planting machine and digs holes into the bottom of the furrows between the potato hills. The holes are intended to improve water infiltration and to help retain water near the plants, while minimizing surface runoff and soil erosion, and preventing waterlogging in depressions. A dye tracer experiment showed that in treated furrows, water infiltrates into the compacted subsoil below the ploughed horizon, while in untreated furrows, hardly any water infiltrates deeper than 20 cm below surface. In order to assess the effectiveness of the Dyker in conventional potato farming with regard to soil erosion and waterlogging, several plots were planted in alternating sets of rows with and without use of the Dyker. A series of drone photographs showed that the Dyker effectively reduces stagnant water in depressions: while in treated furrows rainwater was evenly retained in small holes and infiltrated the soil locally, in untreated furrows it drained to the lowest point of the plot. Due to saturation, excess water remained in the untreated furrows for several days and created anaerobic conditions in the adjacent potato hills. This inhibited plant growth and ultimately led to crop failure. By contrast, potatoes grew well in the hills between treated furrows. In addition, measurements of temporal and spatial changes of the cross-sectional geometry of furrows showed more erosion and accumulation processes in untreated furrows. In a steep section (10-15%) of a plot, the average cross-sectional area of untreated
furrows increased by almost 44% after 90 days and 466 mm of precipitation, and decreased by almost 50% in a concave section at the end of the plot where the soil accumulated. The changes during the same period were much smaller for treated furrows, with erosion at +24% and soil accumulation area at –24%. The positive changes in surface structure diminish in time, as the small holes between the micro-dams gradually fill up, depending on rainfall amounts and intensities. However, increasing vegetation cover protecting the soil can partly compensate this effect.
BE R N,  1 5  F E B R U A R Y  2 0 1 8


S I N C E R E L Y ,

D R .  T A T E N D A  L E M A N N

©

T A T E N D A  L E M A N N

U N I V E R S I T Ä T

B E R N

C D E

C E N T R E  F O R  D E V E L O P M E N T  A N D  E N V I R O N M E N T

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3 0 1 2  B E R N ,  S W I T Z E R L A N D

T E L .  + 4 1  3 1  6 3 1  8 8  2 2


E D I T O R I A L  B O A R D

C A T E N A

C O V E R  L E T T E R
The effect of the Dyker on infiltration, soil erosion, and waterlogging on conventionally farmed potato fields in the Swiss Plateau

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²Physical Geography – Paleo-GEOecology Group, University of Bern, Switzerland
³Agroscope, Research Division Agroecology and Environment, Switzerland

Abstract:
Tubers and root crops are a typical element of the crop rotation system widely practiced in the Swiss Plateau and especially prone to soil erosion by water, resulting in recurrent soil loss and considerable off-site damages. Thus, improved cultivation practices are needed to counteract and mitigate the erosion risk. This research evaluates the effectiveness of a device called the “Dyker”, which was trialled during two cropping seasons. The Dyker consists of a set of wheels (three, in our case) with three inclined shovels each. It is attached to the rear end of a potato planting machine and digs holes into the bottom of the furrows between the potato hills. The holes are intended to improve water infiltration and to help retain water near the plants, while minimizing surface runoff and soil erosion, and preventing waterlogging in depressions. A dye tracer experiment showed that in treated furrows, water infiltrates into the compacted subsoil below the ploughed horizon, while in untreated furrows, hardly any water infiltrates deeper than 20 cm below surface. In order to assess the effectiveness of the Dyker in conventional potato farming with regard to soil erosion and waterlogging, several plots were planted in alternating sets of rows with and without use of the Dyker. A series of drone photographs showed that the Dyker effectively reduces stagnant water in depressions: while in treated furrows rainwater was evenly retained in small holes and infiltrated the soil locally, in untreated furrows it drained to the lowest point of the plot. Due to saturation, excess water remained in the untreated furrows for several days and created anaerobic conditions in the adjacent potato hills. This inhibited plant growth and ultimately led to crop failure. By contrast, potatoes grew well in the hills between treated furrows. In addition, measurements of temporal and spatial changes of the cross-sectional geometry of furrows showed more erosion and accumulation processes in untreated furrows. In a steep section (10-15%) of a plot, the average cross-sectional area of untreated furrows increased by almost 44% after 90 days and 466 mm of precipitation, and decreased by almost 50% in a concave section at the end of the plot where the soil accumulated. The changes during the same period were much smaller for treated furrows, with erosion at +24% and soil accumulation area at -24%. The positive changes in surface structure diminish in time, as the small holes between the micro-dams gradually fill up, depending on rainfall amounts and intensities. However, increasing vegetation cover protecting the soil can partly compensate this effect.

KEY WORDS: Infiltration, soil erosion, water logging, potato farming, Dyker
1 Introduction

Soil erosion is a major threat to the soil resource at the global (Borrelli et al., 2017) and the European level (Panagos et al., 2015; Stolte et al., 2016). The literature on agriculture points to the high erosion risk by cultivation of crops on ridges, due to the furrows between dams that serve as tramlines for surface runoff (Anderson et al., 2013; Auerswald et al., 2006; Fiener and Auerswald, 2007; Xing et al., 2011). However, such soil loss has rarely been measured or mapped. On runoff-erosion plots in New Brunswick (Canada), Chow et al. (1990) measured soil loss of between 17 and 24 t/ha/year for fields of potato planted across the contours of hillsides. In the same region, Chow and Rees (1994) showed with rainfall simulations erosion rates that were four times higher on dammed potato fields than on fields with a level surface. In England, studies mapped on 171 potato fields an average soil loss of 3.3 t/ha/year between 1982 and 1986 (Evans et al., 2016), and observed in a 10-year monitoring programme (2004-2013) erosion on 11 out of 15 potato fields (Evans, 2017). In a measurement series of 11 years in Germany, Bug and Mosimann (2012) identified the highest mean soil loss on potato fields (4.2 t/ha/year).

Soil erosion by water, combined with compaction, poses the main soil threat in the case study area of Frienisberg in the Swiss Plateau. Sheet, rill, and gully erosion in mixed-crop/livestock farming systems are causing loss of fertile topsoil on the cultivated fields (on-site). This erosion also leads to economic and ecological costs for society, related to the deposition of eroded material downslope (off-site) (Ledermann et al., 2010), e.g. on adjacent downslope fields or on public and private infrastructure. As in other parts of the world, potato fields are most frequently affected by soil erosion and accounted for the largest soil losses in the hilly case study area (Prasuhn et al., 2018). Prasuhn (2012) showed that out of 149 observed potato fields, 82 (55%) showed soil erosion between 1997 and 2007. Over 10 years, a total of 521 t of soil was eroded from these potato fields at an average of 2.87 t/ha/year. This corresponds to 26% of total soil erosion in the region, despite potato fields only covering 7% of the total agricultural area. The most severe soil erosion events measured – at 89 t and 72 t respectively – occurred on potato fields (Prasuhn, 2012).

Soil erosion by water is best controlled by maximizing in situ rainfall infiltration. Various measures are known to increase infiltration in row-crop fields, such as increasing vegetation cover, mulching, different tillage systems, terracing, water harvesting, or technologies to change the soil surface structure. These measures could be combined in terms of local biophysical conditions, cost-benefits, and impact on control of erosion on-site (e.g. splash, sheet, rill, and gully) and off-site (sedimentation). However, conservation tillage practices or other suitable erosion protection measures on potato fields are largely lacking. Various micro-dam techniques have been applied since about 1990. Since the early 2000s, newly implemented devices to build small holes and micro-dams in potato furrows such as the Dyker (from Grimme) or Barbutte (from Ets Cottard) show promising results, e.g. in France (AREAS, 2005; Martin and Real, 2016), Belgium (FIWAP, n.d.; Olivier et al., 2014), England (Anderson et al., 2013; Hayes, n.d.), Germany (Aurbacher et al., 2012; Billen and Aurbacher, 2007), Czech Republic (Mayer et al., 2016; Vacek et al., 2015), Israel (Agassi and Levy, 1993), and Switzerland (Bandi, 2016; Jaunin, 2016; Prasuhn et al., 2018).

The Dyker used in this study consists of three wheels to which, respectively, three inclined shovels are attached (Prasuhn et al., 2018). Attached to the rear end of the planting machine, it digs small holes into the bottom of the furrows and builds micro-dams in between. Dyker applications report improved water infiltration and water retention near plants, combined with a prevention of water logging in depressions and minimization of surface runoff and soil erosion; however, robust scientific evidence is largely lacking. Studies with systematic results have so far only been published in grey
literature and could not be found in academic publications. This study tested the impacts of the changed soil surface caused by the Dyker on infiltration, soil erosion, and waterlogging over two years with different methods, within the scope of the research project RECARE (Preventing and Remediating Degradation of Soils in Europe through Land Care, 2013–2018, [www.recare-project.eu]).

In the framework of RECARE, 17 case studies assess the influence of measures against various soil threats all over Europe.

The detailed description of soil profiles and measurements of their permeability, provides the basis for a better understanding of the subsoil infiltration behaviour indicated during a tracer study on furrows with or without Dyker treatment. The effectiveness of changing surface runoff and its influence on soil erosion or waterlogging were determined by measuring cross-sectional geometries of furrows and observed with photo-monitoring and aerial photos respectively. Even if quantitative soil loss information could not be generated within this project due to a lack of heavy rainfall during the research period, our multi-methodological approach provides comprehensive information on the effect of the Dyker for scientists. In addition, it is also useful for farmers who want to reduce soil erosion on potato fields, and policymakers who need to understand the impact of these conservation measures to adapt policies to prevent soil degradation.
The case study area of Frienisberg, located in the Swiss Plateau, is characterized by moderate hill slopes with altitudes ranging from 475 to 720 m. The study area lies in the moderate climate zone with an annual average temperature of approximately 8.5°C and an annual precipitation range from 1,000 mm to 1,150 mm. Collected hydroclimate data show that precipitation varies greatly within the study area. During the potato growing periods in 2016 and 2017, the highest measured daily (24h) amount of precipitation was 39 mm and 29mm respectively. During winter and early spring, melting snow can contribute to erosion.
The geology of the study area is mainly made up of last glacial till. These stony to sandy deposits cover in variable thickness Miocene Molasse dominated by sandstone and marl, which crop out at steeper slopes. Late glacial to Early Holocene slope deposits of a few decimetres in thickness, dominated by silt, and mixed with local material are widespread and can reach 1 m thickness in cryogenic pockets (Mailänder and Veit, 2001; Veit et al., 2017). Millenia of land use have partly moved erodible silty loams, leading to their accumulation downslope and in depressions. Most soils in the stratified parent materials are Cambisols and Luvisols. These are mostly sandy to silty loams with variable stone content, which have been rated as having moderate to high erodibility (Prasuhn and Grünig, 2001).

In the study area there are 189 farms managing a total of 2,632 ha of arable fields, which make up the dominant land use type in the Swiss Plateau. The predominant family farms apply mixed farming methods of growing crops and keeping livestock. Prasuhn (2011) investigated 203 arable fields in the region with a total area of 265 ha, reporting a mean slope of 6.5% (range 1-25%) and a mean slope length of 68 m (range 15-210 m). Crop rotations are versatile and mostly have a high proportion of temporary grass-clover mixtures: 40% is planted with cereals and rapeseed, 37% with root and tuber crops, and 20% with temporary leys (grass-clover mixtures). Winter intercrops are widespread; 90% of the arable land is covered with either intercrops or regular crops over winter (Prasuhn, 2011).

As test plots we selected potato fields of different shapes, with slopes > 5% or depressions (Figure 1). Due to crop rotation, different test plots had to be selected for the two years of research. In 2016 the Dyker was tested on three test plots, and in 2017 on four. An additional experimental plot was set up for some experiments outside the growing period. The potential erosion risk of the test plots was determined from the erosion risk map of Switzerland (Prasuhn et al., 2013). It is a product of the slope length and steepness factor (LS-Factor), the Soil erodibility factor (K-factor), and the rainfall erosivity factor (R-factor) of the Revised Universal Soil Loss Equation (RUSLE) and multiple flow algorithms in a 2x2 m raster. The numbers calculated with the erosion risk are all much higher than in reality, because the soil cultivation (c-factor) has been excluded and incorporated as a constant with the value of 1 (Prasuhn et al., 2013). Plot 4 shows a low potential erosion risk and is relatively homogenous, while plots 1, 5, and 6 show a large spatial heterogeneity and have a medium potential erosion risk. Plots 2, 3, and 7 have a high potential erosion risk with a large spatial heterogeneity (see Figure 1 and Table 1).

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3 Materials and methods

3.1. Experimental design and treatment

To assess the impact of the Dyker on the soil surface structure and the infiltration behaviour on potato fields, seven test plots and one experimental plot were selected (see above). On all test plots the furrows were alternately treated/not treated with the Dyker. To compare the structure of soil surface and the resulting infiltration processes in the furrows, the plots were divided into sections according to slope (flat, gentle, moderate, and strong), slope shape (concave, convex, and linear) and furrow placement (along the contour or across the contour). Observations and data from all test plots, including cross-sectional measurements of the furrows and visual observations, are available. But to illustrate the findings of this study, this paper mainly presents the results from test plot 2 (Figure 2) and test plot 3 (Figure 7), which are representative for the whole study area. In addition to the test plots an experimental plot was set up with treated and untreated furrows, where the dye tracer experiment was carried out outside the growing period and without destroying planted potatoes.
3.2. Field data and sample collection

**Dye tracer experiment**

To investigate the changing subsoil infiltration behaviour, the water movement during infiltration was studied on the experimental plot with a dye tracer experiment on treated and untreated areas with a size of 1 m$^2$ each. Dye tracer experiments provide qualitative pictures to show infiltration behaviour and flow pathways in the different soil layers (Alaoui and Goetz, 2008). For each of the two experimental areas (1 m$^2$), we prepared 80 l of tracer solution with ordinary tap water and “Sanolin Blue AE90” with a concentration of 4 g/l (Alaoui and Goetz, 2008; Weiler and Naef, 2003). To simulate high-intensity rainfall for wet conditions, the 80 mm of water was sprinkled within one hour. 24h later, four vertical soil sections were prepared every 25cm for surveying dye patterns and infiltration behaviour in the treated and untreated furrows. For photo analysis, the “BMPtool” image analysis software (Anken et al., 1999) was used to classify and quantify the stained/not stained pixels.

**Furrow cross-sectional measurement**

To compare soil erosion and soil accumulation in the treated and untreated furrows, the geometry of the furrow cross-sections was measured with a horizontal meter lying on the dams and a vertical meter at a defined spacing (0, 17.5, 27.5, 37.5, 47.5, 57.5, and 75.0 cm). The furrows have a width of 75 cm. The cross-sections were measured every 5-50 m along selected furrows on the different plots. The distance of defined points depended on the complexity of the shape of the field. One point consists of the average of the measured cross-section of three adjoining furrows. Each treated furrow was measured twice (on the micro-dam and in the small hole) to obtain an average geometry of the cross-section. The measurements of the points were repeated three times during a growing period. As there was less erosive rainfall and less soil erosion in 2017 than in 2016, we used for this paper mainly data from 2016 to illustrate the results. To compare the overall changes over time of treated and untreated furrows, plot sections with the same slopes on different plots were combined to an average cross-section. To analyse more detailed erosion and accumulation processes, the cross-sections of adjacent treated and untreated furrows of a specific plot section were combined to an average treated and untreated cross-section, e.g. for every 10 m of a slope.

**Visual observations**

To document erosion and accumulation features and waterlogging, the plots were monitored with aerial photographs from the eBee drone from senseFly, Switzerland. These overview photos enabled us to identify, document, and analyse different sections of the plots with waterlogging processes, soil accumulations, and crop failures.

Photographs from the ground were taken for systematic documentation of soil erosion and accumulation processes and their influencing factors (Bosshart, 1997). Photo monitoring was occasionally conducted randomly and photographs were taken at hotspots and whenever a remarkable event occurred (Ledermann et al., 2010). Consequently, sections of fields showing soil erosion or accumulation processes were monitored with a series of photographs throughout the growing period.

**Soil sampling**

Soil erosion studies focus mainly on factors and processes along the surface, while soils are usually not described and analysed in detail. During the tracer experiment, it became clear that both tested
soils are Luvisols, but with different properties. Soil profiles of 1 m depth were dug 15 cm behind the
last profile of each tracer experiment and described in the field according to the German soil
mapping instructions (Eckelmann et al., 2005) and FAO standards (FAO, 2006). To determine the
permeability, five undisturbed samples from three representative horizons of the two profiles
(un-treated and treated profile) were taken by hammering 4 cm-high core cylinders of 100 ml volume
vertically into horizontal planes dug into the sections. Sampling positions are within and below the
dams (Figure 6), as we expected a very high structural variability in the treated furrow, which makes
it impossible to quantify $k_f$ values representing the respective horizons. According to the ÖNORM L
1065 (Österreichisches Normungsinstitut, 2006), a minimum of five samples is necessary to
determine permeability, because of the high variability of $k_f$ values in soil.

3.3. Laboratory analyses

Permeability analyses were done in accordance with ÖNORM L 1065 (Österreichisches
Normungsinstitut, 2006) in the Physical Geography laboratory of the University of Vienna, one day
after sampling. After carefully watering the fresh core samples in a water basin for 24-48 h to release
the remaining air by capillary flow from below, the samples were mounted into the 09.02 Laboratory
Permeameter by Eijkelkamp (Eijkelkamp Agrisearch Equipment, 2013). The slightly higher water
column in the basin compared to the sample in the core cylinder holder results in waterflow through
the sample in the direction of the natural flow. Measurements of water volume (up to 40 ml) per
time (up to 600 s) or vice versa were done four times during 1.5 h ($t = 0, 30, 60, 90 \text{ min}$). To calculate
the permeability $k_f$ in m/s, we used the following formula according to ÖNORM L 1065
(Österreichisches Normungsinstitut, 2006):

$$ k_f \left[ \frac{\text{m}}{\text{s}} \right] = \frac{V \left[ \text{m}^3 \right] \times t \left[ \text{m} \right]}{A \left[ \text{m}^2 \right] \times t \left[ \text{s} \right] \times h \left[ \text{m} \right]} $$

(1)

where $V$ is the water volume, $l$ the length of the sample, i.e. of the height of the core cylinder (0.04
m), $A$ the area of flow (0.025 m$^2$), $t$ the time, and $h$ the water level difference between sample space
and water basin. Although the reproducibility of the results per increment was good, a few clear
outliers within the four measurements of each sample had to be excluded, mainly because of
operational errors during the first measurement or the tendency of (very few) samples to block the
flow during the end of the experiment.
4 Results

4.1. Treatment effectiveness on soil surface structure

Figure 3: The Dyker in use with an all-in-one potato planter (left); treated and untreated furrows after plantation (right)

The inclined shovels of the Dyker have a length of 35 cm. Attached to the rear end of the planting machine, the shovels of the Dyker dig holes every 80 cm into the bottom of the furrows. The Dyker also piles up soil, which then acts as a micro-dam along the furrows between the potato hills. Compared to a compacted and smooth untreated furrow, the treated furrow shows a loose uneven soil surface (see Figure 3). This uneven soil surface structure decreases surface runoff and increases infiltration. The holes enable water to be stored evenly over the whole field. In addition, water better infiltrates the soil because the shovels of the Dyker reach below the ploughed horizon (see section 4.2). During the growing period, the damming effect of the holes and micro-dams diminishes. This is because the holes become filled up with sediment eroded from the dams and, in steeper areas, with sediment eroded from the upper part of the furrows (see section 4.3). The sedimentation processes depend among others on the amount and intensity of rainfall and the slope and shape of the plots. The change of the soil surface structure over time varies, therefore, between the different plots and sections within the plots.

4.2. Treatment effectiveness in terms of infiltration

Ground and aerial photos to monitor the surface drainage behaviour of the different plots indicate an increase in infiltration in furrows where the Dyker was used. Evenly distributed over the plots, collected water in the small holes from the Dyker was apparent for a few hours after a rainfall event. In the smooth untreated furrows, no dammed water was visible because most water drained as surface runoff. Only in depressions, where surface runoff from the whole plot stagnated, surface water was visible in untreated furrows for several days due to oversaturation of the soil (see section 4.3).

The below-ground observations with the dye tracer experiment showed considerable differences in infiltration behaviour between the treated and untreated furrows. The blue stains (dye tracer) in the untreated profiles are distributed almost evenly in the top 15 cm of every profile. Slightly higher colour intensity can be observed below the potato hills due to looser soil. In the treated profile, the blue stains in the potato hills show a similar pattern to the untreated profile, but the intensity of the colour below the furrow is higher and varies in depth in every profile. 0 cm and 25 cm profiles are located close to the micro-dam – and 50 cm and 75 cm are located in small holes in the treated furrow.
In the 0 cm and 25 cm profiles of the treated furrows, coloured stains are visible only slightly below the Ap horizon and only below the furrows. By contrast, in the 50 cm and 75 cm treated profiles, blue stains can be observed deep in the dense EBl and Bt horizon (see Figure 4). In the untreated profile of Figure 5, 21% of the area of the profile is coloured blue, while in the treated profile 33% of the profile contains blue-coloured soil. But especially between 20 cm and 40 cm so as between 40 cm and 60 cm the percentage of the coloured area is much higher in the treated (42% and 8%) than in...
the untreated profile (14% and <1%) (see Figure 5). This is caused by the dammed water on the soil surface and the shovels of the Dyker penetrating the Ap horizon. More water is available for infiltration and due to the penetrated Ap horizon, infiltrated water reaches a network of macropores comprising root and earthworm channels, which enabled the water to infiltrate into the unploughed EBt and Bt horizons. Blue stains can also be observed along the plough horizon between the Ap horizon and the compacted EBt horizon (40 cm below the surface of the potato hill). That shows how infiltrated water can also reach the interior of the potato hill, where the potatoes are planted. Another interesting observation is that in the centre of the Dyker impact, there is no infiltration into the deeper horizons. A plausible explanation for this is a local compaction through the tip of the Dyker shovels.

Figure 5: Infiltration behaviour below untreated and treated furrows with the share of blue-coloured soil. Photos processed with “BMPtool” (Anken et al., 1999)

The treated and untreated profiles are located less than 6 m apart. The two profiles investigated 15 cm behind the two dye tracer plots (see Figure 6) have an overall loamy texture and correspond to Luvisols, due to the widespread occurrence of clay coatings on aggregate surfaces and an expected high cation exchange capacity and base saturation (IUSS working group WRB 2014), which is typical for soils of the region (Mailänder & Veit 2001). Both Ap horizons of the studied profiles are very similar in their properties, due to the intensive agricultural mixing of the topsoil. Also, the first horizon below the plough line is comparable in colour and texture, yet barely present in the untreated profile. This horizon is a transitional EBt horizon that may correspond to a colluvial layer (M horizon) due to its partly inhomogeneous appearance. Despite their close location, there are significant differences within the subsoils: The untreated profile is stonier and has a higher sand content, which corresponds to the last glacial moraine as parent material. The profile with Dyker treatment (treated profile) is still dominated by a silt-loam texture, probably due to the presence of a cryogenic pocket with a higher amount of aeolian silt (Veit et al. 2017). But the results of permeability measurements (Figure 6 and Table 2) show that the advanced infiltration into the treated profile is not related to the soil properties. On the contrary, most samples from the treated profile have a lower permeability compared to the untreated profile. The large variation of permeability in several samples corresponds to the presence of root channels. Differences in the Ap horizons are probably related to differences in compaction during the preparation of the field.
Figure 6: Descriptions and results of permeability measurements of the two soil profiles 15 cm behind the Dyker experimental plot (the blue pigment originates from the dye tracer experiment nearby and can be ignored).

The results of permeability measurements are listed in Table 2 and visualized in Figure 6 using a negative logarithmic scale. The results vary considerably in most horizons, except the treated EBt horizon and to some extent the treated 2Bt1 horizon, which both have kf values partly below 10^{-6} m/s. Such values are reached by three samples of the untreated Ap horizons. The Ap horizon of the treated profile has overall much higher permeability values (10^{-3} to 10^{-5} m/s). The subsoil horizons of the untreated profile have slightly lower kf values and higher variability than those of the treated profile. Overall, the permeability of the untreated profile is slightly higher than the treated profile, with the exception of the very variable Ap horizon. In the field and in the lab, strong differences in compaction could be observed, which may be related to the highly dynamic construction of the dams during the planting process. Variations down profile are related to the presence of channels created by roots or by faunal activity, an effect visible during the analysis.

Table 2: kf (m/s) from representative horizons of the two profiles behind the Dyker experimental plot, each sampled with five core cylinders. Sampling positions and data visualization in Figure 6

<table>
<thead>
<tr>
<th>Sample</th>
<th>No. of core cylinder (1-5) and kf (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>untreated Ap</td>
<td>8.1E-07</td>
</tr>
<tr>
<td>untreated EBr</td>
<td>1.4E-04</td>
</tr>
<tr>
<td>untreated 2Bt2</td>
<td>1.6E-06</td>
</tr>
<tr>
<td>treated Ap</td>
<td>1.5E-05</td>
</tr>
<tr>
<td>treated EBr</td>
<td>1.0E-06</td>
</tr>
<tr>
<td>treated 2Bt1</td>
<td>8.7E-07</td>
</tr>
</tbody>
</table>
4.3. Treatment effectiveness in terms of soil erosion and waterlogging

The cross-sectional geometry of treated furrows differs from that of untreated furrows. While untreated furrows are smooth and compact after plantation, the shovels of the Dyker create holes and micro-dams within the treated furrow. Observations showed that first rainfall events erode soils from the potato hills into the furrows, but that the treated and untreated furrows behave differently regarding surface runoff and transportation and erosion of soil.

Figure 7 shows that after plantation, the average cross-sectional area of all furrows are similar, even if there are differences along the treated furrows in terms of holes and micro-dams. In steep plot sections, the cross-sections of untreated furrows increase faster over time than treated furrows. Between the first and the second measurement, the plot received 278 mm of precipitation distributed over 13 rainfall events (> 5 mm) with a maximum rainfall intensity of 32 mm/24h. Within this period, the cross-sectional area of the untreated furrow increased on average by 27% (treated) and 30% (untreated) over the whole length of a 10-15% slope. While the untreated furrows increase their depth due to soil erosion at the bottom of the furrows, the change of the treated furrow can be explained through the decrease in micro-dams. In the treated furrows, big differences can be observed between the highest points in the furrow (micro-dam) and the lowest point (small hole). While the micro-dams slightly decrease in height during rainfall, the holes get filled up with sediment from the potato hills and the micro-dams. Between the second and the third measurement, 187 mm of precipitation occurred with a maximum daily precipitation of 39 mm. But less erosion was observed in this time period due to a higher vegetation cover. The cross-sectional area of the treated furrow remained almost the same, while the untreated furrow increased in depth. In the concave plot section at the end of the field, the cross-sectional area of untreated furrows decreased on average by almost 50% due to accumulation processes; the figure for treated furrows was on average 24%. But these processes vary on every plot, depending on vegetation cover, slope (incline, length, and shape), furrow placement, and intensity and amount of rainfall.

![Figure 7](image.png)

Figure 7: Changing average cross-sectional area and shape of furrows in an erosion and accumulation area of the fields. The maximal standard deviation of treated and untreated cross-sectional area is 2.8 and 2.1 respectively.
Aerial photos show not only accumulation and erosion processes, but also water logging, where water in untreated furrows accumulates in a depression and can neither run off nor infiltrate, due to saturation excess. Figure 8 shows in section 2 of test plot 3 stagnant water in untreated furrows coming from section 1 and section 3, while the water in treated furrows is distributed over the whole field in the small holes. In the depression, the stagnant water leads to anaerobic conditions where potato plants are not able to grow. Therefore, no plants are visible on the potato hills between the untreated furrows in section 2 of Figure 8. But in the treated furrows, rainfall is evenly distributed over the field in the small holes where it infiltrates within a few hours. No serious water logging can be observed in the treated furrows and no crop failure occurred.

Figure 8: Aerial photo of test plot 3 with a depression (section 2) where in untreated furrows the water from section 1 and section 3 is flowing together and accumulating
5. Discussion

5.1 Treatment effectiveness in terms of infiltration

The study showed that in the area of Frienisberg, the Dyker is changing the soil surface structure in the furrows of potato fields and increasing infiltration even below the Ap horizon. Even if the subsoils of the two profiles used for the dye tracer experiment differ, both soil profiles have a medium to low permeability due to the compaction of the loamy substrate by heavy machines. As visible from the dye tracer experiment, effective infiltration takes place preferentially in medium to large channels created by roots and faunal activity. From our observations, we can assume that a positive effect of the Dyker is the breakup of the Ap boundary and the opening of the soil pore network to infiltration. Higher infiltration rates can in addition be explained by the presence of looser soil in the treated furrows (because soil was thrown upside down by the shovels of the Dyker), and by the micro-dams (which dam water on the soil surface for local infiltration). In the study area, where most fields have a compacted plough horizon, the effect of the hole is crucial, and is missing when using other micro-dam-techniques like the Barbutte, which “pulls” the soil for building micro-dams without digging holes into the furrows (Olivier et al., 2014).

5.2 Treatment effectiveness in terms of soil erosion and waterlogging

As a result of increased infiltration, we observed less surface runoff in treated furrows, an effect which could, however, not be quantified. Previous studies have shown that with the Dyker, surface runoff could be reduced significantly (Olivier et al., 2012) and that in a rainfall simulation test with precipitation rates from 50 to 100 l/m²/h, hardly any surface runoff occurred in furrows with micro-dams compared to untreated furrows, where 14-52% of precipitation drained as surface runoff (Aurbacher et al., 2012; Billen and Aurbacher, 2007). As a result, less soil is eroded and accumulates in the furrows. But because most intense rainfall events missed the test plots, and the highest measured daily (24h) amount of precipitation was 39 mm in 2016 and only 29 mm in 2017 in the growing periods during the two years of research, no heavy soil erosion occurred on the observed plots and only small differences in the cross-sections of the furrows could be measured. Therefore, the measurements could not be used for reliable quantification of soil erosion, even if erosion and accumulation features could be shown with visual observations (see Figure 9). Not only the amount of rainfall was a limiting factor, but also the temporal occurrence of rainfall within the growing season. For planned quantification, we also generated a digital elevation model (DEM) with a horizontal and vertical resolution of 2 cm to compare two DEMs of the same plot, one before a rainstorm and one after a rainstorm, to calculate the eroded and accumulated soil in the furrows of the different plot sections. Unfortunately, the first rainstorm occurred in both years after the potato plants reached the surface, making it impossible to generate a second DEM for soil erosion and accumulation quantifications. Nevertheless, it could be shown that at the beginning of the growing period, when there is little or no vegetation cover, soil erosion mainly occurred on untreated furrows, while the small holes in the treated furrows retained eroded sediments from the potato hills and the micro-dams. But later in the growing period, when the effectiveness of the soil surface structure in the treated furrows diminished, the vegetation cover increased and the erodibility of the plots decreased (Gyssels et al., 2005). Therefore, the changed surface soil structure through the Dyker has to be efficient at the beginning of the growing period, when there is only little vegetation cover. Other studies tried to quantify soil erosion with collector funnel trays, but due to overflow of
the container, soil loss during intensive rainfall could not be measured properly (Jaunin, 2016; Olivier et al., 2014). Nevertheless, a reported reduction in soil loss of at least 66% (Olivier et al., 2014), 75% (Jaunin, 2016), or 88% (Mayer et al., 2016; Olivier et al., 2012) show the potentials of micro-dams in the furrows of potato fields. Vacek et al. (2015) reported that the soil control effect of holes and micro-dams depend on the time of occurrence, the amount and the intensity of rainfall and varies between 74% and 88% in terms of soil loss reduction.

Figure 9: Accumulation area of treated and untreated furrows in plot 2, section 5 (40 days after plantation with a total of 252 mm of precipitation)

In addition to reduced soil erosion, increased infiltration, and reduced surface runoff, the Dyker can also prevent water logging on gentle to moderate slopes with small to moderate rainfall intensities. Within this study, it was not possible to quantify the effectiveness of the Dyker, but an example showed that less water accumulates in depressions of Dyker-treated fields, as the water can be retained in the small holes between the micro-dams in the furrows over the whole field. This effect is not only important for plant growing but also for soil erosion. Large erosion damages on or from potato fields are mainly caused by overflow of the furrow or by a broken dam in a depression (Prasuhn, 2012). With only a gentle slope, overflowing water fills the next furrow and breaks the next dam, and more and more water from all the furrows drain across the furrows in the direction of the slope. This can also be avoided with the Dyker, because precipitation is collected in the small holes over the whole field.

5.3 Overall discussion

Even if the effect of the Dyker on infiltration, soil erosion, and water logging is made visible and is obvious for famers involved, general quantification and limitation of the effectiveness is challenging. Many different parameters – such as slope, weather, vegetation cover, or soil – influence infiltration and runoff processes, making results condition-specific. With our multi-methodological approach, we were able to show the positive effects of the Dyker on infiltration, soil erosion, and water logging. But due to unforeseen weather conditions and missing heavy rainfall during our research period, we were unable to quantify e.g. the amount of reduced soil loss for different slopes or different rainfall patterns. Further, it is not clear to what level of slope and rainfall intensity the holes and micro-dams show a sufficient effect and reduce surface runoff and soil erosion. It can be assumed that on steep slopes or with heavy rainfall, the small holes can be filled and the micro-dams can break, resulting in erosion damage. In this respect, the Dyker is a promising technique to reduce surface runoff and soil erosion on gentle to moderate slopes with small to moderate rainfall intensities. Nevertheless, slope and precipitation are still limiting factors for potato cultivation.
4 Conclusions

This study used a multi-methodological approach to show how the Dyker changes soil surface structure and increases infiltration, thereby reducing soil erosion and preventing waterlogging. Analysis of infiltration with a tracer experiment showed that in furrows treated with the Dyker, water infiltrates even below the compact plough horizon into a network of macropores comprising root and earthworm channels in the B horizon. By contrast, in untreated furrows a high share of water drained as surface runoff without infiltrating into the B horizon. This result indicated that even on intensively cultivated plots with compacted soils and a plough horizon, infiltration can be drastically increased with a combination of holes and micro-dams between the potato hills.

Higher infiltration rates and deep infiltration lead to a better spatial and temporal distribution of soil moisture, reducing water oversaturation and water scarcity for growing row crops. A reduction in soil erosion processes was observed on slopes of up to 15% and precipitation events of up to 40 mm/year. But this study has no evidence for the limits of the Dyker regarding slope and rainfall amount and intensity, even if it is obvious that after a certain threshold of these parameters the effectiveness of the Dyker diminishes, and that soil erosion and water logging also occur in furrows treated with the Dyker. In this respect, the Dyker is a promising technique to reduce surface runoff and soil erosion on gentle to moderate slopes with small to moderate rainfall intensities. However, even with the Dyker, selection of fields appropriate to potato cultivation in terms of slope and slope shape is key. These findings can help farmers to reduce soil erosion and soil compaction with new and innovative conservation measures; agricultural equipment companies to improve micro-dam-techniques; and policymakers to adapt policies to prevent soil degradation in the cultivation of row-crops.

Acknowledgements

The research leading to these results received funding from the European Union Seventh Framework Programme (FP7/2007–2013) under grant agreement No. 603498 (RECARE project). The authors wish to thank the farmers involved, for their support during fieldwork and for sharing their knowledge. Further, we are grateful to Robert Peticzka (University of Vienna) for allowing and discussing the use of the permeameter of the Physical Geography Laboratory, University of Vienna, as well as to Christa Hermann for technical support during the analyses. Finally, we thank Tina Hirschbuehl of CDE for editing this article.
References


491  Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall, Hennef, Germany.


514  Eijkelkamp Agrisearch Equipment, 2013. 09.02 Labor-Permeameters (Gebrauchsanweisung).


FIWAP, n.d. Stop au ruissellement! Le cloisonnement des interbuttes en culture de pomme de terre: une technique de lutte efficace contre le ruissellement et l’érosion!


The effect of the Dyker on infiltration, soil erosion, and waterlogging on conventionally farmed potato fields in the Swiss Plateau

Table 1: Potential risk of soil erosion on selected test and experimental plots, based on the soil erosion risk map of Switzerland with a 2 m × 2 m grid (Prasuhn et al., 2013).

<table>
<thead>
<tr>
<th>Sites</th>
<th>Area (ha)</th>
<th>Potential soil loss mean t/ha/year</th>
<th>Potential soil loss Std. dev. t/ha/year</th>
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<tr>
<td>1</td>
<td>2.7</td>
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<td>2</td>
<td>0.5</td>
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<tr>
<td>EP</td>
<td>0.2</td>
<td>57.9</td>
<td>33.0</td>
</tr>
</tbody>
</table>

Table 2: kf (m/s) from representative horizons of the two profiles behind the Dyker experimental plot, each sampled with five core cylinders. Sampling positions and data visualization in Error! Reference source not found.

<table>
<thead>
<tr>
<th>Sample</th>
<th>No. of core cylinder (1-5) and kf (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>untreated Ap</td>
<td>1.0E-06 8.1E-07 2.5E-05 4.8E-07 4.7E-04 7.4E-07</td>
</tr>
<tr>
<td>untreated EBT</td>
<td>1.4E-04 1.2E-05 1.2E-06 1.1E-06 6.4E-06</td>
</tr>
<tr>
<td>untreated 2BT2</td>
<td>1.6E-06 9.3E-07 2.2E-05 2.4E-06 n.d.</td>
</tr>
<tr>
<td>treated Ap</td>
<td>1.5E-05 n.d. 4.9E-04 9.2E-04 8.8E-05</td>
</tr>
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<td>treated EBT</td>
<td>1.0E-06 5.9E-07 5.3E-07 1.6E-06 8.0E-07</td>
</tr>
<tr>
<td>treated 2BT1</td>
<td>8.7E-07 8.7E-07 4.1E-06 1.3E-06 9.4E-07</td>
</tr>
</tbody>
</table>
Figure 7
Click here to download high resolution image

Section 1: Gentle slope (2-5%)
Section 2: Depression (concave)
Section 3: Gentle slope (2-5%)
Figure 8

Erosion area and concave slope shape

- Linear slope shape
- 10-15% slope
- Furrow placement across the contour

Plantation

Cross-sectional area (average of 15 points):
- Treated: 538 cm²
- Untreated: 534 cm²

45 days after plantation (+ 278 mm rainfall)

Cross-sectional area (average of 15 points):
- Treated: 684 cm²
- Untreated: 696 cm²

90 days after plantation (+ 466 mm rainfall)

Cross-sectional area (average of 15 points):
- Treated: 670 cm²
- Untreated: 770 cm²

Accumulation area and concave slope shape

- Concave slope shape
- 2-5% slope
- Furrow placement across the contour

Cross-sectional area (average of 3 points):
- Treated: 538 cm²
- Untreated: 579 cm²

Cross-sectional area (average of 3 points):
- Treated: 596 cm²
- Untreated: 770 cm²

Cross-sectional area (average of 3 points):
- Treated: 406 cm²
- Untreated: 300 cm²
untreated furrows

treated furrows
The effect of the Dyker on infiltration, soil erosion, and waterlogging on conventionally farmed potato fields in the Swiss Plateau

Figure 1: Overview of the study area in the Frienisberg region and the test plots with the specific erosion risk.

Figure 2: Experimental design of test plot 2 (2016)

Figure 3: The Dyker in use with an all-in-one potato planter (left); treated and untreated furrows after plantation (right)

Figure 4: Treated and untreated profiles of the dye tracer experiment with the soil horizons (FAO, 2006) and the profile depth

Figure 5: Infiltration behaviour below untreated and treated furrows with the share of blue-coloured soil. Photos processed with “BMPtool” (Anken et al., 1999)

Figure 6: Descriptions and results of permeability measurements of the two soil profiles 15 cm behind the Dyker experimental plot (the blue pigment originates from the dye tracer experiment nearby and can be ignored).

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Figure 9: Accumulation area of treated and untreated furrows in plot 2, section 5 (40 days after plantation with a total of 252 mm of precipitation)
Title: The effectiveness of two contrasting mulch application rates to reduce post-fire erosion in a Portuguese eucalypt plantation

Article Type: VSI: Testing soil conservation

Keywords: wildfire; post-fire soil erosion; erosion mitigation; forest logging residue mulching; eucalypt plantation;

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Abstract: Wildfires are well-known to increase runoff and erosion during the initial stages of the window-of-disturbance, and mulching has been widely documented to effectively minimize this impact. However, the relationship of mulch application rate with erosion reduction is poorly studied, in spite of its potential importance for optimizing mulching costs and efforts per ha. Therefore, a field experiment was carried out in a recently burnt eucalypt plantation in Central Portugal that had been burnt by a moderate severity fire during August 2015, comparing mineral soil losses and organic matter losses from three untreated 2 m x 8 m erosion plots with losses from six plots mulched with eucalypt logging residues at two contrasting rates of either 2.6 or 8.0 Mg ha\(^{-1}\). The two mulching treatments resulted in the targeted litter covers of 50 and 79 %, and these covers hardly changed over the ensuing year. Over this first post-fire year, the mulched plots produced significantly less mineral soil as well as organic matter losses than the untreated plots. At the same time, the plots with the high mulching rate lost consistently less sediments and organic matter than the plots with the low mulching rate but the differences were not statistically significant over all measurement periods. Total sediment losses over the first post-fire year were, on average, 86 and 96 % lower following mulching at 2.6 and 8.0 Mg ha\(^{-1}\), dropping from 8.0 Mg ha\(^{-1}\) y\(^{-1}\) to values around and well-below (1/3) of the widely-accepted threshold of tolerable soil loss of 1 Mg ha\(^{-1}\) y\(^{-1}\). If this threshold value is acceptable to land managers, they could treat a three times larger area with the same amount of mulch.
Graphical Abstract

Treatments immediately after wildfire

- Untreated (0% cover)
- Mulched with 2.6 Mg/ha (50% cover)
- Mulched with 8.0 Mg/ha (70% cover)

Sediment losses over the first post-fire year

- 8.0 Mg/ha
- 1.1 Mg/ha (86% erosion reduction)
- 0.3 Mg/ha (96% erosion reduction)
The efficacy of two mulching application rates was post-fires in a Portuguese eucalypt plantation. J. J. Vieitez-Peleayo, O. Compo, I. Antene, S.A. Prats, CESAC, Center for Environmental Studies, E-Hydro Laboratory & Ethanol Processes Team, Department of Environment and Planning, Ministry of Agriculture, 3810-193 Aveiro, Portugal.

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Abstract

Wildfires are well-known sources of off-site dust and mulching has been widely used to minimize this impact. However, mulching with poorer spread, in spite of its potential importance for optimizing mulching as well as for phytosanitary reasons, the experiment was carried out on a eucalypt plantation in Cal Porgal, burnt by wildfires during August 2015, comparing mineralized soil and organic matter from untreated 2 m x 8 m plots with mulch from six plots with eucalypt ginning residues at two application rates of 6 and 8.0 t ha-1. The two mulching treatments resulted in coverage rates of 50 and 79%, and significantly exceeded the first post-fire. Organic matter produced significantly more mineralized soil and organic matter than untreated plots. A second survey

Keywords: wildfires; soil erosion; forest logging residue; eucalypt plantation.
The EU-PROTEC (www.re-protec.eu) is oriented towards its objectives and donation, mitigating and monitoring measures against 11 soil threats across 15 countries with ongoing discussions through two dedicated workshops. In the Portuguese study, addressing the threat of soil erosion by wind, particularly following wind, much influenced from an initial set of national and non-governmental organizations and a network of local, national and non-governmental organizations, which was published for own and management as well as regulatory actions from local, national and non-governmental organizations. The study on family wood among forests in Portugal (Reirol et al., 2015) wild forest phenomenon in Portugal, they many other counties in southern Europe and across the climatic regions of sign and spread (Cred et al., 2016; Reirol et al., 2014; Sanagua and Caimia, 2009). In Portugal, wild forest affected, on average 100,000-110,000 hectares of rural lands, but much larger in emergency years such as 2003, 2005 and 2017 with 426,000-536,000 hectares (IC 2017). The study unprotected and possibly leading forest in Portugal over past decades largely used due to the spread of forests, not only from outdoor (Sant 2009) but also through land use schemes such as land and planning forest-pronounced as (Reirol et al., 2009; Reis et al., 2011; Vite et al., 2015).

Wild forests have frequently been producing and sometimes economically and hydrological and soil responses to reality burning, especially during the early stages of soils and key role of soil burning severity (Ceder et al., 2013; Reis et al., 2011; Vite et al., 2015). Better enhanced responses have been reported for especially prone types (Reis et al., 2016; Reis et al., 1993; Vieir et al., 2016). In loss of runoff and soil rates following wild forestally attributed to (partial) insufficient vegetation and also as hang-induced changes in soil properties and soil filtration changes and erosion, affecting soil water balance and grade stabilization (Cedro et al., 2005; Ceder et al., 2013; Taiar-ler et al., 2011; Reis, 2011).

A range of measures has been found for their effectiveness to mitigate post runoff and soil (Basta et al., 1996; Fernand et al., 2011; Robich et al., 2008, 2013; Wåhren et al., 2006). Robich et al. (2010) and Veg et al. (2009)
The study was designed to evaluate the suitability of mulching as a post-fire silvicultural measure, focusing on the role of mulching applications rates on post-fire soil properties, especially during the initial stages of forest recovery, i.e., wood and associated organic matter losses in particular, ground vegetation and soil moisture (the "mulch" application rate). (iv) Post-fire organic matter losses in particular, forest management settings.

The study was carried out in the Colmeias burned area, in a municipality in central Portugal. The fire occurred on 8 August 2015 and burned an area of 715 hectares (96%), in particular, Eucalyptus globulus L. plantations (ICNF, 2017). A post-fire E.I. (2015) resulted in moderate severity by forest classification, classified as moderate (Csb, medium to high). The climate of the area is mesothermal (Csb, medium to high).
4

With the burn, the provides Elyp g bu ois L hill. plantation on tee p (270), E  fig s sp was s ted as study s. Two important factors to study t w a l lar nes running in downs p tio n, possibly found imp o o of sms o n o v lan d f w r tio n a n d sim od o s  n, esp i e l y at tw o p p o of 2-3 y rs into os r o tatio n cy t th mi nimi ng e c a n c. savg g ing w ou k sp d u r th mo n ito r p sp d  d d r of sp (impo o of 1) sval g g ing on os w ��d ied �� s a m b u r n �� b y l v et al. (2017). Fir s ��� y at tw o s ��w ��s ��f f �� ��r oug v us so ii p ro f t th at w �� �� r at st �� o f �� �� at st �� b o tto m o f t h p lantatio n a n d dug up som e 5 m ups sp. All profiles w ��s t ated as up ��g g i n g o n os w ��d ied �� s a m b u r n �� b y l v et al. (2015) b u f ��  o bs v�� n s d ur l y Sep mb 2015 s ug �ted ��mo d ��� v e g ��� n as w e as so il b u r n s e v �� y. T h fo r m w as in dicate d b y p tial emb u s tio n of �� ��o w n s a n d ��a g e T w i g Dia m 0.4 (s M et al. 2012 ��b on me asu r e mts o f 3-5 shrubs n in st �� n �� p o �� a lon g �� a n s st  r u n n fr om t h b o tto m � e p o f ��p n tatio n ) , w h �� t h e  lat ter w as in dicate d b y co m p ii e m ent o f ��e �� �y an d ��e pr o mi n a n b �� ��r o f ��h ��y (s Sh e s b y a n d ��r, 2006). T h at is tw o os f tw at st �� d u th vi us so il p ro f  t h at w �� �� r at st �� o f �� �� at st �� b o tto m o f t h p lantatio n a n d d u g up som e 5 m ups sp. All profiles w ��s t ated as �� Umb ro o (I USS, 2014), imp r i n th i n (35 mm i c k) ��y o f a sh a n d p l an m�� �� 1 a n d Ah 2 h o r izo n s o f 1-4 0 , a n d C h o r izo n s o f p y w th p re-ad o vi s c h �ts o f ��sp ic s s if (P eir e f a t a k, 1995). Tw o os h a d �� b r o w n ��r (7.5 4) , ��y x r �� mo de ate f ��b ��y s u ba n g u lar s su i r e, ��p r i g in g fr om 4.6 4.8 da h s o ��r g a n ic matter in of �� �� s. 3.1. Ex ment a s n a n t a t t ment s Al mos on m on af ter th f �� (07 Sep tem b 2015) , ��tal o f n i n os n p w �� s���  at b o tto m p �� o f e p lan tatio n (f or r os o s s fr om f o r �k i mm ate l b elo w ) , d, as r or , b etw th ep lan n g n es. T h p p w �� d iv o v �� b ��s ��d, w ith �� b ��, t h t h p p w �� a s s i g n o n e  o f ��t h r � t me n �� r �d o m ma n n. E h p pw o x i m 2 m w e d 8 m n g, w b o un d � b y g tex le h eld u p r i g h t b y o d s tak e s a n d, at t h b o � o m o f e p t, b y stee r es, w b w a s p ro tec t e i n s � u p-r �n-o n b y �c h E h p pw u s me n ted a its u p p p w h o n e o r t wo so ii m ot u r,p ro b es(-5, u p-s pr u n-o n b y �c h E h p pw u s me n ted a its u p p p w h o n e o r t wo so ii m ot u r,p ro b es(-5, u p-s pr u n-o n b y �c h E h p pw u s me n ted a its u p p p w h o n e o r t wo so ii m ot u r,p ro b es(-5, u p-s pr u n-o n b y �c h E h p pw u s me n ted a its u p p p w h o n e o r t wo so ii m ot u r,p ro b es(-5,
Dec 30 2019, a grid of 2.5 m x 2.5 m was set up in 5 min intervals, whereas this study was summarized.

When two fertilizer rainfall gauges (house design) and two tipping-bucket rainfall gauges (ARG100, Campbell Scientific) were used, (HOBEP and Evg, SET).

15 Sep 2015, before our risk of yield from these red mulch piles were chipped in a reflective manner of books and twigs and leaves at a rate of 30 € per ast as they being mass energy plants. Before application, sieved 30 and then 4 cm meshes were excluded to the largest as we see this fraction, as the form may reduce variability and the latter experimentally less effective in reducing soil erosion (�� and Webb, 2010). Mulch was done by applying these uses homogeneously across plots at two application rates, i.e. ��� and d of 8 t ha-1 similar that found by trees may efficiently in reducing fires and fires in the region (Prat et al., 2012, 2014b, 2016a) and "run rate" of 2.6 Mg ha-1 that was found by hypo lab and laboratory simulations of simulated rainfall and runoff (Prats et al., 2017). Figure 1 illustrates a sample of two mulching rates shortly after their application.

3.2. Field data as sample collection

By Sep 2015 and Aug 2016, ���ods were sent on ��g text tiles at bottom of �� plots and collected at roughly weekly intervals, and so on our record of rainfall during each f, the volume of rainfall through the fertilizer gauges was measured. The ground evaporation which is monitored roughly monthly by taking non-water photos from breaks in the fixation in each plot (at 250 and �� quarter rates of �� per n).

3.3. Laboratory analysis

The collected samples were dried by mining the dry mass content through oven-drying at 105 ºC for 24 h (APHA, 2005). Absence, samples of organic matter content was done using a muffle furnace at 550 ºC for 4 h.

3.4. Analyzing

The samples of soil moisture probes were treated for probe-specific determination based on red gardens for four fluids with oof dielectric permittivity. These standard red gardens were converted into wet values per monitoring period. The ground evaporation was done by drawing a 1-m g of 10 cm by 12 cm

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4. Results
4.1 Treatment in terms of varied

4.1.1 Application of mulch in S
2015 produced insignificance in
2015, ranging from an average of 2
in the unmulched and mulch
percentages (Figure 2). The differ-
ences between unmulched and mulch
were slightly worse statistically.
The study, which had two application rates being signed in 2016. Even so, of the applications, both mulching treatments were below 10%.

Both mulch treatments were reviewed and compared to current patterns, drastically from September 2015 till June 2016 and even some at roughly 10%. This drop was noticeably faster in the case of sand than wood chips roughly -4 vs. -2 per month from September 2015 till June 2016. The litter after June 2016 was not used and was observed in unmulched plots.

4.2. Treatment impacts on non-edible variables:

soil type and soil moisture

Besides, sanded and sand soil treated was significantly effective over the entire study period (F: 59.4 vs. 45.3, respectively). In September 2015, sand soil treated from 37% to 23% 9 in the mulched and sanded respectively, while aged the same order, from 21 to 13% 7% (Figure 3). Over a few months, sand soil tend to some extent (minimum 24%) as well as wood chip with roughly -15% (minimum 15%), while being somewhat the same - sand mulching. Average sanded soil was lacking any significant variation which were respectively. By contrast, high-potential importal pattern that was significant for the treatment, generally up till maximum June 2016 dropping to some extent. This suggests that mulching hampers vegetation. In the meantime, minimum high-potential plan was high in untested plots and in unclean (52 vs. 38-42% sand, maximum moss was high in untested plots as it in 38-42% sand, respectively, 5 vs. 3 vs. 1%).

Topsoil volumetric moisture was significantly impacted by the treatment order as who. Also, average moisture was significantly high in the plots which had sand mulching and in the plots which had wood chip at roughly -3-4% of -3-4%. By contrast, significant differences typically responded to a volume of soil moisture of 3-4%. By contrast, significantly high differences were barely lacking, which was significantly high in two periods (September 2015 till April-June 2016). In these cases, topsoil was distinctly pattern for average soil moisture from untested to sand mulching in.
4.3. Treatment of tesserae of the principal till layer

Table 1: The significance of I30 on site indices over study period, while I30 soil moisture
10% over time, positive and high vegetation effective, negative effect (Table 1: The significance of I30 on site indices was not for 1 month following wild fire -1 for unsted period, 1.1 for period mulched at 0.3 ha-1 for post-fire period, while the study period ranked following wild fire at Chal station.

The monolayer site indices suggested the role of mulching (with content of first post-fire year, with used systematically from unsted to mulched stand mulching (Figure 5). The differences between water and no mulching was significant for 10% in the month period. When monthly rain fall exceeded 100 mm following wild fire and, at some maximum rain intensity 20 mm h-1 (Figure 4). The peak value was relatively more pronounced of unsted period and 39 as opposed to 22 of seed site indices over study period.

In the wet season significant differences in monthly site indices between mulching rates during September 2015 showed relatively the same during autumn and (spring) winter months (77-80 vs. 88-98%).

4.4. Treatment interests of soil organic matter site indices
The organic matter content of the soil varied somewhat between months, with smaller values for plots with mulching (17-23%) and unmulched plots (15-27%).

The monthly organic matter contents weakly linearly related with the monthly nitrogen contents for a period (P<0.98-0.99). Surprisingly, for plots with nitrogen, monthly statistical results for organic matter closely matched those of simulations (Table 1, Figure 7) and monthly patterns in the term effectiveness were so...

5. Discussion

5.1. Term effectiveness of principal components

The present results fit well with two principal findings of the laboratory study by Prat et al. (2017). They found that an overall mulching of 50% was sufficient in the fall runs (as produced by simulated runoff) but, at the same time, over 70% was highly effective, using surface runoff with 99%. The difference in effectiveness between Prat et al. (2017) and our study (94 vs. 86% and 96 vs. 99%) was surprisingly more, given the more species in the two studies' simulations as well-illustrated by the runoff of 250 ha of equipment "so and the study of Prats et al. (2017).

The present results were well within the findings of the principal components of the study region, which suggested that mulching with weekly pugging rates of roughly 10 ha yielded highly effective results in the equipment for the initial period of induced window-d-. Prat et al. (2012) found an 84% and effectiveness post-3 years in weekly rates at 8.7 ha, losing amounts of 5.4 and 0.7 ha, respectively, approximately 1 year precedingmulching. Possibly, some somewhat effective was due to some initially after mulching (70 vs. 79%) but later moment of the mulching (four months after the initial period, the effectiveness of "weeds" more than the present one was...
The authors found that micro-scale plots (0.5 m²) hydro-mulched at 11 ha⁻¹ produced 93% simethoxasone in post-fires compared to a similarly large-scale plot (roughly 100 m²) hydro-mulched at 14 ha⁻¹ producing 96% simethoxasone. Possibly, similarly, small-scale deforestation in point-wise efficiency in Forero et al. (2016) selected the role of size (associated with distance) as opposed to mulching application rates as the micro-scale plot had higher evaporation than mulching and large-scale plots (87 vs. 77 %) but, at similar production rates (9.5 vs. 4.6 ha⁻¹) Thoapkates of coarse-run were often good similar with extremely good results with immediately post-mulching in Galicia, northern-northern Portugal and similarly vegetable (Fernández and Veg 2014, 2016). Fernández and Veg (2014) found mulching at 3.5 ha⁻¹ resulted soil moisture with 87 %, whereas Fernández and Veg (2016) reported mulching at 11 ha⁻¹ hydro-mulched soil moisture with 84%. Worthington's results was further that the hydro-mulch application rate was sufficient to post-fire simethoxasone sessions within the bounds of provision of a value of smaller-scale plots of 1 ha⁻¹ prop by Verheij et al. (2009, 2012). Even so, a more ambivalent target may be proposed long-term sustainable yield in the north-northern Portuguese soils typically showed (et al., 2013; esbys, 2011; T-Wør et al., 2016) and chemicals likely to shorten run time (Codoj Pérez et al., 2006; Núñez et al., 2018). The proportion of minimum rain intensity over rainfall total in post-fire sessions was similar with the results of pre-planting burn similarly plantations in north-northern Portugal. In some of these, minimum rainfall intensity over 15 mm (I15) was often the same as for runoff amounts. It is assumed that I15 must be combined with micro- and large-scale plot data as (Perez et al., 2012) I15 proportionally larger part of the variation in sessions, while the opposite was true for runoff amounts. 5.2. Treatment is of the soil organic matter opposite sessions observed with two practices that are 'sand' and 'application rates of only poggio mulching in fire plantations in northern-northern Portugal. In some of these, hydro-mulch application at 88 % was much larger than mulch in unburnt plots, which was only used.
In spite of the low organic matter contents of the study plots (20-22%), mulch kg ha^-1 applied by Prates et al. (2012, 2016b) led to 1-1.5 years following wild fire. Thus, organically rich peatlands were used for eucalyptus plantations, with values ranging from 41% (Prates et al., 2012) to 46% (Prates et al., 2016b) and 56% (Prates et al., 2016b) for small-scale plots. In unmulched micro-scale plots, Prates et al. (2016) reported that nitrogen contents of approximately 50% of the plots were very low immediately after eucalyptus planting, possibly reflecting reduced pre-fire fuel masses as a result of unmanaged vegetation management in 2000-2011 and why the study plots of 2012 mulch kg ha^-1 plotted between 46 vs. 23%, significantly lower than the large-scale plots of Prates et al. (2016) 41 vs. 23% compared to the same magnitude (15-18%). By contrast, the unmulched plots of Prates et al. (2016b) mulched with 46% vs. 56% of the same order of magnitude (62 vs. 56%).

5.3. Overview

The results of this study constitute an important argument for further mulching in extremely high eucalyptus plantations, due to the predominant and, at same magnitude, as a result of pre-forestry management in the area from 1996 to 2017, as large-scale sites are not suitable alternatives to mulching with sawing rates of 2-3 ha^-1, mostly applied in post-forestry management in both A (Robichaud et al., 2010) and Galicia (Vega et al., 2013), i.e., application of sawing rates of 2-3 ha^-1 from field experiments such as Butta et al. (1996) and Fernández et al. (2011). Even so, large-scale application of eucalyptus sawing mulching should be detailed yield studies of all kinds of sawdust management, and in particular eucalyptus sawdust provision,
bodily and hormonal. Also, the adoption of post-megacy stabilization measures, in particular, mulching by plate down systems for forest management, has been taken for greater, in part, as a lack of familiarity with these methods. The was one of the key outcomes of the third workshop on the REC E study in Portugal, where the lack of familiarity (including their digital aspects) and their being presented as main barriers.

In summary, further recommend, under the circumstances, if mulch application rates through any high-forest. Laboratory results of Pret et al. (2017) did suggest that mulch sips highly effective, especially the use of (in turn, up) or other or for key plantations in northern Portugal.

6. Conclusion
The main outcomes of the study in terms of application rates of pines prevailed on as well as targeted and untargeted application rates of pines during the following:

- The mulching application of 8.0 ha-1 was found to be highly effective as the study provided whole duration of the initial, most rigorous months;
- The effective means of roughly 3-month low rates was found to be highly effective as opposed to the monthly simulation sips at roughly 3-months;
- The effects of both application rates were affected organically matter is expected to run-off closely matched versus total efficiency and more than 40 percent in the simulations.

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Refereces


B tis ta, S., B t, J., Vallejo, R H, P/14898016, r etiv y.

C doso P eir a, J., C reir, J., Sil v, J., Vasonc os, 2006. Un es intoc s b asico s s o b r o s f ugos r u r ais e m Portugal, : P eir e  J. S., Pe e  J. C. (Eds.), Insos s en Portugal: c eter c, ps p ro. I P r ess, L ob o, pp. 133.

C A., 2005. Infe n o of vetatio n rev y o n soil hyd r gy a nd sod ety follow ing e: 11-ye g e n. In ter national J. Wild lan d 14, 423–


A - C e n o – Dir  o R i o nal do b en te d o C oo, 1998. Plan o do b n te gr fo R i o 1 f as lis dis n o s d is itu o d r s b f A n e x o s. L ob o Portugal.

E IS, 2015. C ERCUS–Em g ec y en me nt Ser v e. http://ff.jr.orrop h r ysis subd e x.html (ss b 2015)

Fer n d, C., Jg J. A., 2014. Ef f e y of bk s and s au mulchng af ter wil f ed : Ef f e on o sl and v egetat 63, 50–57.

Fer n d, C., Jg J. A., Jim, E., n rbel, T., 2011. Ef f tiv e ns of tr pos t-f ed at r u n g s o il sod es G alicia ( ��n ). Int. J. Wild lan d 20, 104–

R. B., Wbr n , S., 2010. A n eval u a tion o f tr w ood shr blen ds for post–r u n sod en o l u s eg and o o si m u l ated r ain e n t on s mp p. C A T E N A. 80, 86–94.

ss n i M., n e y o , eues A. R., R its e m C., Geiss e n, J. J., 2017. Th short–te ef f e v e s s of surf n g mulch ing ut men ti n ru n f of sod s, Geodm 307, 231-237


Robich��, P. R., Ashmun, L. E., Cms, B., 2010. Post-rewet Technique Efficiency for Hills ronenln. i. T echnical R for R R-240. ����e of rewet er servies  Rocky Mountain Research


aka by, R. A., 2006. Wild fire hydrological and geomorphic agent. E��-i. R. 74, 269-��

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Figure 2
Figure 4
Figure 5

- no mulching
- reduced mulching
- standard mulching

[Graph showing data distribution over months from Sep/15 to Aug/16]
Figure 7
Figure Captions
Fig 8: Effective rates of two negative forest accumulation rates to monthly growth measures in Portugal for following model dates - vegetation wild
Abstract: Mountain depopulation in the Mediterranean over the past decades has led to a decline in the use and maintenance of agricultural terraces and consequently the collapsing of dry-stone walls, which increases soil erosion rates and downstream sedimentation. A field experiment has been set up on a degrading terraced slope in the Troodos Mountains of Cyprus, to quantify the effectiveness of terrace maintenance on protecting cultivated land against soil erosion. The monitored site is a mountain slope cultivated with grapes. The terrace riser (22-m long) that forms the linear outlet of the slope has 11.4-m of standing dry-stone wall and 10.6-m of collapsed wall. It has been instrumented with seven 1-m wide sediment traps, three on standing sections of the wall and four on collapsed sections. Sediment was collected from the traps after rainfall events, from December 2015 to November 2017. Uncertainties in the drainage areas of the 31.5-m long slope were quantified both for the terrace wall and for the individual traps through hydrologic delineations based on a detailed topographic survey. The sediment data were complemented by laser scanner surveys that were conducted in November 2015, May 2016 and April 2017, on a dry-stone terrace wall upslope from the outlet section. Wall degradation was assessed from the consecutive 3D model reconstructions. Rainfall was 469 mm in the first year and 515 mm in the second year and the average erosivity was 1148 MJ mm ha⁻¹ h⁻¹. The average soil erosion rate was 2.4 Mg ha⁻¹ y⁻¹ for the linear slope (693 m²) and 3.2 Mg ha⁻¹ y⁻¹, when considering the delineated drainage area (520 m²). Nearly half of the soil erosion (43%) occurred during two very intense rainfall events (maximum 30-min intensity exceeding 35 mm h⁻¹), out of the 34 monitored events. Erosion from standing terrace sections was 3.8 less than the erosion from the collapsed sections. For the scanned terrace wall, soil loss from the standing sections was 2.2 lower than from the degraded sections. The laser scanner surveys identified some preferential erosion paths, but failed to recognize single stone collapses, whereas possible wall displacement was masked by scanning artefacts. The sediment traps were found to be an effective method for understanding and quantifying soil erosion in terraced mountain
environments, while laser scanner surveys proved to be less ideal for this particular environment.
To: Dr. María Estela Nadal Romero  
Editor-in-Chief Catena  
Departamento de Geografía y Ordenacion del Territorio  
Universidad Zaragoza  
Spain

Milano, February 20th, 2018

Dear Dr. Nadal Romero,

I am submitting the enclosed manuscript on behalf of all the listed co-authors. I would be very grateful if you could consider it for publication in Catena as part of the special issue about testing soil conservation practices. In our study, we set up an experiment to monitor soil erosion by water in a mountain Mediterranean catchment located in Cyprus. We complement traditional sediment trap data with laser scanner surveys, to target not only soil loss but also dry-stone wall degradation. We think our study will be highly relevant for the readers of Catena and the above-mentioned special issue.

Kind regards

Corrado Camera
Title: Quantifying the effectiveness of mountain terraces on soil erosion protection with sediment traps and dry-stone wall laser scans

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Other files enclosed in the online submission:
Highlights.docx
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Tables.docx
Fig1.tif
Fig2.tif
Fig3.tif
Fig4.tif
Fig5.tif
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Quantifying the effectiveness of mountain terraces on soil erosion protection with sediment traps and dry-stone wall laser scans

Highlights (for review)
Title:

Quantify the effective sediment transport with sediment traps and laser scanner

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Abstract:

Mountains population in the Mediterranean is affected by coastal erosion, which easily leads to landsliding on slopes in the mountains of Cyprus. The study site is a cultivated land with grass. The terrace is silted, and the sediments have been collected and used for

Manuscript

Click here to view linked References
The sediment trapping was carried out for two years, from 2016 to 2017, to quantify both for a catchment area and for individual tracks through single and collective trap sections. The sediment trend was evaluated by a survey that considered the standing stock in 2016 and April 2017 on a yearly basis and compared the consequent data. Rainfall in the first year and in the second year and the erosivity were quantified at 48 MJ h⁻¹. The age of the trap sediments was 4 Mg ha⁻¹ yr⁻¹ for the traps and 2.2 Mg ha⁻¹ for the stands, representing less than 2% of the sediment collected. Erosion from standing sections was less than erosion from collapsed sections. After analysing the differences, it was identified some erosion threats, some of which were recognized as erosion from ponds where the displacement was masked by vegetation. These traps were found to be peculiar method for and to identify erosion from standing terraces. The method showed a less accurate environment.
1. Introduction

...
Due to extensive economic externalities found about in yards, authors (2016) published a comprehensive review in the category data set erosion in the Mediterranean Region. In doing so, authors quantitatively arise these issues investigated by many receptors (Becetti et al., 2017; Rodrigo-Comino et al., 2014) although these are scientific analysis are included, a topographical characteristic as conservation high for digital sensors and boom vis a innovations.

In the last decade, group-clas and case studies have been deeply analyzed in erosion assessment, due to growing capabilities, the extensive, accurate ground use. Acquis sampling and low-cost SfM techniques are extensive, accurate ground use. Acquis sampling and low-cost SfM techniques.

Studies that combined and low-cost SfM techniques (SfM) techniques for comparison. The authors (2016) compared both and extensive to cover. They found that these techniques are almost and comparable to each other on back. The changing in case topography and Bauart (2015) looked specifically at the change in TLS formulas, (TLS) study focused on the crucial sites (TLS) to determine the evolution of these sites and gullies (Las et al., 2014). The authors analyzed the effect of these sites and calculated more than compared to traditional measurement techniques especially on some and measurement Soil erosion assessment studied by Teatrial Laser Scanner and laboratory scale (Baugere-Pegoretti, 2017). No studies that apply agging techniques for erosion assessment, (ag) found...
The estimation with observation to analyze, lacking in terms of

2. Case study area and monitoring site

The site is in the 112-Pepona Watershed, on the steep slope the Troodos Mountains in Cyprus showing a landslide area to analyze to quantify amount of erosion by rain. Scientifically, it storing experiment, i) to compare erosion among non-organic (a and b group) and fully or partly collapsed clayey loam layer to quantify amount of erosion to analyze relations between erosion factors, infiltration erosivity and runoff to cement tradition erosion measures to eliminate curves degrading in all a.

The monitoring site is mountain cultivated with species, trees in mountain community as in the mountains. Soil analyze represents sample 0-15 cm and -30 cm, with values obtained to compare the sample at depth, with the initial command by Hoogsteede et al. Soil analyze with 1-unit test, values in one third of the monitoring site found to vary for water) to another (water) to more than one third slope extinction (water) to steep.15 cm small vegetation...
Fig. 1: Location of the Peristerona Watershed case study area and the Alona monitoring site. The images show the sediment traps used for capturing and measuring the eroded soil.
3 Materials and Methods

3.1 Experimental design and field data collection

...
3.1.1 Soil loss by sediment traps

Fig. 2: Scheme of the monitoring experiment.
3.1.2 Sediment trap drainage areas

3.1.3 Relations between soil loss, rainfall erosivity and intensity
3.1.4 Laser scanner surveys

Scans are made on the year-end to evaluate (e.g., displacements, detailed cuts). The survey covers 21.8 m by stone and terrace analysis. The main image area is measured to 3 m. To ensure the survey systems are comparable, a topographic network is installed to cover the whole year and seeds with a 3D system (Leica SS System, Leica SS GS10/GS15). Scans are performed at a phase-aerated laser (Surphaser® 25HSX, Irix), giving a range between -30 m and 3 m, and an uncertainty range lower than ±3 mm. In November 2015, laser scanner -3 m, with a horizontal solution of ±mm for each point cloud equivalent to 35 LP by 2016 and April 2017, in comparison to previous, necessary due to a leveler view over scanner, using in 2016 and April 2017.

3.2 Laboratory analyses

3.2.1 Soil loss by sediment traps

The sediment collected in traps for 16 years, 2014) and then lightened. The > 2 mm and < 2 mm are by 3D and lighted. The dry matter is adjusted to 100 °C and the porosity is size of P90 for the loss by 30 LP ±

..
3.3 Data analyses

3.3.1 Soil loss by sediment traps

\[ SL_{tot} = \sum SL_{dt} \frac{A_{dw}}{A_{dt}} + \sum SL_{st} \frac{A_{sw}}{A_{st}} \]

3.3.2 Drainage areas
3.3.3 Relations between soil loss, rainfall erosivity and intensity
3.3.4 Laser scanner surveys

Following acquisition of point clouds with CloudCompare V2.9 (Ope rations on point clouds with CloudCompare V2.9), the following steps were followed: i) segmentation of the point clouds to move vine edges and bushes (a point cloud segmented together since they were of the same time series), ii) a automatic alignment and simplification point clouds (satellite by each case) to a point to point accuracy (0.0007 m) for the three models; ii) a calculation between the point clouds at different times in May 2015 – May 2016 – May 2017) on a horizontal solution grid and visualization into a python script C-c loud was used to visually analyze to identify cloud on slopes and displacements, using cloud main erosion errors. The errors were calculated to highlight dimensions and values of the volumetric change by multiplication with pixels as. A and a control of volumetric change calculated to highlight points. For bulk sample a collected with 425-3 cm and a age bulk sample computed after drying and weighting. The average volume of the three samples cm-3. The accuracy between cloud and control to each cloud was to compare, especially the total change in the first year. Soil was estimated to amount to 0.1 Mg-1 while soil added each change Mg-1. The ratio between the control and standing water is 3.8, because of the control cloud.

4 Results

4.1 Treatment effectiveness on soil loss reduction

4.1.1 Soil loss by sediment traps
The standing wall sections showed a significant difference (p = 0.01) according to the measured variable. Figure 3 shows the amount of sediment collected at traps for degraded and standing wall sections, and over the full slope, per drainage area, for all collection events. Error bars represent maximum and minimum soil amounts collected at individual traps.
Table 1: Total soil loss, rainfall and erosivity for December 2015 – November 2016 and December 2016 – November 2017, per drainage area.

<table>
<thead>
<tr>
<th>Drainage Area</th>
<th>Total Soil Loss (Mg ha(^{-1}))</th>
<th>Rainfall (mm)</th>
<th>Erosivity (MJ mm ha(^{-1}) h(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Area</td>
<td>469.3</td>
<td>851</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>514.6</td>
<td>1200</td>
<td>4.0</td>
</tr>
</tbody>
</table>

4.1.2 Soil loss range derived from drainage areas

The soil loss range derived from drainage areas indicates the variability in soil erosion across different areas. The range varies from 2.6 to 73.6 m\(^2\) for traps on standing water, and 2.3 to 70.0 m\(^2\) for traps on standing water with similar topography. The occurrence of small differences in values suggests that runoff plays a significant role in erosion during intense events, as well as the presence of stones and turf, which can change the flow of water, affecting soil erosion significantly.
The study indicates that erosion processes are intensified by inter-tree openings and standing dry-stone wall sections. Observations show a small area in due to aging areas. Furthermore, we observe a trend that the aging areas are decreased.

The analysis suggests that sediment traps, derived from the detailed topographic survey; and the location of standing and degraded wall sections of the upslope walls (W1 to W5). TD and TS denote the traps on degraded and standing dry-stone wall sections, respectively.

Fig. 4: Location and drainage areas (minimum and maximum) of the sediment traps, derived from the detailed topographic survey; and the location of standing and degraded wall sections of the upslope walls (W1 to W5). TD and TS denote the traps on degraded and standing dry-stone wall sections, respectively.
Table 2: Erosion at degraded (TD) and standing (TS) traps for the delineated drainage area range, during the two year monitoring period, and the ratios of upslope degraded wall length over total wall length inside the maximum drainage area of each trap (from W2 to W5, see Fig. 3). Nat. denotes natural vegetation, and NW means no wall.

<table>
<thead>
<tr>
<th></th>
<th>TD 1</th>
<th>TD 2</th>
<th>TD 3</th>
<th>TD 4</th>
<th>TD 5</th>
<th>TS 1</th>
<th>TS 2</th>
<th>TS 3</th>
<th>TS 4</th>
<th>TS 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nat.</td>
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<td>Ratio</td>
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</table>

4.1.3 Relations between soil loss, rainfall erosivity and intensity
Fig. 5: Correlation between soil loss over the slope per unit of drainage area, for 22 sediment collection events, and the maximum rainfall erosivity (a), runoff ratio erosivity index (b), and the 10-min (c), 30-min (d) and 60-min (e) maximum rainfall intensities of the event.
Fig. 6: Average hourly soil moisture (Ave. Soil Moist.) at 10-, 30- and 50-cm depth, hourly rainfall and sediment and maximum erosivity (MaxEI30) for sediment collection events.
4.1.4 Laser scanner survey results

The assumed areas are presented in Figure 7 and in Table 3. Each stone comes along with a cloud of terrain points as shown in Figure 7 is a cloud capture from the survey point times. From Figure 8, photographs are taken on the gates and the cloud data are obtained. Each fence highlights three major aspects of the evolution of only collection downslope. It can be clearly recognized by the method shown in Table 3. This is caused by shallow layers (<10 cm) on the right (SS 8 and a smaller dimension of 10 cm) and observed in Table 3. The three surveys are taken with voids between but, according to the cloud, the values range from 0 to 10 cm at SSS 3 and a smaller coherence over SS 6 at the top degree of the gates (SS 7, both as points and gates) causing considerable damage. This seems to be major cause for this terrace as the camera image was moved from the point cloud May 2016 and manual segmentation at the same time, but some - cloud distances larger than 10 cm measured that the largest error (3 kg) at the top degree of the gates (SD 7, both as points and gates) causing considerable damage. A smaller coherence for this terrace as the camera image was moved from the point cloud May 2016 and manual segmentation at the same time, and a considerably larger value at SSS 8 and a smaller coherence over SS 6 at the top degree of the gates (SS 7, both as points and gates) causing considerable damage.
Fig. 7: Cloud-to-cloud absolute distances (x-y-z) of the façade of the dry-stone wall for the periods November 2015 – May 2016 and May 2016 – April 2017. SD indicate degraded sections, SS are standing sections. Dry-stone wall polygons represent standing sections of wall.
Table 3: Summary of the laser scanner surveys. SD means degraded section, SS means standing section. Season 1 is November 2015 - May 2016, Season 2 is May 2016 - April 2017. In parenthesis, the uncertainty range due to instrument accuracy.

<table>
<thead>
<tr>
<th></th>
<th>Season 1</th>
<th>Season 2</th>
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<tbody>
<tr>
<td></td>
<td>Length [m]</td>
<td>Length [m]</td>
</tr>
<tr>
<td>SD1</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>SD2</td>
<td>2.2</td>
<td>1.5</td>
</tr>
<tr>
<td>SD3</td>
<td>3.6</td>
<td>3.2</td>
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<tr>
<td>SD4</td>
<td>0.8</td>
<td>0.7</td>
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<tr>
<td>SD5</td>
<td>5.0</td>
<td>4.6</td>
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<tr>
<td>SD6</td>
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<td>0.9</td>
</tr>
<tr>
<td>SD7</td>
<td>1.3</td>
<td>1.2</td>
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<table>
<thead>
<tr>
<th></th>
<th>Volume [Mg·m]</th>
<th>Volume [Mg·m]</th>
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<tbody>
<tr>
<td>SD1</td>
<td>1.1</td>
<td>0.7</td>
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<tr>
<td>SD2</td>
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<td>2.5</td>
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<tr>
<td>SD3</td>
<td>3.1</td>
<td>1.9</td>
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<tr>
<td>SD4</td>
<td>0.5</td>
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<td>SD5</td>
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<td>SD7</td>
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<th>Volume [Mg]</th>
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<tr>
<td>SS1</td>
<td>1.0</td>
<td>0.8</td>
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<td>SS2</td>
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<tr>
<td>SS3</td>
<td>3.6</td>
<td>3.2</td>
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<tr>
<td>SS4</td>
<td>0.8</td>
<td>0.7</td>
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<tr>
<td>SS5</td>
<td>5.0</td>
<td>4.6</td>
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<tr>
<td>SS6</td>
<td>1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>SS7</td>
<td>1.3</td>
<td>1.2</td>
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<th></th>
<th>Volume [Mg·m]</th>
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<td>SS7</td>
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Fig. 8: Images of sections SD1 and a small part of SS2 (left), and section SS6 (right).

5 Discussion

Doranda and Rey (2004) discussed the role in quantifying particular, they report mean values representing erosion in terraced and non-terraced environments with lessening soil sub-surface phenomena to more than 95% in Malaysia. More recently, mainly on the processes for the development of abandoned non-terraced environments without quantifying erosion between serve and degraded terraces. In a erosion by 2% of the area data from 14 areas, Maetens et al. (2012) found that terraces were reducing erosion by an average of 3%, compared to without terraces. They compared with the under terraces without a coverage of 8% due to terracing around 91%.
The effectiveness of erosion reduction by a tank was 0.73 from field experiments in central Myanmar, concurrent with mean values reported by (2005) and with terms of the study by Dor and Rey (2004). Also, terms of resistances, these studies are compared (saw dust magnetitude model by Ben and Connolly et al. 2017), in their environment. Although the terms coincide with previous studies, it is necessary to note that these studies do not coincide and non-acidic. Rather, focuses on a single degraded slope, where terraces are collapsed and terms of the surveyed water she has been undone. This value is much higher than 2.4-3.2 Mg m\(^{-1}\) y\(^{-1}\) for a tank and observed in this study, the surveyed water sheb by different GPS years after reclamation, and an option that the terraces were in unchecked state, they could not be estimated. The detailed survey was done to examine aging powder, and I have found that these consecutive weaknesses are along the line that a process could be a 30 cm. Moving long terms of the erosion environment Lecinena (2008) and terrace by the high correlation of the runoff erosion index. This finding is with the study by Meerkrake et al. (2009), conducted in a smaller terrace, the authors found collapsing termites had significant connection with height. However, the two values are to interpret with caution more than these values. e.g., stones and agriculture are included in this topography e.g., cations were surveyed run off. Small small could move between two consecutive erosion events in this environment, the DEM could not likely address this change partly addressed by the simulation with a potential difference could occur. This study shows that TLS is some aspects and does not use this method as a method in this environment at some time aging powder and does not use this method as a method.
6 Conclusions

The conclusions of this study arise from the data obtained from the monitoring of soil erosion in field cultivated with vines, with an average age of 27 years and length of 31.5 m, during a year period of 4 Mg ha\(^{-1}\) y\(^{-1}\), which could be reduced by 3.2 Mg ha\(^{-1}\) y\(^{-1}\) due to soil and debris accumulation. This would reduce the field to 1.0 Mg ha\(^{-1}\) y\(^{-1}\).

Maximum and minimum intensity explained a larger area compared to minor. The measured soil erosion tended to be affected by dimension and depth concentration under a good correlation.
Acknowledgements

We thank to the members of the community Alona for supporting us and Klosa and Stylianou for helping us with the work. We gratefully acknowledge the Cypriot government for providing the European Solidarity Fund for any needed equipment and to the European Commission for supporting the project (E.2015.1.603498).

References


C how, L. R e e s, W., a nd J. L. Re e s, 1999. c ass t e a c h rass w a ter w a y sy s t e m for and t e conser v a a fie ld e luation. Journa a n d W a ter 54, 577-3.

sta, Ny J., P n, J., c a Mo e rsons, J., c n ess in c ontroll ing e rosion on cropland in Tig y, Nor 21, 287–4. doi: lO.l079/ SUM2005321.

Distef a C., F e o, P a Pea c Me a surin g rill e rosion g struc tur e oti x x riment. C a 156, 383-392. doi: a .2017.04.023.

Djuma, B ge man C a mer a C., Z o umi s, C., c ombi qua tative a n d qua nti tative erosion assessme on c on tro a c on c a slopi Mediter n e a n ter shed, y L a de d. -4. doi: .2016.04.023.

Dor L., R ey, F., 2004. vie the ef fect of ter c on e Ass e len, S., B oix - Fa y ons, C., Imeson, A. ( Eds.) briefin ��rs �� S C W��hop, C. e I t a l y , -4-

B a g a P., a c y cint ter stria L a dta for e rosion mea a on to a a n e a n fie ld omorpho log y 245, 243–6. doi: 5.06.008.

C asti o, C., R lk, c g F., e n, 2016. is e ac e c ruc on in phometr y - mer s, a nd te nts. S sf. D y dm. 4, 359–389. doi: f-4-359-2016.

A b a n, S c o �� Time e struc - mot et ry �� c g e moni ngs �� S sf. Proc e Landa rms -4-

F a P. L., F alcone r, S.E., a e i, C., a Sa a L g crm a c in foothil Cy J., e a c si. -4-doi : 10.1016/j .jas.2012.02.010.
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La nd  Gr a d. D e v e ���–296. doi: ��
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�� �� y �e g e tat e ��s. �� ��. P roc e �� L a n ��ms 41 , 308–322. doi: ��


Table 1: Total soil loss, rainfall and erosivity for December 2015 – November 2016 and December 2016 – November 2017, per drainage area.

<table>
<thead>
<tr>
<th>Drainage Area</th>
<th>Total Soil Loss (Mg)</th>
<th>Rainfall (mm)</th>
<th>Erosivity (MJ mm ha⁻¹)</th>
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<tbody>
<tr>
<td>W1</td>
<td></td>
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<td>W2</td>
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<td>W5</td>
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</table>

Table 2: Erosion at degraded (TD) and standing (TS) traps for the delineated drainage area range, during the two year monitoring period, and the ratios of upslope degraded wall length over total wall length inside the maximum drainage area of each trap (from W2 to W5, see Fig. 3). Nat. denotes natural vegetation, and NW means no wall.

<table>
<thead>
<tr>
<th>Drainage Area</th>
<th>Erosion at Degraded Traps (TD)</th>
<th>Erosion at Standing Traps (TS)</th>
<th>Ratio of Upslope Degraded Wall Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td></td>
<td></td>
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<tr>
<td>W2</td>
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<td></td>
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<td>W3</td>
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<td>W4</td>
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<td>W5</td>
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</tbody>
</table>

Table 3: Summary of the laser scanner surveys. SD means degraded section, SS means standing section. Season 1 is November 2015 - May 2016, Season 2 is May 2016 - April 2017. In parenthesis, the uncertainty range due to instrument accuracy.

<table>
<thead>
<tr>
<th>Drainage Area</th>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td></td>
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<td>W2</td>
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<td>W3</td>
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<tr>
<td>W4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Dirt Road - Top of the slope

Natural Vegetation

Wall height = 1.65 m
16.0 m
10.0 m

Wall height = 0.45 m
19.5 m
3.0 m

Wall height = 1.25 m
21.8 m
6.5 m

Wall height = 0.50 m
20.1 m
4.0 m

3D scan

Wall height = 1.25 m
22.0 m
8.0 m

SM2
SM3
SM4
SM5
SM6

Rainfall station and data logger
Soil moisture sensor, three depths
Soil moisture sensor, two depths
Sediment trap on degraded wall
Sediment trap on standing wall

Figure 2
Click here to download high resolution image
Figure 5

Click here to download high resolution image
Cloud-to-cloud distance [cm]

- Red dot: < -10.0
- Orange dot: -10.0 - -5.0
- Yellow dot: -5.0 - -1.0
- Green dot: -1.0 - 1.0
- Blue dot: 1.0 - 5.0
- Light blue dot: 5.0 - 10.0
- Dark blue dot: > 10.0

Dry-stone wall

Nov 2015 to May 2016

SD1  SS2  SD3  SS4  SD5

May 2016 to Apr 2017

SS6

SD7  SS8

Scale: 0 1.25 2.5 5 Meters
Title: Effectiveness of T. harzianum in soil and yield conservation of tomato crops under saline irrigation

Article Type: VSI: Testing soil conservation

Keywords: saline irrigation; salinization; Trichoderma harzianum; Solanum lycopersicum; greenhouse

Abstract: Protected horticultural crops in the Mediterranean region are typically under deficit irrigation and intensive cultivation practices and must cope with poor irrigation and soil quality due to salinization. The effects of variable irrigation water quality and use of the beneficial fungus Trichoderma harzianum on the evolution of soil salinization and yield during a single cropping season are examined at a small-scale Solanum lycopersicum L. cv Elpida greenhouse experiment. The experiment simulates typical coastal Mediterranean greenhouse cultivation conditions of the RECARE Project soil salinization Case Study in Greece (Timpaki basin in Crete). Local NaCl-free but highly calcareous planting soil as well as local cultivation practices are used to replicate prevailing conditions at the Case Study. Plants are drip irrigated with NaCl solutions of low (L) (ECw = 1.1 dS m−1) and high (H) (ECw = 3.5 dS m−1) concentration so simulate a typical "good quality" and "marginal quality" irrigation water. T. harzianum (T) is selectively applied resulting in a total of 4 treatments (LN, HN, LT, and HT). Results show that T. harzianum successfully colonized plant roots under production conditions which included temperature extremes and a highly saline environment. Monitoring of soil nutrients showed increased P bioavailability in T. harzianum treatments. As a result of the LN and HN irrigation treatments, and the gradual replacement of bioavailable Ca by Na, respective Sodium Adsorption Ratio (SAR) values settled at 6.64 and 22.20. However, T. harzianum treatments lead to a significant inhibition of SAR. By the end of the growing season, total and marketable yield for treatments LN and HN were reduced by 28% and 42%, respectively, with T. harzianum treatments having an insignificant effect at harvest. Fruit quality characteristics were overall less sensitive to higher irrigation salinity that to timing of harvest. We determine that besides irrigation water quality, timing of harvest is important both for soil health and yield, especially under high salinity and use of T. harzianum.
The effectiveness of a certain nutrient action on tomato crop under saline conditions, I. A., A. Giani, A. Burger, A. T., and C. M. D. the table of Agriculturally Meditarranean Institute of Lebanon. Box Chan, Lebanon.
Abstract

In order to overcome the irrigation and cultivation issues, and must cope with irrigation and water quality, the focus of the irrigation system is beneficial to fungous Tri...mistry

The system simulates the diurnal Agrohouse cultivation cycle...lization C...Study in Gree...R A R Proje...linization C...Study Pla...H N...H T. R...col...ant...und...included...text...as......y...ag...e...soil......s...to...g...s...son, to total and major...R. B...the...s...son, to total and major...h...s...i...g...f...t...v...t...Fruit...char......d...i...g...h...the...bes...use of T...
Gl ation, currently 7.5 billion is expected to exceed 9 billion by 2050 (United Nations). Agriculture results in global growth significantly increased food security (Rabot, 2001), and global agriculture in recent years has been cultivated extensively that identifying fully is globally World-wide, while many of the most productive and intensive systems (Agliolo, 2007a), with special emphasis on such sensitive cultivation (Test, 2006), and depending on its form, they have been already 25% irrigated or less (Gale, 2003; Masic and Beka, 2011) and of the most ominous soil degradation threatened the Mediterranean region (Dilotos, 2016b).

The alleviation of soil degradation through a range of measures, including technical innovation, to align irrigation (Dalipoulou et al., 2010, Tissi et al. 2011) has been reported to values by 10% or more to the unit in the same fruit, thus affecting relatively over 15% of the productivity of specific activity.

Electrical conductivity (EC) measured in the irrigation water (w) is higher than 2.3 m–1, resulting from reduction in its (Ali and Islam, 2010; Dai al., 2000; Masic et al. 1991; Valkiukonis 1992) reported to an EC physician to a number of the most productive and intensive systems (Smyth 1951).
4. Number and size of fruit depends on tillering (Dor & ��; ��; ��). At harvest, size and yield are determined by fruit number (Lep ��). In general, the range is 4.6–8 m–1 for yield increase because of education in fruit size, where yield values (12 m–1) reflect the number size of fruit (Ades, 2015; Gaim & al., ��; Hao et al., ��).

Biological yield, for nutritive quality is important quality in market (Dai et al., ��). Total Solubility (TS) and Total A (TA) and A (A) of fruit yield characteristics contribute to the nutritive value of the tree (Chen et al., 1977). Tillage decreases fruit zinc increase (Beter et al., 2005; Gait et al., ��; George et al., ��; Richard, ��). About Brix (Poy & al., ��) total TS (TA) about 0.4 mg 100g–1 (Kader et al., ��); yield rate of 100% acceptable good taste (Bell ��). Specifically for help, cultivar, Ili (��) found total A of 0.25 mg 100g–1. Also, Baker &kinson (��) generally ripe green house tastes have 21 mg 100g–1 whereas cultivar (��) measured yield value betw 8.1–16.3 mg 100g–1 and Ili al (��) measured 14.3 mg 100g–1 for.

Dcultivation C wound superficial solubles, forose glucose titrated and involving minerals, viruses, A containing fruits and Doss, ��; Stens & al., 1992; Pstein & al., 1984; Mizrahi et al., ��) at usual about 2 m–1 in used for green 7 m–1 broken 0 m–1.
m–1
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administer phytostimulants (Lopez-Bucio al.,
2013; Wner et al. (2012) reviewed their
Triphoma was f't fringe conditions in their main
per tension and perti of hea yield, fruit quality
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irrigation is treated reporting suc for
T. triala iat ion and...
root size boost (Cinti et al., 2014) and seed yield and fruit characteristics (Hamedi et al., 2006). It is

noteworthy that both root treatment and the two related treatments in the pilot experiment. A part
their sparsity and significant shortcomings that they substantiate, soil fruit operation and yield are

restricted and explicit view of soil - water - ion interaction in its impact on crop productivity in terms of

yield and yield quality under (Ng et al., 2016).}

2 study and more, I. Grönström et al have identified the option for Panagiotou et al., 2016) in the
treatment conflict with that (Fig. 1) and the local water intrusion to the local irrigated area (O.D., 2016).

Due to a desert climate south of Greece, the activity rate is higher of erosion in irrigation (Panagiotou et al., 2016) with irrigation to that (Fig. 1) and the coastal site of the center of Greece due to the few factors of water

limits as or the objective of the activity due to the few factors of water

concentration of a few factors of water
In the winter period (Vardev et al., 1... the four sites (Boles et al., 2008) Groun dewatering occurred from the intensive irrigation system in the aquifer and the water infiltration as local water reserves significantly (Dipopoulou et al., 2016a;... study to limit uncontrolled flows and minimize irrigation doses at the experiment for local farms, the experiment was conducted at the lotrnhouse and T. K. University. Irrigation quality was evaluated at two levels; they were red to local water quality depending on irrigation rates (Panagiotakis et al., 2016) In parallel with the pilot experiment of the Land Ce in a part, Timpakis eventually read their subjective effect of local health productivity throughout the crop season.

3 Material and methods

3.1 Experiment setting
The experiment was conducted from October 2015 to April 2016. Tomato (Ipida F1 commercial) were transplanted to 35 L cylindrical plastic pots containing loam (pH: 6.5% C: 8%) of Timpakis area. It was characterized based on the 1st month tested mineral number 1. C, N, P, K, Mg, Ca, Fe, Zn, B, Cu, Mn, Mg, and Ca were measured in the plant tissues (Table 1).
Sieved soil homogeneity was also visually scored and measured for composition uniformly to avoid outliers. The initial treatment identified that soil was sodic-fractured and highly saline and the content determined by ICP-MS (Table 1). The following were: 0.15 dS m$^{-1}$ water concentration with pH 7 and irrigation through (see Table 2). Since local irrigation had less impact, organic amendment was increased by 10 g$^{-1}$ furniture (analysed using 2100S, HACK...). Hence, irrigation did not affect $\ldots$ (H 0.11; H 3.5 dS m$^{-1}$ respectively). Therefore, irrigation not only $\ldots$ was TRIANUM-��Kött B. V. (N 0.1 and contained T-22 �� powd... generally (A ��). After initial 10-day period to establish irrigation manipulated: water concentration (3.5 dS m$^{-1}$) was... A further (H 2.4 and... Acelvive as �� w of r... After initial 10-day period to establish irrigation manipulated...
3.2 Dataset Collection

Start if November 2015 when treatment will be effective, soil samples were taken if equally spaced (to the extent possible) from the experimental area (November 2015, February 2016) to determine soil quality. Soil samples were collected at two depths (0-10 cm) for vitality soil properties. Soil moisture was measured using TDR probes (Ø cm) and used in all soil samples. Indoor door temperature (T indoor and T outdoor) were monitored at four locations, HOB U 23 v2 or final T temperature/relative humidity data logger (Onset Computer, USA) in the greenhouse. All clarifications were monitored in the Diri ratio precision (Diri Instruments, USA) as Fig 2 summarizes the results.

3.3 Theory and Hypothesis
Air circulation at 45 °C for about 48 h, and the lot of debris, then milled, and mesocosms were dried to 2000 µg. The nitrogen port is where the soil analysis. Several soil fertility parameters (Tl 2) were measured (a) to estimate nitrogen uptake (b) to identify clearly treatable jurisdictions. Us

(1) correction was done to the HAC 2800 species at 3%. Biological Phosphorus was determined using Olsen (1956) method, and the typical calculation.
For TOC and TN analysis, soil N/C (Analytik Germany) was evaluated by drying at 650 °C with transformations measured using the soil non-sensible and mineral lines since detection reactivity is usually measured after the method after KC1M with concentration determined at 34%.

In order to quantify the self-contained soil function (van Beek and Tóth 2016, they the parameterization of the productivity of the soil solution indicated where the percentage of soil 


\( N - NH_4^+ \) (N - NO_3^-)

\( EC_{5e} \) 

\( EC_{1:2} \)

\( EC_{5e} = 0.94[14 - 0.13C] \) \( EC_{1:2} \)

\( SAR = \frac{[Na^+]}{\sqrt{0.5([Ca^{2+}] + [Mg^{2+}])}} \)

\( Na^+ \) Ca\(^{2+}\) Mg\(^{2+}\) SAR
comunication with Inductive Y C Planta (ICP) from formation finally if the soil significantly if greater the soil is milk by itself – because it is Bides it re on lightly a if it to biological activity so with range 5.5-6 of human fertilization (I et al). Based on measurement soils collectively correspond to treatment and their quotient potential for the 2 and 4 (t), very reactive, very reactive (Maxima red (R reis Reid, 1998). Firmness were scored to points per fruit sum with (ZHANG T Institute China) 1 and mm head. Fig 3 show that firmness weighting generally uniformly with b to t 4 node fruit w membrane at the 247 lirsh in this time harvest.

Dish harvest treatment and sensory fruit externally all measured with homogenized fruit (JU) with mixture acidity with sugar sucrose (TTens et al. 1977). Consistently T can ��esed °Brio of the which oil of sugars glucose and other fruitsTSs (TSS) with acid response at the m of acids and the 252
The text appears to be a scientific report or article, discussing experimental results and calculations. Here is a transcription of the visible part of the text:

\[ TI = \frac{TSS}{20 \times TA} + TA \]
This result determines the T-22 ratio at the distance.

4.2 Time of soil salinity

Regarding high literacy treatment (HN and HT) generally not significant with the experiment (on 0.5 degree growth) and the initial carbon (T1). Differences between Tripterygium and non-Tripterygium treatments are generally not significant for the experiment start February values than and organic matter reduction to the initial high concentration in the soil generally lower than Na. Nevertheless, Tripterygium treatment kept relatively higher (275 ± 4% L-1 February and December by Ail) as well as having a character scatter of 380 ± 3 mg L-1 (not with lactic and HT) equally R values show increasing for the initial sodi-fertilizations, primarily to irrigation treatment I daily, and HT treatment made remarkably R increase by the final month compared with and "(Fig.5; irrigated) respective R values" 5 ± 20 (mm L-1) and T. Tripterygium treatment R inhibition was 37% ± 5%.
14. Trichodermale treatment significantly reduced the final yield of the experiment (April) with the following Trichodermale treatment. As Fig 5 shows, at the end of the experiment, the limit of soil and sodic-alkali (treatment H) rapidly sodic-alkali (treatment H).

4.3 Time impact of treatment

Initially, the Trichodermale treatment ranged from 6.1 mg 1 g of soil utilization and quickly reduced to 5.3 ± 2 mg kg 1 g 2 months of the experiment (Fig 2; left) and the soil decays immediately after at the end of the experiment, (Fig 4; left) after initial values may be attributed to soil fertility for (Fig 3). The relative vitality beside the increase of similar matter in February, the Trichodermale treatment decreased from a relative "lower" 1 mg kg 1 g, followed by the rise of soil inorganic matter shows a relative increase of soil P to the end of the experiment, rather than inoculated treatment (Fig 3).

N – NH4+ N – NO3

N – NH4+ N – NO3
Treat me impact that to produce

Ry it the final yield (t) timed at 104.2 ± 2.3 th (Fig 6; top line), where the control made timed at 76.0 ± 1 (Fig 6; top right).

ider intensity 30,000 ant. Salinity as estimated, resulting in production

rem H or 21 of total ± (or 28 of total) made treatment (or

L T. At the same, effects were with treatment H and LT. At the same, effects were on size her figure (Fig 6; top right) as another. A more vigorous to yield with 20% (or 28% of total) made H, (or 28% of total) made H (Triema).

The fruit number show that treatment H, especially, for production. Also, TS values are for fruit treatment as A arms to be unaffected treatment, but the higher concentration the 4 node irrigation the 2 is obvious. Also, T A treatment H with the ltest value at the 4 node harvest.

Finally, coincided with the T and I the treatment is sized than first, with treatment H produce of the experiment.

2

( FIG ) and 4FIG (arch) node for treatment appear and for treatment H, relative total treatments. Also, TS values are for fruit treatments as A arms to be unaffected treatment, but the higher concentration the 4 node irrigation the 2 is obvious. Also, T A treatment H with the ltest value at the 4 node harvest.
Theworks the betterment of the HT treatment 346 and the TA and is not...

Discussion

5.1 T. harzi T. findi comment to high colonization of T-22 desribed H. human (5) me, the fungus outside the germ wih the immunological surrounding of 5°C. Fig. 2; st.) C. d.-taneous number wirst sorted by Loo et al. (2016) confirmed A. 200 for the T-22 349°C. C. d.-taneous gene function similar to-colonizing organisms by T. and C. roney (5) O. r. confirmed these if t. treatment is cabbable in condition of microbial infection wih quality is abse...
higher than the, as shown in Fig 4.

Fig 6. General, P-O well bel t to the right and mg -1 on support Z .

T is is not only experimentally in the soil (e.g. Great and rake, 1998) but also essentially with little treatment with off-site irrigation levels (summarized in Fig 4f). The abrupt decrease of P-O treatment in the Aili may reflect the cross section certain irrigation tendency in the April, the highest value of R (Fig 5; center left) . The resistant depletion increases of bivalve treatment and H T may pertinent to a value of TP in the a and al treatment s (Fig 4e) but obviously to prevent the irrigation values in the interaction itself through various solubilization mechanisms (Altene et al., 1996). Th is version is evidently with only the P wall and only reduced pr oduction cost (Adese et al., 1990).

5.3 Soi l salinity

Soil salinity of the application of the two irrigation treatments had, expectably founded for within the optimum range of 5.5-6.0 (I . . , 108) basically to reduce the availability of such C u, Z n, and Mn (Brady 1965). T is is, irrigation literacy in the case is replaced by those cations in the soil increasing the quality of B based on the soil measurement conducted in this
While the benefit of irrigation treatment is obvious, it is important to note its limitations, the use of *T. harzianum* off sets its negative effects, especially in the case of *R. oryzae* treatment. The treatment reduces the soil quality of rice and yield, especially in the case of fruit grains (Richard et al.). While the effect on R is obvious, it is still possible that soil health is restored and the yield and quality of rice are increased. Under the experimental conditions, increased A is typical for fruit grains under similar conditions (Dede et al., 2006, Dede et al., 2009; Dede et al., 2001) and gene *T A* value which is close or more mg 1 \-1 (Katjari et al., 2000; Yetven et al., 2006) Similarly, observations were made by...
made i n t e n t (Fig 7) re f i r m m e n t (Apost o l i c 418, 2016a; W a g n e r et al., 2016).

I n u s i n g f i r m n e s s i n v e s t m e n t t h e i n t e n s i v e t y t o l e r a n c e l e v e l r e s u l t s (Fig 7).

C o u l d b e m o n i t o r e d w i t h t h e s i s. F i r m n e s s c o u l d b e a c h i e v e d b e t w e e n h a r v e s t s, a l l i n g u i t y c o n t r i b u t e s t o f u r t h e r s o l i t u d i n e.

( F i g 7; r i g h t M i l l e r ) W h i l e u s i n g a v a i l a b l e t h e g r a d u a t e l e v e l c h a r a c t e r i s t i c s.

C o n s i d e r t h e r e a s o n a b l y i n t e n s i v e h a r v e s t (Fig 7; r i g h t M i l l e r) i n t e n s i f i c a t i o n.

5.5 y i e l d

P r i m i l y i n t e n s i f i c a t i o n b u i l d s t h e s o l i c h a r a c t e r i s t i c s s o f m a k i n g f r a i s s a b l e, s h o w i n g l i t t l e n t i v i t y t o h a r v e s t i o n.

C o n s i d e r t h e r e a s o n a b l y i n t e n s i f i c a t i o n c o n t i n u e s, c o m p a r a b l e w i t h t h a t a c h i e v e d t r e a t m e n t s o f c o m p a r a b l e l e v e l s s o f e r a t u r e b u i l d - i n t e n s i f i c a t i o n.

T. i n a m i b o t a n i c a i n i n t e n s i v e h a r v e s t i o n c o n t i n u e , c o m p a r a b l e w i t h t h e i n t e n s i f i e d o p e r a t i o n c r e a t e s h a r p e n i n g, c h a r a c t e r i c s c u r r i n g m i d t e r m (Fig 6), a n d t h e u n t e r i o r a t i o n of s o i l h e a l t h, f r o m q u a l i t y, y i e l d l e s s t h a n e x p e c t e d n o d e s (Fig 7; r i g h t M i l l e r) i n t e n s i f i c a t i o n.
The treatment is important steps to list and in a total of T. This is of soil so the presence of T. with con soil and the health.

Results show T. successfully colonize to some extent under irrigation and a single environment which intensely fed the irrigation treatment with

especially for T. fully in the higher quality irrigation, particularly the order of the fertilization rock only. relatively of the in the view needed to be monitored and to accept the process role of T. haiba. However, we concluded that control to the ant reduced yield due to
tility I to productivity loss was significantly for the market of yield, that in the completion when one compare that and make able yield. Forward, this characterization with higher quality come of 

economically sustainable. All this, the irrigation will be needed for the financial feasibility of each patient. 

Known T. trawed the fact of I Panagia M.G. Grillis, A. K. Thrulis, and N. K. Grigas, who led in various parts of this area as impakti as support of the.

Acknowledgments


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"References"


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Table 1: Value and order of the measured characteristics of the soil usage 1.

Table 2: Nutritional fruit properties measurement.

Table 3: Salt-free oil purification method (van Beek and Thompson).
Fig 1: Arrangement and treatment of soil (left) and compost (right). Source: Panagiotakis, 2015; et al.

Fig 2: Current soil and compost during the experiment: indoors (T. and outdoors (R). In: R. indoor (RH). 2: In (RH). A: In the soil.

Fig 3: Color and firmness of fruits harvested in 2015 (wet: 4). Recorded with colorimeter, respectively tested when constant treatment was carried out for the hold of red and yellow. Treatment: (low – normal) LT (low – T. citrus), HN (normal – normal) and HT (normal – T. harzianum). 3: horizontal.

Fig 4: Citric acid concentration chart from January to February 2015. Statistical results show increase; treatment: (normal – normal) LT (normal – T. citrus), HN (normal – normal) and HT (normal – T. harzianum). 4: horizontal.

Fig 5: Citric acid content chart from November to February 2015. Statistical results show increase; treatment: (normal – normal) LT (normal – T. citrus), HN (normal – normal) and HT (normal – T. harzianum). 5: horizontal.

Fig 6: Citric acid total (right) and makable yield (left) of fruit (treat) after treatment noted with time in makable yield fraction. Treatment: (normal – normal) LT (low – T. citrus), HN (normal – normal) and HT (normal – T. harzianum). 6: with different color.
Fig 7: Results of Tomotom for various node (gr) values. The results are given in L divisions. Treatment (L — normal) and (L — T) have no effect on the results. The treatment (H N — initial — normal) and (H T — high) are horizontal.
Table 1
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* Analitik Jeremen; * HAK (��) A T A G O; ‡ A O A C (��).
Table 3

Table: Table 3.docx
Figure 1

- Major rivers
- Tinipaki
- Seawater intrusion
Figure 2

- **Figure 2**

- **Data Description:**
  - **X-axis:** Time (in days)
  - **Y-axis:** Value of a specific variable (e.g., temperature, humidity)

- **Graphs:**
  - Left graph shows data with markers indicating specific events.
  - Right graph presents a different set of data with varying lines and markers.

- **Legend:**
  - Markers and lines correspond to different categories or conditions.

- **Axes:**
  - X-axis: Days (from 0 to 750)
  - Y-axis: Value range (from 0 to 150)
Figure 3

![Box plots showing factor a, factor a/b, and firmness.]
Figure 4
Figure 5

[Graphs showing data for T. harzianum and another strain over a period from November 2015 to February 2016, with error bars and annotations.]

T. harzianum
Figure 6

Cumulative yield [t ha$^{-1}$] and marketable yield (top and number of crops when marketable action becomes minimum – normal), nitrophenol – T. harzianum and H. hansii – normal, and H. hansii – T. harzianum grown with different crops.
Figure 7

- TSS [%]
- ASA [mg 100g⁻¹]
- TA [g citric acid 100g⁻¹]
- Taste Index

Legend:
- T. harzianum
- H. (high
- N. (normal)
- T. harzianum

Measurement LN (low
- N. (normal)
- T. harzianum
- H. (high
- N. (normal)
- T. harzianum

Data from April 2015 and the respective media measured by (2014) using a cultivation of the tomato. Measurements LN (low
- N. (normal)
- T. harzianum
- H. (high
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Title: Risk assessment of soil compaction in Europe - rubber tracks or wheels on machinery

Article Type: VSI: Testing soil conservation

Keywords: subsoil compaction; rubber track; risk assessment; agricultural practices

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Abstract: Subsoil compaction is persistent and affects the wide diversity of ecological services provided by agricultural soils. Efficient risk assessment tools are required to identify sustainable agricultural practices. Vehicles should not transmit stresses that exceed soil strength. Wheel load is the primary source of high stress in the subsoil. However, very low contact stress without reduction of wheel load would also help reduce stress in the subsoil. The aims of our study were to: (i) test experimentally the use of tracks instead of tires as a technical solution to increase contact area and reduce the magnitude of contact stresses, (ii) compare effects of traffic on soil physical properties using tires or tracks, and (iii) evaluate a state-of-the-art method for risk assessment of soil compaction beneath tracks or tires at the European level. We measured contact stress below a fully-loaded sugar beet harvester equipped with either a large tire or with a rubber track in a realistic harvest situation. Seventeen stress transducers were installed across the driving direction at 0.1 m depth and covered with loose soil. Dry bulk density and air permeability were measured at 0.35 m depth after traffic. The contact area was larger and the maximum and vertical stress smaller beneath the rubber track than beneath the tire. Nevertheless, stress distribution beneath the rubber track was far from uniform, presenting high peak stresses beneath the wheels and rollers. Dry bulk density was similar after traffic for the two undercarriage systems, but air permeability was lower after traffic using the rubber track. Measured stress distributions beneath the tire and the track were used as input to calculate the soil profile vertical stress for comparison with soil strength at 0.35 m depth. Wheel Load Carrying Capacity was calculated for European soils for assessment of subsoil compaction risk when using the tire, the rubber track, and the rubber track assuming an even stress distribution. As expected from the contact area and stress measurements, the rubber track could carry higher loads than the tire. However, the air permeability results are interpreted as soil distortion due to high shear forces under the rubber track. This calls for a further development of the risk assessment method.
To the Editors of CATENA

With this letter follows a manuscript entitled “Risk assessment of soil compaction in Europe – rubber tracks or wheels on machinery”, which we kindly ask for consideration of publication in CATENA’s Virtual Special Issue: “Testing soil conservation”. The study first compares the effects of traffic using rubber tracks or wheels on soil physical properties, and then evaluates the state-of-the-art approach for risk assessment of subsoil compaction at the European scale using three different undercarriage systems for traffic in agricultural fields.

Kind regards

Mathieu Lamandé
Senior Researcher
1. **Highlights**

2. Maximum vertical stress was smaller beneath the rubber track than beneath the tire

3. Stress distribution was highly uneven beneath the rubber track

4. Low air permeability beneath the rubber track indicates high shear forces

5. The results call for quantification of shear stresses under tires and tracks
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Title:

Risk assessment of soil compaction in Europe – rubber tracks or wheels on machinery

Abstract:

Subsoil compaction is persistent and affects the wide diversity of ecological services provided by agricultural soils. Efficient risk assessment tools are required to identify sustainable agricultural practices. Vehicles should not transmit stresses that exceed soil strength. Wheel load is the primary source of high stress in the subsoil. However, very low contact stress without reduction of wheel load would also help reduce stress in the subsoil. The aims of our study were to: (i) test experimentally the use of tracks instead of tires as a technical solution to increase contact area and reduce the magnitude of contact stresses, (ii) compare effects of traffic on soil physical properties using tires or tracks, and (iii) evaluate a state-of-the-art method for risk assessment of soil compaction beneath tracks or tires at the European level. We measured contact stress below a fully-loaded sugar beet harvester equipped with either a large tire or with a rubber track in a realistic harvest situation. Seventeen stress transducers were installed across the driving direction at 0.1 m depth and covered with loose soil. Dry bulk density and air permeability were measured at 0.35 m depth after traffic. The contact area was larger and the maximum and vertical stress smaller beneath the rubber track than beneath the tire. Nevertheless, stress distribution beneath the rubber track was far from uniform, presenting high peak stresses beneath the wheels and rollers. Dry bulk density was similar after traffic for the two undercarriage systems, but air permeability was lower after traffic using the rubber track. Measured stress distributions beneath the tire and the track were used as input to calculate the soil profile vertical stress for comparison with soil strength at 0.35 m depth. Wheel Load Carrying Capacity was calculated for European soils for assessment of subsoil compaction risk when using the tire, the rubber track, and the rubber track assuming
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Keywords: subsoil compaction; rubber track; risk assessment; agricultural practice

1. Introduction

Agricultural soils provide a wide diversity of ecological services. Root growth, water movement, aeration, and heat transfer are directly influenced by the physical properties of soils. Therefore, food production, water storage, carbon sequestration, water quality and flood protection are all ecological services that depend on the structure of soils. One major threat to the quality of soil structure is compaction, especially in the soil layers beneath the ploughing depth (i.e. the subsoil). Detrimental effects of subsoil compaction on soil ecological functions may persist for several decades (Schjønning et al., 2013).

Quantification of the acreage of agricultural soils likely to be compacted by field traffic requires measurements of soil physical properties, which is laborious, especially for the subsoil. Hence, only few inventories of the extent of soil compaction damage based on measured indicators exist. Schjønning et al. (2016a) calculated the Relative Normalized Density (RND) for European soils. In short, RND is an expression of the packing density relative to what is considered a natural state for a given soil. The exercise was based on the SPADE8 database, which includes estimates of soil texture and dry bulk density derived from expert judgments (Koue et al., 2008; Panagos et al., 2012). About one-quarter of European soils was found to have critically high densities in soil horizons covering the 0.25-0.70 m depth interval.

In the European Union (EU), society concerns prompted a comprehensive review of threats – including compaction – to the quality of agricultural soils. Following stakeholder consultation, a “Soil Thematic Strategy” was formulated as a follow-up to the review (van Camp et al., 2004). A Soil Framework Directive (SFD) was proposed to oblige member countries to take actions to secure a sustained quality of the soil resources. However, the EU Commission withdrew the SFD proposal in 2014. At present (February 2018) it is unclear whether any initiatives to regulate field traffic in order to avoid compaction will be launched within the EU. Public endeavors to minimize soil compaction have been established at the local scale, for example in the Swiss canton of Bern and in some German federal states.
Mechanization in modern agriculture implies an increase in the mechanical stresses reaching subsoil layers (Vermeulen et al., 2013; Schjønning et al., 2015a). A range of studies clearly indicate that many agricultural field operations are very likely to induce compaction of the subsoil (e.g. Arvidsson et al., 2003; Duttmann et al., 2014; Gut et al., 2015). Irrespective of potential legislation targeting the compaction problem, it is therefore important to develop tools to identify the risk of soil compaction.

Jones et al. (2003) suggested a procedure to estimate the risk of soil compaction across soil types. This includes an initial estimate of the inherent susceptibility to compaction based on soil texture and soil density. Soils in their natural state display variation in bulk density (BD) related to their texture (Heinonen, 1960). A soil packing density (PD) may thus be normalized to the content of clay (Renger, 1970). Based on expert judgment, Jones et al. then suggested four classes of susceptibility for different combinations of soil textural classes and PD: low, moderate, high, and very high. This was to be followed by an assessment of climate on the actual vulnerability to compaction by calculating the potential soil moisture deficit (PSMD: evapotranspiration minus precipitation) during the growing season. However, van den Akker and Hoogland (2011) deemed the expert model by Jones et al. (2003) to be rather arbitrary with results that are not in agreement with reality. In any case, vulnerability estimated from PSMD will never be able to describe the specific vulnerability for a given traffic situation in winter or early spring. In addition, the approach suggested by Jones et al. (2003) does not consider the size and type of machinery used in field traffic.

Another approach in risk assessment for soil compaction involves a quantitative comparison of stresses transmitted to the soil profile with soil strength, which should not be exceeded by stresses (van den Akker and Hoogland, 2011). This includes modeling of stresses from machinery in combination with estimates of soil mechanical strength from pedotransfer functions (PTFs) using readily available soil properties. The stress distribution in a tire-soil contact area may be predicted from tire characteristics (Schjønning et al., 2015a).

Transmission of stress from the soil surface to the subsoil can be reasonably estimated using the analytical solution obtained by Boussinesq (1885) for the problem of normal loading of the surface of a homogeneous, isotropic, elastic half-space by a concentrated normal force (Keller and Lamandé, 2010). Soil strength, in turn, may be estimated from only three soil parameters: clay content, dry bulk density, and matric potential (Schjønning and Lamandé, 2018). In contrast to the risk assessment procedure suggested by Jones et al. (2003), the mechanistic comparison of mechanical stresses with soil strength enables evaluation of the risk of soil compaction for specific machinery and soil conditions. The approach can be used for mapping
purposes, as will be demonstrated in this study, as well as decision support systems (e.g. www.terranimo.dk).

Limiting the risk of subsoil compaction calls for the use of large tires. Schjønning et al. (2015b) estimated that sustainable traffic with a ~75 kN wheel load in moist soil conditions would require tires wider than 1.3 m (~2 m² contact area). However, there are limitations to the height and the width of agricultural vehicles driving on roads, which limits the size of tires.

Using a rubber-tracked undercarriage instead of a wheeled undercarriage is a technical solution to increase the contact area without increasing vehicle width and height (Alakukku et al., 2003). However, the few studies available show an uneven distribution of stresses at the track/soil contact, characterized by high peak stresses below the track wheels and rollers (Blunden et al., 1994; Keller et al., 2002; Arvidsson et al., 2011).

The objectives of this study were: (i) to compare the stress distribution at the soil surface as well as the soil stress propagation beneath a large, low-inflation-pressure traction tire and a rubber track mounted on identical sugar beet harvesters; (ii) to evaluate the consequences of traffic with both vehicles on soil physical properties; and (iii) to evaluate the potential of using rubber tracks instead of tires to reduce the risk of subsoil compaction in Europe.

2. Materials and methods

2.1 Field test

The experiment took place in November 2013 at the Krenkerup Estate, which is located on the island of Lolland in Southwestern Denmark (54.773° N, 11.685° W). The soil was classified as a Eutric Cambisol (FAO, 1988). The soil texture class was a loamy sand in the topsoil (Table 1). Soil water potential was close to -100 hPa at the time of the experiment (Table 1). The test soil was ploughed annually to ~0.25 m. The field had been grown with small-grain cereals in the year of investigation (stubble not tilled after harvest two months prior to the tests).

2.2 Contact stress measurements

We measured the distribution of vertical stress at the interface between soil and wheel or track of a sugar beet harvester using the procedure described in Schjønning et al. (2008). Two identical harvesters were equipped with either a large traction tire (1050/50R32) with low inflation pressure (150 kPa) or a rubber track (0.92 m × 1.325 m; a front and a back wheel with two support rollers) (Fig. 1). Note that both wheels of the rubber track were lowered to
increase the contact area. The tanks of both harvesters were filled with beets to yield a load of approx. 10.5 Mg on the tire or rubber track at a weighbridge. During the tests with the rubber track, the experimental conditions required a slight twist of the harvester relative to the tractor. This resulted in a higher load being put on the rubber track. Based on the readings of the stress transducers, the real load under the track was approx. 12 Mg. The track unit by itself weighs approx. 1 Mg more than the rim-mounted tire. Thus, the tests are close to a comparison of a rubber track and a tire with identical loads of beets in the tank.

Seventeen stress transducers were installed at 0.1 m depth and covered with loose soil (Fig. 2). Measurements were made in 2-μs bursts at 2 kHz to obtain a very detailed picture of the tire/track footprint during the drive. A laser sensor tracked the positioning of the test wheel axle. The driving speed during the tests was approx. 0.4 m s$^{-1}$ (1.6 km h$^{-1}$). For both machines, stresses were measured on three plots in the field and with four repeated passes across each sensor installation (six sensor installations and 24 contact stress measurements in total). The six experimental plots were distributed in three blocks in the field.

2.3 Soil sampling and physical measurements

Undisturbed 100-cm$^3$ soil cores (inner Ø 60 mm, H 34.8 mm) were sampled in the experimental plots before (Series 1) and after (Series 2) the passes.

Series 1 included a total of 24 cores sampled at 0.13-0.17 m depth close to but outside the trafficked area, i.e. four cores per plot. The cores were weighed to record the water content at field conditions, saturated with water from beneath and then drained on tension tables to a soil water potential of -100 hPa. Two cores from each plot (12 in total) were used for the uniaxial confined compression tests with strain-controlled stress application as suggested by Koolen (1974) and with equipment described by Schjønning (1991). Precompression stress, $\sigma_{pc}$, was determined from stress-strain data using the numerical method developed by Lamandé et al. (2017). The twelve remaining cores were tested for shear strength with the torsional shearing device described by Schjønning (1986). In short, two replicate soil cores were subjected to one of six levels of normal load (range 36 to 186 kPa). The torque was measured during the rotation of a shear annulus with a mean rate of 46 mm min$^{-1}$. The cohesion, $C$, and angle of internal friction, $\phi$, were calculated from the Mohr-Coulomb model using normal stress as effective stress.

Series 2 included a total of 48 cores sampled at two depths, 0.13-0.17 m and 0.33-0.37 m, at the six experimental plots in the middle of the wheel/track rut. The cores were taken to a matric water potential of -100 hPa as described for Series 1. Air permeability was then
measured by the procedure described by Iversen et al. (2001): a steady-state advective air flow was established at a pressure gradient of 1 hPa. Air flow was measured by standard flow meters, and air permeability, $k_a$, was calculated according to the Darcy law.

Finally, all cores were dried in an oven at 105°C to determine the dry bulk density, $\alpha$.

2.4 Soil stress calculations

Vertical stresses in the soil profile were calculated using the Söhne summation procedure (Söhne, 1953), which is based on the Boussinesq (1885) solution for the problem of the load transfer from a concentrated normal force to an isotropic halfspace medium:

$$
\pi \int_0^\infty \frac{1}{r^2}f(r)dr = \int_0^\infty \frac{1}{r}P(r)dr
$$

(1)

where the contact area is divided into $n$ small elements, and for each $i$ element, $n_i$ is the vertical stress, $P$ is the vertical point load, $r$ and $\theta$ are the polar coordinates, and $\pi_i$ is the concentration factor introduced by Fröhlich (1934) to account for the elastoplastic behavior of the soil. For $v = 3$, Eq. (1) satisfies the elastic theory of Boussinesq (1885). For a loading condition, the concentration factor increases as soil becomes softer (Koolen and Kuipers, 1983). A value of $v = 5$ was chosen for the experimental conditions (Söhne, 1953). For each pass (2 vehicles $\times$ 3 blocks $\times$ 4 passes = 24 passes), the measured contact stresses beneath the tire or the rubber track were used as input to the Söhne summation procedure (Eq. 1).

2.5 Wheel load carrying capacity maps

The Wheel Load Carrying Capacity (WLCC) was defined by van den Akker (2004) as the maximum wheel load for a specific tire type and tire inflation pressure that does not exceed the strength of the subsoil at a selected depth. We calculated WLCC for all of Europe based on a comparison of stress and strength at a depth of 0.35 m. For the tire, the contact area and the contact stresses for WLCC maps were calculated using the FRIDA model with parameters estimated from the tire dimensions (Schjønning et al., 2015b). For the rubber track, we selected the test with a median value of the measured maximum stress for WLCC calculations. A third, theoretical, loading situation was labeled “perfect rubber track”, assuming a perfectly even stress distribution at the contact between the soil and the rubber track. In such a case, the maximum stress at soil contact is equal to the mean ground pressure. The subsoil strength was estimated from the clay content and the dry bulk density of soil from the SPADE8 database (Koue et al., 2008), and for a soil water potential of -50 hPa using the PTF established
by Schjønning and Lamandé (2018). In this we applied a scaling factor of 0.5 to account for the
effect of shear stresses (as discussed in section 3).

The Spade database was compiled as a follow up of the publication of the Soil map of Europe
on a scale of 1: 1 mill, the Soil Profile Analytical Database (SPADE). This was done to populate
the mapping units on the Soil map of Europe with analytical data. For each mapping unit
national experts formed a representative soil profile with the requested data. In our WLCC
calculations, soil strength was estimated only for polygons with a dry bulk density in the range
1.2 to 1.8 g cm$^{-3}$, corresponding to the range used for the development of the PTF for soil
strength.

2.6 Statistics

Effects of undercarriage (tire vs. rubber track), number of passes, and the interaction of
equipment and number of passes were tested for the measured contact area, $A_m$ (m$^2$), mean
ground pressure, $P_{\text{mean}}$ (kPa), maximum vertical stress at soil contact, $\sigma_{\text{peak}}$ (kPa), and maximum
vertical stress at 0.35 m depth, $\sigma_{35}$ (kPa). None of these variables followed a normal
distribution and a one-way ANOVA on ranks (Kruskal-Wallis test) was applied. Effects of
undercarriage on the dry bulk density and the air permeability were tested using a simple but
robust one-way ANOVA on ranks (Kruskal-Wallis test). Air permeability was log-transformed
prior to the test, and the geometric means are presented. We used the program R (R
Development Core Team, 2005) for all calculations.

3. Results and Discussion

3.1 Contact area and stress distribution in the contact area

The stress distribution beneath the tire presented several peak stresses across the tire and one
maximum peak in the driving direction (Fig. 3). This pattern has been observed in several
studies (e.g. Gysi et al., 2001; Way and Kishimoto, 2004; Keller, 2005; Lamandé and
Schjønning, 2008). The stress distribution beneath the rubber track presented peak stresses at
each of the wheels and rollers (Fig. 3). Similar patterns were reported also for older types of
rubber tracks by Blunden et al. (1994), Keller et al. (2002) and Arvidsson et al. (2011). A tension
of 110 bar was applied to the rubber, but seemingly it was not enough to distribute the load
between the wheels and rollers. There is a large diversity of rubber tracks, which might give
various distribution patterns of the load on contact with soils. However, all studies presenting
stress measurements beneath rubber tracks report high stresses beneath the wheels or rollers
of the tracks. It seems that the technological developments of rubber tracks since the 1990s have not improved the distribution of the load.

The contact area, $A_m$, was significantly larger for the rubber track than for the tire (Table 2; Fig. 3). $A_m$ was not influenced significantly by the number of passes of either type of undercarriage, although it tended to increase with the number of passes of the tire ($P=0.099$; data not shown). Peak stresses in the contact area, $\sigma_{peak}$, were high for both systems, but were higher beneath the tire than the rubber track. As for $A_m$, no variations in $\sigma_{peak}$ were detected with the number of passes (data not shown). For the rubber track, $\sigma_{peak}$ reached 5.7 times the theoretical mean ground pressure, $p_{mean}$, calculated from the load and the contact area (Table 2). A $\sigma_{peak}/p_{mean}$ factor of 3.8 was observed by Keller et al. (2002) for a tractor equipped with rubber tracks. These authors used load sensors similar in principle to those applied in the present study. Accuracy of the sensors was found to be satisfactory in a previous study (Lamandé et al., 2015). Marsili et al. (1998) observed much lower peak stresses using a pneumatic sensor, the response of which (the mean normal stress) depends on the Poisson’s ratio of the surrounding soil. Such sensors are expected to underestimate soil stresses (Keller et al., 2016). For the tire, $\sigma_{peak}$ was 3.9 times $p_{mean}$ (Table 2). This is larger than the $\sigma_{peak}/p_{mean}$ ratio of 3.29 reported by Lamandé and Schjønning (2008) for implement tires loaded to 6 Mg. The difference could be due to the type of tire, as traction tires have higher lugs and a stiffer carcass than implement tires, or it could be due to the larger load.

### 3.2 Calculated stresses in the soil profile

As expected from the contact area and contact stress measurements, the calculated maximum vertical soil stress at 0.35 m depth, $\sigma_{35}$, was higher beneath the tire than the rubber track (Table 2). Across a range of soils loaded at field capacity water conditions, Keller et al. (2012) found plastic (persistent) soil deformation if soil stress exceeded approx. 40 kPa. Based on this, the beet harvester would be expected to induce soil compaction at 0.35 m depth irrespective of undercarriage. Interestingly, $\sigma_{35}$ beneath the tire decreased significantly with the number of passes (285, 238, 199 and 190 kPa for pass no. 1, 2, 3 and 4, respectively). This probably relates to the abovementioned trend of increase in $A_m$ with number of passes. The same pattern was not observed beneath the rubber track, which may indicate less interaction with the soil in the contact area.

Figure 4 illustrates the attenuation of vertical stress with depth for the tire as well as for the rubber track with real and with theoretical contact stress distribution. The difference between the curves for the real and theoretical stress distribution beneath the track indicates clearly
that the rubber track tested is far from utilizing its potential for its large contact area. When comparing the real track with the tire, it should be kept in mind that the load was approximately 1.5 Mg higher for the track than for the tire. Although the comparison is reasonable because of the higher unladen weight of a track-mounted harvester, the failure of a present-day rubber track system to mitigate soil compaction is disappointing. Blunden et al. (1994) showed that the peak stresses beneath rubber tracks propagate to the subsoil, but that peak normal stress measured at 0.5 m depth was lower beneath a tracked than a wheeled vehicle. This is in accordance with our results.

3.3 Loading effects on soil physical properties

The topsoil dry bulk density, $\rho_b$, increased from 1.32 g cm$^{-3}$ prior to loading (Table 1) to approx. 1.45 g cm$^{-3}$ after loading, independent of undercarriage system (Table 3). Topsoil deformation was expected due to the level of peak stresses in the contact area being much higher than the measured precompression stress (Table 1) for both undercarriage systems. For the topsoil layer, air permeability, $k_a$, reduced during loading from $\sim$36 µm$^2$ to $\sim$9 and $\sim$5 µm$^2$ for the tire and the track, respectively, but the undercarriage system effects were not significantly different (Tables 1 and 3). In contrast, in the subsoil $k_a$ was tested significantly smaller beneath the rubber track than the tire (Table 3). From the higher soil stress calculated beneath the tire, the opposite would have been expected. Interestingly, neither could Blunden et al. (1994) measure any difference in dry bulk density, but found a higher penetration resistance at 0.3 m depth beneath a tracked vehicle than beneath a wheeled vehicle. Also in that study, the highest soil stresses were measured beneath the wheeled vehicle. Dry bulk density can help detect changes in the volume of soil pores, but it does not provide information of the direction of deformation. In contrast, $k_a$ is very sensitive to changes in the shape and continuity of air-filled macropores. Our results show that for the subsoil, traffic with the tracked undercarriage led to a larger increase in tortuosity and/or decrease in the continuity of air-filled macropores than with the wheeled undercarriage for the same increase of dry bulk density. This means that deformation by shearing was larger beneath the rubber track than beneath the tire. Shearing dominates at the edge of the loaded area, while isotropic compression occurs mainly beneath the center of the loaded area (Berisso et al., 2013). The distribution of vertical stress in the contact area (Fig. 3) indicates that a tracked undercarriage can be regarded as a series of small wheels passing in the same track inducing more shearing that one pass of a larger wheel. Note that the loamy sand investigated here had a low cohesion at the field water content (Table 1). Comparisons of the effects of rubber-tracks and tires have been performed for various soil conditions, and results are contradictory, as reviewed by Alakukku et al. (2003).
the present study, no effect of the number of passes could be detected beneath the rubber track, but the calculated stresses at 0.35 m beneath the tire decreased with the number of passes (Table 2). This indicates that the largest part of soil deformation beneath the rubber track occurred during the first pass.

The most striking information derived from our results is the significant effect on soil properties in the subsoil at 0.35 m depth. As already discussed, we attribute the significantly lower permeability under the track to distortion of soil from shear forces. Schjønning et al. (2016b, 2017) showed that even with a 6 Mg wheel load, multiple wheel passes (a tractor towing a three-axle slurry spreader) affected soil penetration resistance, air permeability, and crop yields more than a single pass (a tricycle slurry spreader) with a wheel load of 12 Mg. This was interpreted as being due high shear forces for the tractor-trailer system with multiple wheel passes and high traction forces.

3.4 Risk assessment of soil compaction in Europe

The WLCC maps for Europe in figures 5, 6 and 7 show the maximum carrying capacities for soils for three undercarriage systems. We reiterate that stresses from the tire and track were calculated based on the measured results, using state-of-the-art models for stress transmission in the soil profile, and, further, that soil mechanical strength was estimated from soil bulk density and content of clay in the SPADE8 data set (Koue et al., 2008), applying a PTF at a matric water potential of -50 hPa (Schjønning and Lamandé, 2018). The white areas on the maps indicate polygons with missing soil data or dry bulk densities out of range for the PTF for soil strength (please see section 2.5 for details).

As expected from the contact stress measurements (Table 2) and the calculated soil profile stresses (Fig. 4), the maximum wheel load for sustainable traffic was larger for the rubber track than for the tire for a given polygon on the European maps (Fig. 5 as compared to Fig. 6). We defined the “perfect” rubber track as a rubber track of the same dimensions as the one tested here but assuming a perfectly even stress distribution at the contact with the soil. For that theoretical undercarriage system, the maximum wheel load to ensure sustainable traffic was larger than for the real rubber track for a given polygon (Fig. 6 as compared to Fig. 7). We calculated the distribution of the WLCC classes relative to the total mapped area (Fig. 8). For the tire, only a negligible part (1.3%) of European soils is estimated to be able to carry a wheel load above 80 kN. According to our calculations, the use of a rubber track would increase this percentage to 38.1%. This is an important finding because farming operations like slurry
application and harvest of potatoes, sugar beets and maize often take place at soil water
conditions as simulated here.

According to the calculations, using the theoretically “perfect” rubber track would allow
driving on 37.7% of the mapped European soils with more than 120 kN wheel load.
Importantly, this is far from reality because of the documented inability of current rubber
tracks to properly distribute the load across the track contact area (as documented in this and
other studies). We include the result here to encourage further improvements to rubber tracks
for use on agricultural machinery.

In a previous study, we estimated WLCC for European soils at moderately dry conditions (a
matric potential of -300 hPa; Schjønning et al., 2015). In that case, machinery stresses derived
from an 800 mm wide tire, and the estimates related to soil strength at 0.25 m depth. Further,
we took use of another PTF for calculation of soil strength. However, for both PTFs soil
strength will increase with soil content of clay at dry conditions (matric potentials more
negative than ~100 hPa) and decrease with clay at wet conditions. The new PTF applied also
includes a positive effect of soil bulk density on soil strength. We reiterate that in the present
study, WLCC was calculated for wet soil (matric potential of -50 hPa). Based on this, we would
expect small WLCC values for low-density clay soils, and high values for sandy soils with high
densities. This pattern actually fits with our predictions. For the tire-related as well as the
rubber track-related maps, we see low WLCC values for the clay-holding marine deposits in the
marshy areas of Denmark, Germany and the Netherlands (Fig. 5, 6 and 7). Higher values are
observed for the loamy tills in the Eastern parts of Denmark and the Northeastern areas of
Germany, while the highest WLCC is predicted for the sandy soils of Western Denmark and the
Northwestern and Central Germany, the latter deriving from glaciofluvial sandy sediments.

Despite the above encouraging observations, the WLCC maps also display weaknesses of the
Soil map of Europe and the SPADE database. At many of the country boundaries, we see a
jump in the predictions, reflecting unlikely jumps in soil properties. We would recommend the
Soil map of Europe to be updated in several ways; harmonization across boundaries is
necessary. Also, for several countries the soil maps look more like 1:5 mill soil maps than 1:1
mill maps, which calls for expanding the database to cover better the variation of soil
properties.

The maximum wheel loads for sustainable traffic presented on the WLCC maps in this study
are calculated based on the comparison between the maximum soil vertical stress beneath the
undercarriage system and the soil compressive strength at a given depth. This approach
represents state of the art for risk assessment of soil compaction. However, the level of maximum vertical stress might not be sufficient where there is a highly uneven stress distribution beneath an undercarriage system, as indicated by the more pronounced effect of traffic with rubber tracks than with the tire (Table 3). In our WLCC calculations, we attempted to take into account the effect of shear by scaling estimates of precompression by a factor of 0.5. This was based on discussions by Kirby (1991) and results by Keller et al. (2012). The latter study indicated that significant permanent deformation of subsoil was induced when the vertical stress exceeded 0.5 times the measured precompression stress. More studies are urgently needed to quantify the magnitude of shearing forces in the soil profile below tires and rubber track systems.

4. Conclusions

We tested whether the use of rubber tracks instead of tires could prevent subsoil compaction during traffic in agricultural fields in wet conditions. As expected, the contact area was larger and the maximum stress was smaller beneath the rubber track than the tire. The stress distribution beneath the rubber track was uneven with high stresses below the wheels and rollers, indicating that there are still some technical issues to be solved to get an even stress distribution. Calculated maximum vertical stress in the soil profile was lower beneath the rubber track than the tire. Dry bulk density in the upper subsoil was identical for the two undercarriage systems after four machinery passes. However, air permeability was significantly lower beneath the rubber track than the tire despite lower vertical stresses applied. This indicates greater soil distortion due to shear forces beneath the rubber track and is probably because the high peak stresses beneath the track’s wheels and rollers act as multiple passes. A state-of-the-art approach for risk assessment of soil compaction was applied for the use of tires and rubber tracks in Europe and showed a lower risk using rubber tracks. However, according to the findings of this study, risk assessment should not be based solely on maximum vertical stress, but should also include effects of shear forces. Our study also indicates that the Soil map of Europe should be updated in several ways.

Acknowledgments

The authors are highly indebted to the manager of Krenkerup Estate, S. Jespersen, for his help in organizing this experiment, and to professor H. Breuning-Madsen, University of Copenhagen, for giving access to the SPADE8 soil database. The technical assistance of S.T. Rasmussen during the field experiment, of B.B. Christensen and J.M. Nielsen for laboratory
measurements, and M. Koppelgaard for WLCC maps calculations is gratefully acknowledged.

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References


Koue, P.M., Balstrøm, T., Breuning-Madsen, H. 2008. Update of the European Soil analytical database (SPADE-1) to version SPADE8. Report to the European Soil Bureau, EU-Joint Research Centre, Ispra, Italy.

Lamandé, M., Schjønning, P., 2008. The ability of agricultural tyres to distribute the wheel load at the soil-tyre interface. J. Terramech. 45, 109-120.


Schjønning, P., Lamandé, M., Crétin, V., Nielsen, J.Å., 2017. Upper subsoil pore characteristics and functions as influenced by field traffic and freeze-thaw and dry-wet treatments. Soil Res. 55, 234-244.


Table 1. Topsoil (0.13-0.17 m) characteristics of the soil investigated.

| Texture g 100g⁻¹ | <2 µm | 2–20 µm | 20–63 µm | 63–2000 µm | Organic matter | field | -100 hPa | \( \theta \) m⁻³ | \( k_a \) µm⁻² | \( \phi \) m⁻³ | \( \sigma_p \) kPa | C kPa |
|------------------|-------|---------|----------|------------|----------------|-------|--------|---------|-------------|---------|-----------|--------|-------|
|                  | 8.0   | 13.5    | 12.2     | 63.4       | 2.9            | 1.32  | 0.246  | 0.253   | 35.6        | 43.3    | 8.3       | 33     |

*Geometric mean*
Table 2. Mean values of the contact area between the tire or the track and the soil, $A_m$, mean ground pressure, $p_{\text{mean}}$, maximum vertical stress at the contact, $\sigma_{\text{peak}}$, and vertical soil stress at 0.35 m depth, $\sigma_{35}$, calculated using the measured contact stress as input to Söhne’s summation procedure with a concentration factor of 5.

<table>
<thead>
<tr>
<th></th>
<th>$A_m$</th>
<th>$p_{\text{mean}}$</th>
<th>$\sigma_{\text{peak}}$</th>
<th>$\sigma_{35}$</th>
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<tbody>
<tr>
<td></td>
<td>m$^2$</td>
<td>kPa</td>
<td>kPa</td>
<td>kPa</td>
</tr>
<tr>
<td>Tire</td>
<td>0.61b</td>
<td>169a</td>
<td>653a</td>
<td>228a</td>
</tr>
<tr>
<td>Rubber track</td>
<td>1.27a</td>
<td>93b</td>
<td>529a</td>
<td>139b</td>
</tr>
<tr>
<td></td>
<td>$P=0.049$</td>
<td>$P=0.049$</td>
<td>$P=0.126$</td>
<td>$P=0.049$</td>
</tr>
</tbody>
</table>
Table 3. Mean dry bulk density, $\rho_b$, and air permeability, $k_\alpha$, at two depths after four passes by the tire or the rubber track.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Type</th>
<th>$\rho_b$ (g cm$^{-3}$)</th>
<th>$k_\alpha$ (μm$^2$)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.13-0.17</td>
<td>Tire</td>
<td>1.44</td>
<td>9.21</td>
<td>0.954</td>
</tr>
<tr>
<td></td>
<td>Rubber track</td>
<td>1.45</td>
<td>5.49</td>
<td>0.273</td>
</tr>
<tr>
<td>0.33-0.37</td>
<td>Tire</td>
<td>1.56</td>
<td>20.3</td>
<td>0.742</td>
</tr>
<tr>
<td></td>
<td>Rubber track</td>
<td>1.55</td>
<td>7.92</td>
<td>0.041</td>
</tr>
</tbody>
</table>
Figure 2
Click here to download high resolution image
Figure 4
Click here to download high resolution image
Figure 8
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Figure captions

1. Figure 1. Sugar beet harvester equipped with a large traction tire (left) or with a rubber track (right).

2. Figure 2. Procedure for measuring vertical stress distribution at the contact between the wheel/track and the soil. Please consult Schjønning et al. (2008) for details of measurement procedure.

3. Figure 3. Examples of measured vertical stress (kPa) at 0.1 m beneath the tire (left), and beneath the rubber track (right).

4. Figure 4. Calculated soil vertical stress at depths from 0.1 to 2 m below the tire (solid line) and the rubber track (dashed black line). The measured contact stress distribution at each pass was used as input to Söhne’s summation procedure with a concentration factor of 5. The dashed red line without symbols represents the vertical soil stress calculated for a uniform stress distribution below the rubber track. Bars represent standard error (n=12). Figures to the right give P-values where the stresses below tested track and tire were different.

5. Figure 5. Wheel load carrying capacity map for Europe for the tire investigated. The legends give the maximum load (kN) that can be carried by the 1050/50R32 tire without inducing permanent soil deformation at 0.35 m depth.

6. Figure 6. Wheel load carrying capacity map for Europe for the rubber track investigated. The legends give the maximum load (kN) that can be carried by the rubber track tested without inducing permanent soil deformation at 0.35 m depth.

7. Figure 7. Wheel load carrying capacity map for Europe for a rubber track with a perfectly even stress distribution at the contact. The legends give the maximum load (kN) that can be carried by a rubber track with dimensions as the tested (but assuming even stress distribution) without inducing permanent soil deformation at 0.35 m depth.

8. Figure 8. Distribution of European soils into six classes of WLCC for the three undercarriage systems as presented on the WLCC maps (Fig. 5, 6, and 7).
Impact of urbanization on soil production and retention services in periods
different in soil protection level

Case studies: Wroclaw and Poznan

Abstract
1. Introduction

The analysis involves spatial evaluation of agricultural areas over periods with spatial coverage of agricultural areas in the years 1994, 2007, and 2017. This allows to evaluate what types of agricultural conditions for crop production in the current period with and without water management areas. This means that the change in agricultural policies will lead to changes in water retention systems. The European Commision (COM 1, 2006) identified states to initiate the development of agricultural regions, and uses contamination, compaction in biodiversity, and floods and the Mediterranean.
One of the main tasks of your nation is to accelerate the other degree processes (Stzynski 2007).

Consider a pressure applied to the ecosystem and its resilience to the various external influences (Entrop, 2004). Eva of these pressure factors are fundamental to the ecosystem of agroforestry for protection of land and functions. Soil plays a major role in the preservation of environmental stability and a wide area through its potential. Soil quality is a key factor for food quality and biodiversity under population health.

According to the EEA, soil contamination is a major issue for food quality. Soil contamination is a matter of major concern for the European Union (Siebel et al., 2015).

Soil and land take a major role as they practically irreversible processes. Consequently, the accelerated transformation of cultural lands (entrop, 2006) and actual sale in 2006, and 4.4% of the territory is cultivated for agricultural purposes in the EU, are sealed by...
As in Europe (2012) they count to very productive, economic values are strongly needed. Potential protection agencies of character.

As in Europe (2012) they count to very productive, economic values are strongly needed. Potential protection agencies of character.
2. Materials and Methods

2.1. Study areas

- Our work is testing ecological effects of a city in a pressurized urbanization process.
- We evaluate land take rates in these cities and assess quality in urbanisation processes.
- We evaluate ecological aspects of production and recycling of solids, waste for conversion of a cultural land into mandated ministerial acceptance conversion of a sad, in Poland.

- Wroclaw is one of the easiest cities in Poland. It is the administrative capital of Wielkopolska Voivodship. The city area is 85 km², with rural distances to a city 2158 km.
- Posen is round 200 people and the city in city board is 86.6 m.
- Across the city board, the Gawa is one of the longest rivers.
- Across the city board, the Gawa is one of the longest cities.
- Across the city board, the Gawa is one of the longest cities.

- Small city much less represented and cultural in local in the urban part of the city.
The map of USDA soil classes in the area of Poznan, which is a district of Lower Silesia region. It is the capital of Poland. The population is approximately 2 million people. The main city is located on the east side and covers 12 islands in the city. The total city area is 293 km² with a mean elevation of 7 m. Dominant textures of the cultural area are clay and sandy loams, loam in the city part of the city, and loamy sands.

Course soils, such as sandy sands, mainly occur in the north and northeastern sections of the city (Fig. 6). 60% of the agricultural area is used as arable land and only 6% are forested along the Odra and their tributaries. The following centuries are recorded for Poznan: 462, 582, and thousands in the 20th century.
For the purpose of analysis, distances within administrative borders of both cities were measured.

2.2. Analytical approach

This policy insured measures as a commitment to transformation of agriculture and the possibilities for conversion of agricultural land into 1-3 uses. The area then used for agricultural land protection and improvement of land quality or productivity or land protection area was then used for agriculture and improvement of land quality or productivity or land protection area. The decision of the Polish Parliament excluded influence of other economic reasons after 2008 spatial order of agriculture and forestry land protection caused that the area was used as a "ad hoc" decision of investor's part. The order in Slovakia and Czech Republic is approved for transformation of each piece of agricultural area of the best condition class 3 exceeding 0.5 ha. The decision of the cabinet is influenced by the area and its improvement.
I ordered to assess what was called a of with given product for cacies of urbanisation of each class was a a of urbanisation to use for files of interplay of land use context soil quality.

Looking at land use stocks and concerning on-site is important to make a car where the curve land use class is considered for and consequently characterising, less or more sense of that cacy of high productivity or groundwater attention to total cover, years between species – the forest size (measures) of change on soil certain characteristics represents a large change in the convergent as compared to shape of this type in general. The index, a simulation index (I) is proportionate to the extent of agricultural land a given period we calculate. An interpretation of an index is therefore – for example, index of for a given class (e.g., quality (s)) means that with changing land shape of this class is twice a gain in entire total cover.
2.3. Mapping increase in artificial areas
2.4. Mapping soil production and retention ecosystem services
The point system to estimate spatial retention efficiency involves assigning a unique value to each texture polygon on the agricultural map. The values are calculated as the average for each texture polygon at a 1 meter depth. This approach allows for a comprehensive assessment of soil stability and agricultural productivity.
3. Results and Discussion

3.1. Increase in artificial areas in different periods

<table>
<thead>
<tr>
<th>Period I</th>
<th>Period II</th>
<th>Period III</th>
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<tbody>
<tr>
<td>Total artificial areas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrocław</td>
<td></td>
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The expansion of the artificial area in the first period involved extensive conversion of agricultural land, specifically in the north and west of the area. The total area of agriculture has decreased in Period II (1994-2006), indicating a decrease in agricultural areas. The integration of economic development by integrating agricultural and forest land protection has increased the total area from 13.8% in Period I (2006-2017) to 20.3% in Period I (1979-1994). The rate of increase in artificial areas in different periods is shown in Table 2.

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Table 2. Rate of increase in artificial areas in different periods

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The spatial changes of the city's area are evident in Period I, especially in the north and west westward.
The analysis of ends in a city area is conducted in Wrocław. Period I can be counted by less intensity – 1832 in total, with 80 areas (0.33% of the cultural land source within a year period). Period II, in city area we exclude from the protection of cultural areas 1.86 to 0.33 ha).
Analyzing agricultural and urban period I mainly evolved of core and some large developments in outer area. P2007) and I are characterized by less extent of core area artificially used in tea area and behind the core border (Fig.4).

Wroclaw

artificial area until

map

1956
1992
2007
2017
road
river
3.2. Impact of urbanisation on soil production function

...
In Wrocław, production potential is high due to suitable conditions.

Significant parts of these HP areas are located in the area of the city where development pressure on the quality of soils in turn part of the tested area is characterized by very productive potential with a quality index > 65

In general, parts of the city are protected by agricultural land and protected (bonitation classes 1-4).

In total, 6030 ha of cultural land were tested in Poznań since 2006. Within this pool only 11.8% were evaluated, which is a point that Wrocław areas are in majority compared to medium and high-quality sites that T1 index was tested.
I am not sure what the text in the image says. However, it appears to be discussing agricultural soil quality in Wrocław (Poland) with a map of the area and some data tables.
3.3. Impact of urbanisation on soil retention function

Wroclaw
The presence of one of the protective policies raised to 4 times (1). Relatively low intensity of control of HR can hardly be taken as a policy to provide retention at the current level.

In Poznan, especially but also extremely protected is covered by HR (10). HR covers 6% of the area, whereas, for example, in (1) in 2017. This coverage does not represent, meaning that HR is protected in any greater extent. To calculate for HR's role of a full-time employee and 1%.

Poznan

artificial area until:
- 1965
- 1992
- 2007
- 2017

cm available water capacity:
- low (62 - 125 mm/min)
- medium (126 - 175 mm/min)
- high (176 - 200 mm/min)
4. Conclusions

The effectiveness of land protection measures (land protection as a condition of agricultural land intensification) can be achieved through the use of a quality of the same in the context of protecting natural features through the agricultural forest land protection under extensive economy (I) protection of urban areas policy instead but under intensive economy (II) execution of urban areas economic development (III) Rate of these in a given cycle to further determined. It is evident from the data produced for both cases that Wrocław the regulations limit the total rate of artificial surfaces when urban area is selected. This apparently means that the fee levels for transformation of agricultural lands are not sufficiently restrictive. The fees might effectively protect most valuable soils in rural areas, however in urban areas they do not stop investors from sealing soils most capable to fulfill production and retention functions.
to production, the evidence between the periods.

Howe is bank this strategy with any further regulations.

Sadly, the cy of class within the , and right behind the board in period I without protection of best bonitation classes) confirm that a cy

References


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Sy T. Assessment of land use change in Europe in �� context of soil �� c on. P ��y, P oland

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...
Title: Straw mulch as a nature-based solution to delay runoff initiation and reduce soil detachment in clementine plantations in Eastern Spain. An assessment using rainfall simulation experiments

Article Type: Research Paper

Keywords: Clementine; erosion; runoff generation; straw mulch; detachment; rainfall simulation.

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Corresponding Author's Institution: University of Málaga

First Author: Saskia D Keesstra

Order of Authors: Saskia D Keesstra; Jesús Rodrigo Comino; Agata Novara; Antonio Giménez-Morera; Manuel Pulido; Simone Di Prima; Artemi Cerdà

Abstract: Soil erosion is a threat in agricultural soils due to the lack of plant cover as a consequence of the use of herbicides. In Mediterranean areas, citrus orchards exhibit high soil loss rates due to the expansion of drip irrigation that allow the cultivation of sloping terrain, in combination with the preference of farmers to have the soil bare other than the crop. Plantation of new clementine orchards on sloping terrain is carried out with heavy machinery and the intensive mechanization of the crop, which induces high erosion rates after the plantation. To mitigate these non-sustainable soil losses, straw mulch can be considered as an efficient nature-based solution. Therefore, the main goal of this paper was to assess the use of straw mulch as a nature-based solution to reduce soil losses in clementine plantations. Forty paired plots (20 + 20) under rainfall simulation experiments (1 h, 40 mm h⁻¹) on 0.28 m² plots demonstrated that a cover of 50% of straw (60 g m⁻²) delays ponding from 32 to 52 s, the runoff initiation from 57 to 129 s and reduces the runoff coefficient from 65.6% to 50.7%. The effect on sediment transport was even more profound, as the straw mulch reduced the sediment concentration from 16.7 g l⁻¹ to 3.6 g l⁻¹ and the soil erosion rates from 15.7 to 2.6 Mg ha⁻¹ h⁻¹. This research showed that straw can be used as a treatment to control non-sustainable soil erosion rates due to the immediate effect it has to control high soil detachment rates and quick runoff initiation in conventional clementine orchards. We demonstrated that straw mulch is a nature-based solution which: i) reduces the connectivity of the flows at the pedon scale; and, ii) contributes to achieve sustainability.

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Dear Editor,

The paper “Straw mulch as a nature-based solution to delay runoff initiation and reduce soil detachment in clementine plantations in Eastern Spain. An assessment using rainfall simulation experiments” is the result of a scientific research in a research Station in Eastern Spain, Valencia. We found that Straw mulch and no-tillage are very efficient to reduce extreme soil and water losses and improve the soil infiltration, but that they are not accepted by the farmers as a management due to socio-economic concerns.

This paper shows original research developed by a multidisciplinary team from Italy, Germany, The Netherlands and Spain.

We want to submit this paper for the special issue “Preventing and Remediating degradation in soils in Europe through Land Care” handled by the Dr. Jan Jakob Keizer and Rudi Hessel of the RECARE project.

Sincerely
Highlights

- Citrus plantations with bare soils show high erosion rates: 15.7 Mg ha\(^{-1}\) h\(^{-1}\)
- Runoff rates in citrus plantations reach as much as 67% of the simulated rainfall
- Straw mulch reduces runoff up to 50% and erosion rates up to 2.6 Mg ha\(^{-1}\) h\(^{-1}\)
- Sediment concentration can be reduced from 16.7 to 3.6 g l\(^{-1}\)
- Straw mulch is an efficient nature-based solution that disconnects water and sediment flows
Straw mulch as a nature-based solution to delay runoff initiation and reduce soil detachment in clementine plantations in Eastern Spain. An assessment using rainfall simulation experiments

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Abstract

Soil erosion is a threat in agricultural soils due to the lack of plant cover as a consequence of the use of herbicides. In Mediterranean areas, citrus orchards exhibit high soil loss rates due to the expansion of drip irrigation that allow the cultivation of sloping terrain, in combination with the preference of farmers to have the soil bare other than the crop. Plantation of new clementine orchards on sloping terrain is carried out with heavy machinery and the intensive mechanization of the crop, which induces high erosion rates after the plantation. To mitigate these non-sustainable soil losses, straw mulch can be considered as an efficient nature-based solution. Therefore, the main goal of this paper was to assess the use of straw mulch as a nature-based solution to reduce soil losses in clementine plantations. Forty paired plots (20 + 20) under rainfall simulation experiments (1 h, 40 mm h⁻¹) on 0.28 m² plots demonstrated that a cover of 50% of straw (60 g m⁻²) delays ponding from 32 to 52 s, the runoff initiation from 57 to 129 s and reduces the runoff coefficient from 65.6% to 50.7%. The effect on sediment transport was even more profound, as the straw mulch reduced the sediment concentration from 16.7 g l⁻¹ to 3.6 g l⁻¹ and the soil erosion rates from 15.7 to 2.6 Mg ha⁻¹ h⁻¹. This research showed that straw can be used as a treatment to control non-sustainable soil erosion rates due to the immediate effect it has to control high soil detachment rates and quick runoff initiation in conventional clementine orchards. We demonstrated that straw mulch is a nature-based solution which: i) reduces the connectivity of the flows at the pedon scale; and, ii) contributes to achieve sustainability.

Key words: Clementine; erosion; runoff generation; straw mulch; detachment; rainfall simulation.
1. INTRODUCTION

Desertification process treats humankind sustainability, which is affecting arid and semiarid areas such as the Mediterranean territories (Hill et al., 1995; Vanmaercke et al., 2011). Soils are being highly affected by the intensification and non-sustainable agricultural practices (Kairis et al., 2013), and, the future in Mediterranean countries are difficult due to the climate change and the millennia old management (Martínez-Valderrama et al., 2016). Another constrain is the need to make agriculture more productive and the use of pesticides, fertilizers and mechanisation are widespread in the Mediterranean. And citrus plantations are icons of a modern productive agriculture but also they contribute to high erosion rates (Cerdà et al., 2009).

Spain is worldwide well-known for a high-quality citrus production (Picazo-Tadeo and Reig-Martínez, 2006). During the last three decades, the expansion of citrus production in Valencia colonized the hillslopes thanks to the drip irrigation technology (Bono, 2010, Cerdà, 2001). Clementine is a crop that has been moved to sloping terrain to avoid frost events that occur in the valley bottoms due to thermic inversion during the high pressure meteorological conditions in winter. Moreover, the market in Europe, Japan and USA demands easy-to-peel citrus fruits such as clementines. This reallocation of citrus production from traditional flood irrigation systems in the valley bottom inherited from the Muslim culture (Butzer et al., 1985) to the drip irrigated sloping terrain resulted in an increase in soil erosion rates such as Cerdà et al. (2009) and Rodrigo-Comino et al. (2017a) demonstrated. The acceleration of soil erosion rates is a consequence of the sloping terrain (Cerdà and García-Fayos, 1997), bare soils due to the herbicide applications (Gómez et al., 2004; Keesstra et al., 2016a; Novara et al., 2011), and the compaction of the soil surface layer that results in a decrease in infiltration rates (Di Prima et al., 2017). In citrus plantations of other regions in the world
such as China, Brazil, California, Florida or India, soils also showed similar problems due to
the expansion of the citrus production, although measurements are limited and needed and
updated (Wander, 1949; Xu et al., 2012). China is a clear example of non-sustainable soil
erosion rates due to the impact of new chemically managed citrus plantations (Wang et al.,
2010; Liu et al., 2012; Li et al., 2014).

In Spain, during the last twenty years, the expansion of the clementine production due to
the market demands resulted in the colonisation of slopes under conventional farming (Moll
and Igual, 2006). Clementines get a price premium in the market. This growth of the
clementine production resulted also in an increase in the use of herbicides, which is the
most efficient and accepted strategy for farmers (Cerdà et al., 2018). As a consequence,
there is an increase in bare soils in the sloping terrain in the Valencia region (see figure 1).

Soil is a key resource that offers services and goods to the humankind (Brevik et al., 2015;
Rodrigo-Comino et al., 2018), and a healthy soil is vital to reach sustainable management as
was agreed on in the United Nations Sustainable Development Goals (Keesstra et al., 2016b).
To achieve sustainability new management strategies for agricultural production are needed
that will allow economically sustainable production without damaging soil fertility and the
services soils offer (Keshavarzi et al., 2018; Khaledian et al., 2017). For that, nature-based
solutions may contribute to maintaining a healthy soil and avoid impacts in other regions or
in other spheres of the Earth such as the atmosphere (i.e. air pollution) or hydrosphere (i.e.
aquifer recharge) (Keesstra et al., 2018).

In other agriculture soils, the use of geotextiles was found to be positive to reduce soil
erosion rates (Álvarez-Mozos et al., 2014a), but an increase in soil water repellency was
measured due to the hydrophobic substances found in the cotton geotextiles (Giménez
Morera et al., 2010). Moreover, geotextiles are expensive because they need to be
transported from other regions. They can induce biogeochemical changes in the soil due to components that are not natural (Lassabatere et al., 2005), although they can be efficient to solve local problems such as heavy erosion on road and railway embankments (Álvarez-Mozos et al., 2014b).

An efficient nature-based solution for non-sustainable soil erosion rates in agricultural lands is the use of catch crops. Catch crops reduce soil losses (Auerswald et al., 2003; Kort et al., 2008), however, many farmers in the studied region reject their use due to the cost and due to the their perception that they will lose reputation as good farmers, because the community sees catch crops as weeds (Cerdà et al., 2017). Other strategies to reduce soil losses in the region are the use of rock fragments that were found to be very effective when they reach a cover of 60% (Rodrigo Comino et al., 2017b), and also chipped pruned branches that act as a mulch (Cerdà et al., 2018). The use of leaves as litter and other crop residues can reduce soil losses and offer extra ecosystem services such as the removal of the residue (leaves) from the oil production industries (Parras-Alcántara et al., 2016).

Within all the above-mentioned strategies to control non-sustainable soil losses in agriculture lands, the use of straw mulch resulted in an immediate and efficient tool to reduce soil loss (Prosdocimi et al., 2017). Prosdocimi et al. (2016a, 2016b) found that there is a sudden decrease in the sediment delivery in vineyards, once the straw mulch is applied on the ploughed soils. Other previous research showed that straw mulch apart from reducing soil loss, also increased infiltration (Mannering and Meyer, 1963). This research showed that straw mulch is effective both immediately after applying as well as on a longer time scale (Meyer et al., 1970; Döring et al., 2005; Bhatt et al., 2006; Gholami et al., 2013). Recently, the use of straw mulch was applied also to rangelands affected by forest fires (Robichaud, 2005; Fernández et al., 2011; Vega et al., 2014). In Portugal, chipped material was
successfully used as forest mulch (Prats et al., 2012; 2014). These implementations of the
use of straw mulch in large scale projects would show its potential for industrialised hillslope
citrus farming in the Valencia area. Therefore, this work aims to: i) quantify soil detachment
and runoff initiation in conventional clementine’s farming; and ii) assess the impact of straw
mulch as a nature-based measure to control the water and sediment losses. Runoff and soil
erosion were studied using field rainfall simulation experiments.

2. Case Study area and monitoring sites
A clementine orchard was selected to measure the soil land water losses in Eastern Spain
(Valencia Province, Canals Municipality). The research site is located in a sloping terrain (10%
), at 38° 57’ 27”N; 0° 36’ 32”, 230 m a.s.l. (Figure 2a). Mean annual rainfall is 550 mm and
the average mean temperature 16.5°C. The clementine plantation is located on a pediment
on Cretaceous limestones that developed Eutric Regosols (IUSS Working Group WRB, 2014).

3. Materials and methods
3.1. Experimental design and sample collection
Plant cover, rock fragment cover and soil roughness (chain method) were measured
previously to rainfall experiments. Plant and rock fragment covers were determined by
measuring presence (1) or absence (0) in 100 points regularly distributed at each 0.28 m²
plot and the total amount of 1-values was considered representative of each plot.
Roughness of the soil surface was determined within the plot with a 1 m long chain and
measured twice, from up down the plot. The chain was carefully placed on the irregular soil
surface and the roughness coefficient (m m⁻¹).
Forty rainfall simulation experiments (2 types of management – without and with straw mulch - × 20 plots) in a randomize block were carried out at 40 mm h⁻¹ rainfall intensity for one hour on circular paired plots (0.28 m²; Fig. 2b and 2c). Rainfall intensity was 40 mm h⁻¹, which represents an average return period of 2 years at the study area (Elías Castillo and Ruiz Beltrán, 1971). In order to allow comparisons among plots, all experiments were carried out during the Mediterranean summer drought when the soil moisture is low (July). At each plot, runoff flow was collected at 1-min intervals and water volume was measured. Runoff coefficient was calculated as the percentage of rainfall water running out the circular plot. Runoff samples were desiccated and sediment yield was calculated on a weight basis in order to calculate soil loss per area and time (Mg ha⁻¹ h⁻¹). During rainfall simulation experiments, time to ponding (time required for 50% of the surface to be ponded; Tp, s), time to runoff initiation (Tr, s) and time required by runoff to reach the outlet (Tro, s) were recorded. Tp was determined when ponds were found and Tr when those ponds were communicated by the runoff. Tr-Tp, Tro-Tr and Tro-Tp were calculated and they indicate how the ponding is transformed into runoff and how much the runoff in the soil surface last to reach the plot outlet. More information about the use of these rainfall simulators to asses one plot or to compare different territories can be found in Keesstra et al. (2016a) and Rodrigo Comino et al. (2016).

3.3. Laboratory analyses

Soil samples were collected by the ring method for the 0-60 cm soil layer to determine the bulk density. Soil water content (%) was measured on a weight basis after drying the samples (105°C, 24 h). Soil organic matter was determined by the Walkley-Black method (Walkley and Black, 1934).
3.4. Data analyses

General descriptive statistics were calculated for the environmental paired-plot characteristics (average, standard deviation, maximum and minimum values, coefficient of variation, Skewness and Kurtosis) and the hydrological response (average, standard deviation, maximum and minimum values). Soil erosion results (runoff coefficient, sediment concentration and soil loss) were depicted in box plots adding the mean (dash lines) and median values, and the results between 5th and 95th percentiles. Hydrological responses was summarized in a table.

Differences among treatments (control and straw) in hydrological response and soil erosion results were compared. To check the normal distribution of data, the Shapiro-Wilk test was conducted. To assess the significant differences among treatments an ANOVA-one way was conducted. If the normality test failed, a Tuckey test was used to find differences among treatments. Finally, Spearman’s rank correlation coefficient was computed to assess the possible influence of environmental plot variables on hydrological responses and soil erosion results. SigmaPlot 12.0 (Systat) was used to perform all the statistical analysis.

4. RESULTS

4.1. Treatment effectiveness in terms of targeted and non-targeted variable on soil properties

The slope angle of the plots ranged from 7 till 16% with an average of 10.4 (C) and 10.2% (S).

Rock fragment cover was 12.5 and 14.6% and plant cover 4.2 and 4.1% for the control and straw plots, respectively. The straw cover (applied after the soil surface measurements and soil sampling) showed the unique difference between control (0.0%) and straw plots.
Soil properties also showed no statistically significant differences. Bulk density was 1.33 and 1.34 g cm$^{-3}$, and the soil organic matter was 1.28 and 1.29% on average for Control and Straw, respectively. Soil surface roughness was very low due to the lack of litter cover and the smooth surface relief as a consequence of the pass of machinery and the use of herbicides (see figure 1). Soil moisture was 5.5 and 5.0% and no significant differences were found.

4.2. Treatment effectiveness in terms of principal soil threat for soil erosion results

4.2.1. Runoff generation

The control plots showed on average 82% of the surface bare, meanwhile the straw covered plots were 44.5% bare. Average time to ponding was found after 32 and 52 s for Control and Straw plots. The runoff initiation was measured after 59 and 128 s, and the runoff initiation reached the plot outlet after 98 and 194 s. Those numbers showed that the runoff generation was faster in the Control plots than on the Straw covered plots. Some numbers also showed the impact of straw cover on runoff generation. The mean time from the ponding till the runoff initiation was 27 s on the Control plots, meanwhile at the Straw plots the average runoff was 76 s delayed from the ponding time. Another key parameter that identifies the contrasted response of the straw covered plots is the fact that the mean runoff reached the outlet of the plot after 67 s since the runoff initiation, meanwhile on the Control plots the runoff was found after 39 s. From the mean ponding time till the runoff outlet the Control plots show 66 s on average and the Straw plots 142 s.

4.2.2. Runoff discharge

Runoff amounted to 26.3 l out of 40 l of rainfall in the Control plots. In the Straw plots the runoff discharge amounted to 20.2 l. This is a runoff coefficient of 65.6 and 50.5%
respectively for Control and Straw plots. The variability of the runoff was similar in both sets of plots. The runoff discharge ranged from 22.8 till 28.5 l in the Control plots and from 16.1 till 22.5 at the Straw plots. The differences between Control and Straw plots were statistically significant for the runoff discharge parameters (Table 4).

4.2.3. Sediment concentration

The sediment concentration was highly affected by the straw application. The twenty bare plots generated runoff with 16.7 g l$^{-1}$ of sediment, meanwhile the straw covered plots contributed with 3.6 g l$^{-1}$. The values ranged from 12.3 till 20.1 g l$^{-1}$ at the Control plots, and from 2.3 till 4.8 g l$^{-1}$ at the straw mulch covered plots. Statistically significant differences were found (Table 4).

4.2.4. Soil erosion

The total sediment detached from the 0.28 m$^2$ plots was calculated: 439 g and 73 g for the Control and Straw plots, respectively. That means soil erosion rates of 15.7 and 2.6 Mg ha$^{-1}$ h$^{-1}$, respectively. The sediment yield ranged from 314 till 559 g and from 44.3 and 104.2 g for the Control and Straw covered plots. Soil erosion ranged from 11.2 and 20 Mg ha$^{-1}$ h$^{-1}$, and from 1.6 and 3.7 Mg ha$^{-1}$ h$^{-1}$ for the Control and Straw covered plots. Statistical significant differences were found for soil erosion, runoff discharge and sediment concentration (Table 4).

Straw as a key factor
After conducting a Spearman rank’s coefficient, the straw was found to be the key factor that explained the differences between the paired plots either for the runoff generation as for the runoff discharge, sediment concentration and soil erosion (Table 4). All the other parameters measured did not show any influence on the changes within the two-paired set of plots. It was also found that soil erosion is highly dependent on the sediment concentration, which is the factor that was most affected by the use of the straw mulch.

5. DISCUSSION

5.1. Treatment effectiveness in terms of principal soil threat

There is a clear impact of the application of straw mulch on highly degraded soils from Clementine plantations due to the role straw plays as a protective cover. Figure 3 shows the distribution of the soil erosion, sediment concentration and runoff for the two sets of twenty plots: Control and Straw. In general, the study plots showed a low cover of plants and rock fragments. However, they were evenly distributed and the straw cover added to the Straw plots made the difference related to the soil erosion, sediment concentration and runoff discharge. Figure 4 shows the relationship between the total cover and runoff discharge, sediment concentration and runoff discharge. The plots under the cover of straw mulch show a much lower runoff discharge, sediment concentration and soil erosion. There are five processes the straw cover changes: Splash erosion, interception, the ponding potential, infiltration and the connectivity in the plot.

5.3. Overall discussion

5.3.1. Changes in the splash erosion process
There is a clear contrasted behavior due to the role straw plays to reduce the raindrop impact. This is why the splash erosion is reducing as the raindrop impact reduces his detachment effect on the soil floor when straw is present (Bisal, 1960). There is a need of more research on the splash erosion, and this research should be addressed to find new and sustainable managements that will reduce the raindrop impact (Fernández Raga et al., 2017). Straw acts as a protective cover against the raindrop impact and this reduces the soil erosion rates such as Gholami et al (2013) measured. This verifies previous research developed under field, laboratory and modeling approaches (Poesen et al., 1986) and the key issue is that the soil surface cover is relevant for the splash erosion and then affect the sediment delivery (Angulo-Martínez et al., 2012).

5.3.2. Ponding potential

The plots under the cover of straw mulch show more cover due to the addition of the straw (an increase in 50%). The straw increases the time to ponding and the time the ponded surfaces need to overflow to connect is much longer (Fig. 4). First of all, some of the rainfall is intercepted by the straw, which delays the wetting of the soil surface. Furthermore, the straw creates a rougher surface; creating more potential ponding surface. The effect of straw interception of the rainfall is one of the causes of the delay in the runoff initiation and as a consequence in the total runoff discharge. The change in the rainfall-runoff process due to interception is well-known in forest hydrology where the role the litter plays in the interception was already found by Helvey and Patric (1965) who showed that there is a clear control of the biomass and the storage and drainage capacity of the litter (see also Pitman, 1989). This is also true for other biomass such as straw. The effect of the amount of straw and other mulches and covers is a key topic that must be deeply investigated. An example of
this type of research done for forest litter is Acharya et al. (2017), but in general there is little information available for the effect different type of mulches that are used for soil protection or soil improvement has on the interception and ponding processes.

5.3.3. Infiltration and the other side of the coin: runoff impacts on sediment yield

The straw reduces overland flow velocity and this will increase the infiltration, and therefore reduce the amount of runoff. Similar effects were found by the emergent vegetation (James et al., 2004), in wetlands (Kadlec, 1990) and in vegetated channels (Carollo et al., 2002). The effect of vegetation stems is also researched and found the factor of overland flow hydraulics changes (Zhao et al., 2016) and explain the impact of vegetation on the resistance to overland flow in grasslands and shrublands.

The low and slower runoff reduces the potential of the runoff to transport sediment. This in combination with the lower splash erosion due to the protection of the soil by the cover, reduces the amount of sediment delivered to the outlet of the plots significantly (Table 3).

5.3.4. Plot scale connectivity and implications for upscaling

The straw mulch can be a key factor to contribute to disconnecting the hydrological and erosional system as described above. The hydrological system is impacted by the cascade of interception, ponding, infiltration and finally runoff. The erosion process is more complex, the three mechanisms of the erosion process are all impacted by the use of straw mulch.

First of all, both splash as well as sheet and rill erosion is reduced. The splash erosion because of the protective cover, reducing raindrop impact (Fernández Raga et al., 2017). However, our measurements were carried out at pedon scale and the changes in scale in hydrology are complex (Renschler and harbour, 2002; de Vente and Poesen, 2005). In fact,
Smets et al. (2008) found that there is an effect of the spatial scale on the effectiveness of mulches in reducing the soil erosion. The research presented here confirms that at pedon scale there is an effect of the mulch on runoff initiation and runoff production as was already found by Kramer and Meyer (1969). This process of reduced runoff affects the soil erosion at slope and watershed scale also due to the increase in the role of sinks and then the reduction in the connectivity of the flows (Parsons et al., 2015). Exactly how the pedon process has its effect downstream is an issue that is under discussion over the last years. Several studied have attempted to clarify how land use and management determines the connectivity along watersheds and river behaviour in different climatic zones around the world: in the semi-arid prairies of the USA by Ward and Stanford (1995), in Mediterranean Australia by Fryirs et al. (2007); in semi-arid (Marchamalo et al., 2016) and humid (Masselink et al., 2017) Spain. However, a large-scale study on many catchments in Italy showed that apart from the connectivity within the catchment, also the type of sediment sources can be an important factor in the amount of sediment delivery (de Vente et al., 2006). Also geomorphological features (Cavalli et al., 2013) and man-made structures (Mekonnen et al., 2017) impact the final connectivity of a catchment in terms of water and sediment. However, the small-scale features may have large-scale impacts. Already in 2004, Imeson and Prinsen found that vegetation serves as the key sink in semiarid landscapes, which was also found by López-Vicente et al. (2013) under different plant cover in the Pyrenees. Our research demonstrates that the straw mulch can also act as a sink of water and sediments and then dis-connect the flows. Other researchers found similar results with other strategies to reduce soil and water losses in forest and agriculture land (Mekonnen et al., 2017). In our study case, straw mulch has proved to be a very efficient dis-connecting
element. However, even though we can say the implementation of straw over a whole clementine orchard will reduce the runoff and erosion problems, the accumulated reduction for the whole orchard needs to be measured using a different scale approach.

5.3.5. Nature-based solutions (NBSs), why should they be preferred

The soils in the clementine’s orchards are poor in organic matter and bare surfaces, which results in high soil and water losses. To solve this poor condition, there is a need to first of all stop further degradation and secondly, the soil needs to be restored to be able to function again, and provide the soil functions these soils now have largely lost. Nature-based solutions like straw mulch can be an option to achieve these goals. In a recent review on nature-based solutions in land management (Keesstra et al., 2018) it was explained that there are two types of NBSs, soil and landscape solutions. The use of straw mulch can be seen as a soil solution; it immediately brings the erosion and water loss reduction, as was explained in this study. It will also generate higher water availability for the plants due to higher infiltration. But on the longer term, the straw will increase the soil organic matter, improve the soil physical properties and improve the soil moisture and temperature (Ramakrishna et al., 2006; Mulumba and Lal, 2008; Jordán et al., 2010). It was also found to have a positive effect on nitrogen management (Verma and Bhagat, 1992; Döring et al., 2005), and on the soil microbial biomass (Tu et al., 2006). In addition, straw mulch is an agricultural, local (it is to be preferred over mulch made from residues from the citrus plantation itself), and natural product which needs to be shown as an efficient nature-based solution that can enable the farmers to achieve sustainable management.

6. CONCLUSIONS
The use of straw mulch is very efficient to reduce soil and water losses on chemically managed clementine plantations. The use of straw reduces the runoff by 1.3 times, the sediment concentration by 4.63 times and the soil erosion rates by 6 times. This was an immediate effect due to the impact of the straw mulch against raindrop impact and runoff velocity. Our research demonstrates that there is a clear delay in the runoff initiation and runoff velocity due to the straw mulch. We conclude that straw mulch is a nature-based solution against non-sustainable soil and water losses found in conventional clementine orchards in the Mediterranean belt. Straw mulch has the capacity to act as a sink and reduce the connectivity of the surface flows and with that the sediment delivery.

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References


https://doi.org/10.1080/02757259509532278


the role of geomorphologists in land management research and implementation.
Geomorphology, 47(2), 189-209.

Robichaud, P.R. 2005. Measurement of post-fire hillslope erosion to evaluate and model
rehabilitation treatment effectiveness and recovery. International Journal of Wildland
Fire, 14(4), 475-485.

Rodrigo Comino, J., Iserloh, T., Lassu, T., Cerdà, A., Keesstra, S.D., Prosdocimi, M., Brings, C.,
Marzen, M., Ramos, M.C., Senciales, J.M., Ruiz Sinoga, J.D., Seeger, M., Ries, J.B.,
2016. Quantitative comparison of initial soil erosion processes and runoff generation

Rodrigo-Comino, J., García-Díaz, A., Brevik, E.C., Keestra, S.D., Pereira, P., Novara, A., Jordán,
A., Cerdà, A., 2017a. Role of rock fragment cover on runoff generation and sediment

Impact of Land Abandonment on Soil Erosion in Mediterranean Agriculture Fields.
Pedosphere. https://doi.org/10.1016/S1002-0160(17)60441-7


Smets, T., Poesen, J., & Knapen, A. 2008. Spatial scale effects on the effectiveness of organic
mulches in reducing soil erosion by water. Earth-Science Reviews, 89(1), 1-12.

Tu, C., Ristaino, J.B., Hu, S. 2006. Soil microbial biomass and activity in organic tomato
farming systems: Effects of organic inputs and straw mulching. Soil Biology and
Biochemistry, 38(2), 247-255.
https://doi.org/10.1016/j.scitotenv.2011.01.034


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Table 2. Hydrological parameters related to the runoff generation Av±: Average and standard deviation; Max: Maximum; Min: Minimum; Diff.; Statistical differences; *Shapiro-Wilk did not pass, Tukey. Tp: Time to ponding; Tr: Time to runoff generation; Tro: Time to runoff in outlet; Tr-Tp: Time to runoff generation minus time to ponding; Tr-Tro: Time to runoff in outlet minus time to runoff generation; Tro-Tp: Time to runoff in outlet minus time to ponding.

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Table 2. Hydrological parameters related to the runoff generation

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Av±: Average and standard deviation; Max: Maximum; Min: Minimum; Diff.: Statistical differences; *Shaphiro-Wilk did not pass, Tukey.

Tp: Time to ponding; Tr: Time to runoff generation; Tro: Time to runoff in outlet; Tr-Tp: Time to runoff generation minus time to ponding; Tr-Tro: Time to runoff in outlet minus time to runoff generation; Tro-Tp: Time to runoff in outlet minus time to ponding.
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Diff.; Statistical differences; *Shapiro-Wilk did not pass, Tukey
Table 4. Spearman rank coefficient among environmental plot characteristics and hydrological response

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*: p<0.05; R.f.: Rock fragments; BD: Bulk density; SOM: Soil organic carbon; R: Roughness; SWC: Soil water content; V.C.: Vegetation cover; Tp: Time to ponding; Tr: Time to runoff generation; Tr-Tp: Time to runoff generation minus time to ponding; Tro: Time to runoff in outlet minus time to runoff generation; Tr-Tro: Time to runoff in outlet minus time to runoff generation; Rc: Runoff coefficient; SC: Sediment concentration; Se: Soil erosion
Case study number 8

Country: Iceland

Authors: Thorsen, J.

Affiliations: Icelandic Consulting Company, Gunnthor, Hellin

Principal soil area: Desertification

Additional soil area: Wind erosion and demonstration:

1. Sheep seeding
2. Lupine seeding
3. Organic fertilizer

Version 1.0

Date: 6.2.2018
Individual and organized climate warming began in the 18th century (Edgerton and Lancaster 1993) with up to 1,788 m.

Gunholt and others is the founder of the key wind erosion and desiccation association in Iceland as of the region's (Gigon 2011; Olgeisson 2007) leaving only eolian deserts behind. The best known occurring in the late 19th century, this material has been the source for repeated erosion episodes, the last and carries considerable sandy and volcanic deposits from the immediate Mt. Hekla as south into the end of the 19th century. Today, as a result of climate activities focusing on ecological restoration in Iceland (SC�� was established with its headquarters in the capital, focusing on ecological reforestation wherever possible and in the ecosystems Ágússon, 1997; Olgeisson, 2007; Ólafsdóttir and Ásmundsson 2011). To today, producing fertile soils, hence increasing the resilience and sustainability of the possible to claim, often with diverse plant communities, and what is more important, active foes. Likewise, that we previously black basaltic deserts we now apply equipment became available, as successes we made in the fight against the wind and water has been an intrinsic part of Icelandic landscapes since 2007. Initially the work was based on traditional methods, but as seed, fertility and Gunholt and soon took over the organized land climate work Edgerton and Lancaster, 2015; Thórnson, 1944). These pieces make them inordinately unstable and fragile if they typically having low bulk density, high water holding capacity and low particulate cohesion of Icelandic soils. They are classified as Andosols, soils common throughout the winter. Consequently, wind and water erosion are both active processes, wind erosion is often responsible for modulating degeneration events. Currently, severe soil erosion has been estimated to affect at least 50% of the Icelandic islands as severe and extremely active steps have been taken to stabilize the defting sands (Elgstrand et al., 2013).
A project by the ÍÐ, starting in 1990, focused on involving farmers in land restoration, and was an exception from the traditional approach when the ÍÐ was responsible for most such work. The project was called "Heal the Land" where the farmer would get support in the form of fertilizer and sometimes seed from the ÍÐ to improve the land, but the distribution and provided machinery were their own (Petudottir et al., 2017). This was a strategic change as the farmer was involved in planning and managing the restoration of the lands and has been considered a success although there are some indications that the farmer sees them as passive recipients (Petudottir et al., 2017).

The approach introduced by REAR is novel in Iceland. Involving stakeholders from the beginning has not been practiced and is not the current way of planning land restoration projects, although that is suggested as part of the best practice (Hallsson et al., 2012).

Case Study area and monitoring sites
Two main sites within the Gunnaholt case study area were selected in the spring of 2014, thus occurring before the stakeholders had met to select their preferred methods. These sites are referred to as the No Í and South sites, respectively, Í and Í respectively. They differ in soil type and vegetation as outlined in Table 1, and to the fact that the No Í site already has

Figure 1. A red map of the proposed Icelandic case study area. The No Í and South sites are shown as N and S, respectively. The inset shows a typical area of the region. See also Table 1.
Established to run projects with different treatments which the stakeholders were expected to select, as the opportunity to establish treatments based on the stakeholders preference. This approach was considered necessary as the responses to the selected activities were expected to show slow feedback due to the fact this involved dedicated area in a sub-arctic land where ecosystems mimicking processes inside slowly. This was to increase the probabilities of being able to assess the long-term responses of the selected methods.

No site

The No site was originally established in 2000 as a part of landclamation activity in the area. It is on pumice deposits categorised by frequent elevation of the volcano Hekla (Hólas and Lámsen, 2007) and has little vegetation capable 1 and is the best suited for assessing treatment inputs severely challenging conditions. The treatments at the site include sowing of Nootka lupine (Lupinus nootkatensis) leymus grass (Leymus arenarius) willow (Salix lanata) and birch trees (Betula pubescens). Found different treatments and controlled was selected and the 10 x 10 m experimental plots were established in each of the sites in Figure 2.

Figure 2. Treatments in sequence and location of 10 x 10 m experimental plots at the No site.
The site is a part of a new land cultivation activity hence allowing adaptive management in terms of activity design and selection. It was exposed to dramatic events in the late 19th century featuring sand and enclosed leaves as of the Gunna holm resulting in an erosion event that lasted the weeks and left the area deforested. Today the underlying lava is partly exposed but mostly covered in eolian sands, with pockets of old Cambic Vit soils embedded beneath. Chunks of birch, originating from 3 km north of the site are found at the site. The thickness of the original mineral soil profile that was eroded during this event may have been up to 2 m thick on average, based on the current erosion fronts left behind after the event. The treatments consist of bone meal application with and without fescue grass seeding (Festuca chaschoni and birch planting. The 10 x 10 m plots have been established in the treatments as different years as well as in two controls, edited and vegetated that escaped the soil erosion episode in the late 1800s. More plots will be added in summer 2018. The site, with the treatments and location of the experimental plots as shown in figure 3.

Figure 3. Treatment areas and number to the corresponding area was utilized/seeded and location of 10 x 10 m experimental plots at the No site. Treatment details are not shown. Control plots indicated with arrows and V to edited controls and vegetated controls, respectively. Plots to be added in 2018 not shown.

Table 1. Site descriptions.
<table>
<thead>
<tr>
<th>Location</th>
<th>Dominant soil type</th>
<th>Vegetation cover</th>
<th>Altitude</th>
<th>Annual precipitation</th>
<th>Annual temperature</th>
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<tbody>
<tr>
<td>Northern</td>
<td>Pumice Vitisoll</td>
<td>&lt; 10%</td>
<td>150 m</td>
<td>&gt; 1000 mm</td>
<td>&gt; 3.5 °C</td>
</tr>
<tr>
<td>Southern</td>
<td>Anic / Incimic Vitisoll</td>
<td>&gt; 10%</td>
<td>130 m</td>
<td>1000 mm</td>
<td>3.5 °C</td>
</tr>
</tbody>
</table>
The stakeholder meeting in November 2015 was organized for them to identify their most preferred methods for the Guinaholt case study, i.e., landclamation on deforested land exposed to wind erosion. Use of organic fertilizer and manure legume and sowing included highest on their list. The site is currently using organic fertilizer in the form of bone meal, processed farm slaughter waste, in its operations, but use of sludge and manure is limited due to lack of availability and current transport feasibility. For this reason, bone meal was eventually selected as fertilizer for the activities, amended with fescue grass when native grass seed source was not present, as aged upon by the stakeholder.

No bone meal treatment is present at the North site as those treatments were established before bone meal became available.

For sowing species, sowing with bihold highest followed by the use of legumes, Nootka lupine, clover and sea pea (Lathyrus japonicus). Nootka lupine is an invasive species and is no longer used and suitable seed of neither clover nor sea pea was available, although the site is currently working on establishing its first sea pea seed field for landclamation use in the future. Because of this, these methods could not be selected for the site when treatments were designed and set up. Both were present in limited part of the area and planted to cater strategic seed-source islands—wind. This sowing was not included as it would not have produced any significant results within the timeframe of the project. Both was also present in the North site treatments. It was the general conclusion at the first stakeholder meeting that the cut was set by the stakeholder was met, with the obvious omission of legumes and bihold sowing.

An overview of the treatments is given in Table 2.

### Table 2

<table>
<thead>
<tr>
<th>Selection</th>
<th>Description</th>
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<tr>
<td>Northern site</td>
<td>Soutern site</td>
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<tr>
<td>Bihold planting</td>
<td>Bihold planting</td>
</tr>
<tr>
<td>1,000 plants ha-1</td>
<td>1,000 plants ha-1</td>
</tr>
<tr>
<td>Salix planting</td>
<td>Salix planting</td>
</tr>
<tr>
<td>1,000 plants ha-1</td>
<td>1,000 plants ha-1</td>
</tr>
<tr>
<td>Lupine sowing</td>
<td>Lupine sowing</td>
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<tr>
<td>5 kg ha-1</td>
<td>5 kg ha-1</td>
</tr>
<tr>
<td>Organic fertilizer with fescue grass sowing</td>
<td>Organic fertilizer with fescue grass sowing</td>
</tr>
<tr>
<td>1,000 kg ha-1</td>
<td>40 kg ha-1</td>
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<td>Contaminated (x)</td>
<td>Contaminated (x)</td>
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<tr>
<td>*Stated in methods</td>
<td>Absent</td>
</tr>
</tbody>
</table>

‡: present but no specific treatment (x)
Biomass and soil samples were analyzed for total C and N. Data collection is still ongoing. Due to complications in the 2017 field season, which was intended to be the last data collection season, some data has not yet been collected and will not be collected until summer 2018. This will delay the final report of the case study.

The main data to be collected includes sampling all plots shown in Figures 2 and 3, and adding plots at the southern site for the 2016 activity as well as in the native path. Runoff will also be measured for all experimental sites using a portable rainfall simulator based on Ishio et al. (2012). The rainfall simulator data is critical to assess the treatments as one of the key goals in order to stop desertification and wind erosion is to stabilize the surface, hence reduce water erosion.

Wind erosion is being monitored at the southern site using both dust traps (Elstad et al. 1986) and in situ particle count (Sensit Inc., CA, US; Gillet and Cockton, 1986). This will be continued until end of summer 2018.

Figure 4 shows biomass data at the northern and southern sites. Control, L = lysimeter, S = willow, B = bioc, Lu = lupine, and B = bone meal indicate the treatment year. The horizontal bar indicates SE to the mean.

The graph shows biomass in kg/ha at the northern and southern sites for different treatments. The biomass is highest for the lupine treatment, followed by the bioc and bone meal treatments.
Figure 5. Overview of the different treatments: legumes and lupine at the site and bonemeal (BM) at the site T. The image shows control site; L & lupine site but that treatment was only present at the BM site and shows also very fast and promising response. A peas, also suggested by the stakeholders as feasible were not tested due to limited seed availability. Also with sea peas as, however ongoing and already promising Hanssson, pers. comm. and will be able to be used in landclamation in the future. It can thus be assumed that the stakeholders’ choice of that species would have shown to be successful.

Methods aiming at landclamation in deforested areas, where freezing processes are frequent, soils with Andic soil pedoses can be present - and precipitation is relatively high, must induce key changes to the environment within a short period of time. Each of these systems holds presented by intrinsically unstable substrates subject to wind and water erosion that need to be overcome (2015). Additional approaches used by the ICIS to apply include increment of soil nutrient availability and stabilization of the substrate, achieved by the addition of key nutrients and seeding species able to establish within the first growing season, if suitable seed source is not present at the site (SCE staff, personal communication). Some of the methods suggested by the stakeholders included additional and already belong to the ICIS toolbox, but others are new. The apparent success of the preliminary data seems to indicate that the Icelandic stakeholders have good understanding of how ecosystem processes function and how they can be informed to stop degradation and initiate vegetation succession. A dotted 013) assessed the driving behind ecological restoration in Iceland. Among the findings was that...
Conclusions
This outlines the activities that have been selected and implemented at the Gunnaholt case study. This case study focuses on implementations claiming desired land exposure to wind erosion. The approaches being used were selected by local stakeholders at the second stakeholder meeting. Progress and preliminary results are expected as final data on the methods preferred by the stakeholders will be collected in summer 2018.

Acknowledgements
Augusta Helgadottir, Anne Árnadóttir, and Thórunn Ás are all participants in the work described. Their contributions are invaluable.

References

Aldís, Á., Árnadóttir G.L., 1997. To live in peace with your land [Að búa í sátt við landið], Iceland Agriculture Culture Meeting. The Iceland Agricultural Association, the Iceland Agriculture University of Iceland, the Icelandic Conservation Society of Iceland, Holar University College, Institute of Fish and Fisherman, The Agricultural Economics Iceland, Matis, Reykjavik, pp. 126-35.

Aldís, O., 2015. The islands of Iceland. Óning Docecht.


Title: Effect of riparian vegetation on stream bank stability in small agricultural catchments

Article Type: VSI: Testing soil conservation

Keywords: Stream bank stability; agricultural catchments; root reinforcement; pore water pressure

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Abstract: The hydrological processes associated with slope stability are complex and so difficult to quantify, especially because of their transient effects (e.g. changes throughout the vegetation life cycle). Additionally, there is very limited amount of field scale research focusing on investigation of coupled hydrological and mechanical influence of vegetation on stream bank behaviour in small agricultural catchments, accounting for both seasonal time scale and different vegetation types, and none dedicated to marine clay soils (typically soil type for Norway).

In order to fill this gap we established hydrological monitoring of selected cross-sections within a stream bank, covered with different types of vegetation, typical for Norwegian agricultural areas (grass, shrubs and trees). The soil moisture, soil temperature, ground water level and stream water level were continuously monitored. Additionally, soil porosity and shear strength were measured regularly. Observed hydrological trends and differences between three plots (grass, tree and shrub) were analysed and formed the input base for stream bank stability modelling. There are no particular differences between the grass and shrub plot but there is a significantly lower soil moisture content, lower soil porosity and higher shear strength observed within the tree plot. All three plots were stable during the monitoring period, however modelling scenarios made it possible to analyse potential differences in stream bank stability under different vegetation cover depending on root reinforcement and slope angle.
Submission of original research paper

Dear Editor,

With this letter, we would like to submit our title: "Effect of riparian vegetation on stream bank stability in small agricultural catchments".

In our research, we present results of an investigation of hydrogeological effects of vegetation on stream banks (seasonal hydrological monitoring, soil moisture and pore water levels under vegetation treatment and water level in streams). We test the sedimentation model of stream banks and the importance of long streams among landscape types, could be efficient and sustainable solutions to water-related problems.

As shown, this research is suitable for the TE, especially the Special Issue dedicated to soil sedimentation measures. We encourage any comments or suggestions by the editors.

Of all, D. Krawczuk

Cover letter
Abstract:

Hydrological processes with slopesility are difficult to quantify, especially because of the interactions (e.g., changes throughout the life cycle). Additionally, this very limited number of findings requires additional investigations concerning hydrological and mechanical interactions of vegetation on streambanks. The scale of such investigations is small, and the analysis is conducted at a time scale of effect vegetation types and categories. Biological trends and differences between grass and moss but it is significantly lower than the higher strength observed with these scenarios and it is also possible to analyze potential differences between banks stability.

Click here to download Abstract: 07_Abstract_Krzeminska.pdf
Highlights

Stream bank stability depends on hydraulic actions
Vegetation on stream banks has ecological influence on stability
Tree roots provide high bank reinforcement

Highlights (for review)
Effect of riparian vegetation on stream bank stability in small agricultural catchments.

Abstract:

Technical processes with optimal stability are difficult to quantify, especially because of the transitory nature of vegetation life. Additionally, the study area is limited in terms of field research and investigation of coupled hydrological and mechanical influence of vegetation on stream bed stability in small agricultural catchments. The soil type is typical of Norway (typical soil type), and soil porosity and shear strength were measured. Observations of hydrological processes differ between plots (grasses and shrubs), as differences in the observed soil moisture content, porosity, and other parameters. All three plots were measured historically, but it is possible to analyze the differences in stream bed stability and vegetation cover root reinforcement and slope acting.
1. Introduction

I frame was casted in order to both increase the intensity of precipitation at lower, national names are expected to boost their impact on topic (e.g., Yagar et al., 2014; Hansen-Barr et al., 2008). The area among long led to that fire will be affected by another stream of failures often occur in dry (Tobar et al., 2009) or dry weather. Vegetation buffer zones are often common measures in Norway to improve quality in agricultural treatments (e.g., Blackberg et al., 2016). While these measures aim to slow and retain the same articles from industrial might have significant influence on the site or objectives, 11

S most usual context are water pressure and frictional resistances that are important for influencing soil resistance (e.g., Simonet et al., 2009; Baré & Van As, 2000; Kritzin et al., 2009). The partial soil movement increases the risk of soil migration and soil. Additionally, the proportion of water increases the unit weight of the black mixture ensuring more stable. Addi-

The use of vision to utilize hot receivessignificant count of scientific (e.g., Gray et al., 1995; Abery & Runford, 2000; Get et al., 2009) sal cede interactions occur between vegetation and black stability processes at effect on oxygen ability may be broadly classified as other mechanisms (root reinforcement chemical)
Mechanical effects (erosion) or hydrological (altering moisture). Then effect of vegetation on slopes mainly by root reinforcement (positive influence; Turner & Ford, 2000; Genereux, 2008; Verga et al., 2018). The weight of vegetation (negative influence; Pollen, 2008). The reinforcement above-ground biomass as resistance soil matrix more prone to failure (Wagoner; & Watson, 2001). The effective and disadvantageous effect of vegetation mainly depends on root development (Tisdale & Nelson, 1982). The ecological and mechanical effects of vegetation on slope stability, and indicated to erosion in agriculture, such as: (1) different vegetation types as (2) temporal ages in hydrological responses observed both in and between different. Stream stability model receive great attention (Papacosta et al., 2006).
2. Case Study area and monitoring sites

Monitors are located along the Hobøl River in the southeastern part of Norway. The study area of the Hobøl River is 333 km², with 16% agricultural land, about 5% water bodies, and remains 79% forested (Blaemberg et al., 2006). The most dominant soil type within the study area is sandy loam with little sod land in agricultural areas (Håk 1989). Fluvial deposits with silt and silt loam are found along the river. The mean annual temperature is 1°C measured at Ryen meteorological station. The mean air temperature is 5°C (Skarbøvik & Beca, 2010) caused by different factors. The water level of the Hobøl River from relative elevation (1.0-3.0 m) is rising and falling over the seasons. Most erosion events are associated with water erosion (Skarbøvik & Bechmann, 2010) and there is a risk of floods (Skarbøvik & Bechmann, 2010).
3. Material and methods

3.1. Monitoring

Hydrological monitoring.

Each test plot was equipped with two measurement stations: one located close to the river (at the bottom of the profile at the level of water in the river) and the other located 60 m above the river (Fig. 2). The piezometers were PVC tubes fitted with filters characterized by standard filter section, surrounded by filter sand and closed with gravel.
Monitoring of mechanical properties of roots reinforced soil and bank erosion.

Weather data.
3.2 Stream bank stability modeling

\[ c_T = c' + c_r \]
4. Results

4.1. Monitoring results

Figure 4: Hydrologic model results: Precipitation affects water levels in Hobøl (realm) and river (r), shaded indicates freezing season; fluctuation of groundwater (GWL) above soil water content (T) for four periods with trees planted.

Table 1. Measured soil moisture values averaged over observation periods.
The result of various strength measures own Figure 5: In all parts, various thicknesses show a considerable effect of soil condition (Figure 2) and presence of root-reinforcement roots for different varieties of trees. Figure 5 shows that the soil-removed samples with time showed values of various strengths to be observed during late spring (species importance within a plot, calculated with Figure 4). The trend is a consequence of two factors: identity of a tree. As such, they confirm field observations there was no embankment failure when three plots.

Table 2: Characteristics of the tree height. The following shows boxes of average values + /- standard deviation together with max/min measured values; c) species of the height with time, for the trees.

Figure 5: Measured porosity (and connected parts) and depth depend on the tree.
4.2. Modeling results

In the future weather data analysis, we fill the gap with the dry period. In this period, we filled the worst case scenario: low water level. Additionally, we observed in the plot (Giibow et al. 2009) that G is equal to zero. Additionally, this is a fully developed root system (Table 1; 2009 - slope 24.7°) and a minimum of 54.0°. Figure 6. Factor of hydrostatic moments for the future scenario with a fully developed root system. Different colors represent different slopes.
Fig. 1 (a, b, c) - Sentences

Additionally, Fig. 6b presents slope stability with the assumption of full root development of fresh burying (future scenarios). In all scenarios, 1.3\% meaning (Tale 2 ± variation in values corporate serves the variation is served). And...
5. Discussion

...
6. Conclusion
14. Hydrological conditions

15. Soil-root reinforcement, and its ability in time to incorporate into the root system of typical Norwegian species.

7. Acknowledgements

The research team received funds from the USDA (project 98) for root growth studies, and also from the United States Department of Agriculture (USDA) with the project 2007-2013. The authors also thank Dr. Eddy J. Lendrum of the USDA Department of Agriculture (USDA) for the financial support.
Reference

A newer perspective on trees' ability: An Australian study.

Effet of spatial variation of tree root stability. A case study on Blackbutt (Rhinothorax) and Arbor vitae (Platanus) stools at Lassie, Pleau, China, 2009-15.


Permeability on landfills. PTesis, Delft University of Technology, 2015.

Uncertainty and sensitivity to the bank stability model: Applications to phosphor-limited plants.

Lammès, W., 2015.

Effect of soil erosion on vegetation. PTesis, Delft University of Technology, 2015.


Evaluation of stationarity at the erosion model (BSTEM) for predicting river bank erosion.


Evaluation of stationarity at the erosion model (BSTEM) for predicting river bank erosion.


Evaluation of stationarity at the erosion model (BSTEM) for predicting river bank erosion.


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Evaluation of stationarity at the erosion model (BSTEM) for predicting river bank erosion.
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<td>16.7 (m, m)</td>
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<td>32.0</td>
<td>26.4</td>
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<td>18.0 (l, e)</td>
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<td>Vegetation cover</td>
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<td></td>
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<tr>
<td>trees plot</td>
<td>trees**</td>
<td>40/40</td>
<td>7.18</td>
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<tr>
<td>shrubs plot</td>
<td>grass/ berry bushes***</td>
<td>40/60</td>
<td>0.35/1.37</td>
<td></td>
<td></td>
<td></td>
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Figure 1: Illustration of monitoring plots (a) map, (b) portion, (c) closeup, (d) subsurface.
Figure 2: The stream bank profile with monitoring equipment: (a) trees, (b) shrubs, and (c) grass. Post flood summer of 2016. Date of FDR sensors not specified.
Figure 3: Schematic diagram with the parameters for Lambers, 2015: 

- Species
- Age
- Assemblage
- Root depth
- Water level
- Failure plane
- Ground water level
- Friction angle
- Cohesion
- Weight
- Toe length
- Bank angle
- Bank height
Figure 4: Hydrologic model results: precipitation and water level in the stream. 

(a) Precipitation and water level in the stream

(b) Grass plot

c) Trees plot

(d) Shrubs plot
Figure 5: Measured porosity (and content) and average shear with tree roots.

Grass plot

Trees plot

Shrubs plot

(a) Porosity [%]

(b) Vane shear strength [kPa]

(c) Average shear strength [kPa]

Limited measurements due to blocking by roots.

Measurements not continued in order to ensure roots' development.

Soil depth [cm]

Soil depth [cm]

Soil depth [cm]

07/10/2016 15/01/2017 25/04/2017 03/08
Figure 2. Fact of study vs. time plot (a, c) and future scenario (d). Different colors represent different slopes.
Figure 5. Factor of safety vs. time plot for each scenario.

(a) Grass plot

(b) Trees plot

(c) Shrubs plot

(d) Shrubs plot – future scenario

Factor of safety, Fs

28/08/2016 06/12/2016 16/03/2017 24/06/2017 02/10/2017

06/12/2016 16/03/2017 24/06/2017 02/10/2017
Figure 6: Histories of all scenes, with distinct colors shown for slopes.

- **(a) Grass plot**

- **(b) Trees plot**

- **(c) Shrubs plot**

- **(d) Shrubs plot – future scenario**
**Figure Captions**

1. Figure of monitoring points (example plots (b) for test, (c) for see plots). Subplot.
2. The reason for filling files with monitoring events: (for example, (a) test results and (c) subplot). Post stands for summary of 2016. Depth of FDR sensors is not shown.
3. Figure: A schematic bank diagram with various inputs fed into BEM (adapted from Lermers, 2015).
4. Hollographic model in results: specification of limited water level in Hobøl (area) versus river (ice conditions for freezing; fluctuation of water table (GWL) above soil content (T)) for four months with tests points.
5. Figure: Measurement porosity (l and n) and density with reeds (c) shows boxes of average values ± standard deviation together with maximum and minimum measured values; c) shows age with time across, for the tests.
6. Figure. Fact of evaporation times for the three plots (a, c) and for the "future scope" of the fully developed system (d). Different colors mean different slopes.
7. Figure. Fact of evaporation versus time for the three plots (a, c) for future scenarios at subs (simulate with mid (c) ± mid (c)) slope. The threshold lines are indicated to the graphs: blue - Fشد 'stable slope', and yellow - Fشد 'conditionally stable slope'.
8. Figure. Histories of Fشد simulations with distinction between slopes (in classical style according to the BSTEM model: red - unstable slope; yellow - critical stability; black - operation
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Title: Estimating the effectiveness of crop management on reducing flood risk and sediment transport on hilly agricultural land - a Myjava case study, Slovakia

Article Type: VSI: Testing soil conservation

Keywords: runoff generation; rainfall simulator; plot and slope scale; crop management; hydrological modelling of surface runoff

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Abstract: The paper focuses on generation of floods as a principal soil threat and soil erosion as an additional soil threat on arable lands of hillslope areas. As the most important component of floods causing the degradation of soils on arable lands, the surface runoff is analysed in this study. The protective effect of crop management on the formation of surface runoff and sediment transport on arable lands is estimated at the micro-plot and slope scale. The site of the case study, which is located in the Myjava river basin in western Slovakia, is represented by a hilly agricultural field with an area of 0.29 km². In this location, which is characterized by arable soil, extreme erosion processes, and muddy floods, field rainfall simulation experiments were combined with physically based modelling for studying the formation of surface runoff under various crops and types of soil cover. The field experiments consisted of simulating runoff generation from artificial rainfalls using the Eijkelkamp rainfall simulator on experimental plots with a focus on estimating the volume of surface runoff, the mass of sediments transported by the surface runoff, and the time to runoff. As a result of the field experiments using various crops and under various soil conditions (initial soil moisture, stage of surface), other variables of the surface runoff processes on the plots have been developed. The volumes of the surface runoff and values of the time to runoff have been applied in the parameterisation and validation of the "slope scale" physically-based hydrological model SMODERP. The hydrological modelling of the surface runoff on the selected slope profile confirmed the protective effect of various crops on reducing surface runoff. The outcome of the modelling were the maximum allowed lengths of the slope representing the critical values for the flood and erosion control. When exceeding these critical values, protective measures, e.g., vegetation strips should to be proposed.
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Key words: Runoff generation, rainfall simulator, plot and slope scale, crop management, hydrological modelling of surface runoff

1. Introduction

Floods are related to the physiographic conditions of the land, the state of the soil, land use, and land management (Fiener et al., 2013). They not only represent threats on their own, but can also be controlled by interactions with other soil degradation processes (Hümann et al., 2011; Stolte et al., 2016). Various factors such as meteorological drivers, geomorphology, the properties of the soil, vegetation cover, land use, and surface and subsurface storage affect the formation and intensity of floods (Bronstert et al., 2002; Andréassian, 2004; Brown et al., 2005; Hümann, et al., 2011; Stolte et al., 2016).

Indicators for soil degradation by floods can be either direct or indirect. The direct indicators are linked to soil properties, whereas the indirect indicators are linked to flood properties. Three specific spatial scales are relevant for understanding the formation of runoff on and below a soil surface: the plot, hill slope, and catchment scales (e.g., Smith and Redding, 2012; Stolte et al., 2016). As for plot scales, the climatic and soil property indicators are usually studied. Climatic indicators consist of critical rainfall and snowmelt intensities for flooding. Soil property indicators include physical, chemical, and biological indices such as soil depth, soil bulk density, soil and subsoil permeability, available water holding capacity, and saturated hydraulic conductivity (Romano, 2014), soil
compaction (Alaoui and Helbling, 2006), porosity, soil texture and structure, organic matter content, and soil moisture (e.g., Doran and Jones, 1997; Schoenholtz et al., 2000; Merrington et al., 2006; Smith and Redding, 2012). For the hill slope scale indicators for morphology and land use have to be added to describe the potential of flood generation. This data would include the magnitude and frequency of precipitation intensities (Casas et al., 2004), the time of runoff concentration, the slope steepness and exposure, soil depth, infiltration capacity, coefficients of surface runoff (Markart et al., 2011), runoff pathways, groundwater depths, and characteristics of vegetation and land use (Anderson et al., 2010, Smith and Redding, 2012). Indicators on a catchment scale, such as morphometric parameters (the density of a stream, shape of a catchment, size and distribution of wetlands and sealed surfaces, etc.) or parameters of runoff concentration (time of concentration, time to the runoff peak, catchment lag time) are described in e.g., Fang et al., 2005; Nagy et al., 2016.

One way to protect soils from floods on agricultural lands is to apply methods of land and crop management, benefiting from the protective effect of vegetation cover on reducing runoff. The influence of land use and crop management on runoff generation is strongest for the surface or near-surface zones of the soil. This means that surface or near-surface fluxes and storages are most affected by land-use changes (Bronstert, et al., 2002). The surface runoff on the top of soils is also one of the crucial factors affecting soil erosion as one of the additional soil threats. Vegetation cover influences surface runoff and erosion mainly by interception of rainfall and protection of the soil surface from the erosive impact of rainfall drops. In the long term, vegetation influences the fluxes of water and sediments by increasing the soil-aggregate stability and cohesion as well as by improving water infiltration (Durán-Zuazo and Plequezuelo, 2008).

However, because of variable climatic conditions, soil properties, topography, etc., estimating the effect of crop management on reducing surface runoff is rather complicated. One of the methods for overcoming the random nature of natural rainfall and the difficulties it encompasses involves the use of rainfall simulators. Rainfall simulation experiments are an important tool to study generation of surface runoff and soil erosion (Cerda et al., 1999; Adams, et al., 2005; Finer et al., 2011) and they are often used in field or laboratory experiments to assess the impacts of changes in vegetation
cover (Zhao et al., 2014), tillage management (Vargas et al., 2012) or post-fire revegetation
(Johansen et al., 2001) on the erodibility of soil. As the control of natural rainfall that is
representative for a given location is not possible, the purpose of a rainfall simulator is to precisely
replicate its characteristics. Most of the simulators enable the control of some of the parameters of a
simulated rainfall such as its duration and intensity and thus can repeatedly produce artificial rainfall
of any given characteristics quickly and on demand (Humphry et al., 2002). Based on the mechanism
forming the rain drops, existing rainfall simulators can be divided into two groups: a) dripping or non-
pressurized rainfall simulators, and b) nozzle or pressurized rainfall simulators.

Even though the available rainfall simulator designs always lack one or more of the desired features
and are not able to completely replicate the properties of natural rainfall, they allow for relative
comparisons between various ecosystems and site conditions (Lane et al., 1997), which makes them
the most practical method for studying erosion processes in watersheds. Vahabi et al. (2008) studied
the effect of physical factors such as texture, antecedent soil moisture, or vegetation cover on
erosion processes. They determined that sediment yield was strongly correlated with vegetation
cover. The same results were confirmed under different conditions by multiple authors who showed
that even low densities of vegetation cover can significantly reduce the sediment yield (Gross et al.,
1991; Schindler Wildhaber et al., 2012). Liu et al. (2014) used a nozzle-type rainfall simulator to
examine various types of vegetation cover to reduce the erosion from newly constructed roadside
slopes. They concluded that grass was the most effective type of vegetation that enables a significant
reduction of erosion in a very short time. The effect of soil management on agricultural land was
studied by Jin et al. (2008). They compared six different management practices to determine that “no
till with mulch” was the best practice in terms of erosion and water conservation.

Rainfall simulations are an important and useful tool in analysing generation of surface runoff and
soil erosion on arable lands but such simulations are time-consuming and are usually only carried out
under a limited rainfall, topographical, and soil conditions to answer specific research questions or
hypothesis (Fiener et al., 2011). To overcome these limitations, hydrological or erosion models could
be applied to account for a wide range of climatic and physiographic properties. In various studies
data from experiments with rainfall simulators were applied for calibration or validation of physically
based hydrological models (e.g., Adams, et al., 2005; Adams and Elliot, 2006; Lane et al., 2004). The
development and application of various hydrological or erosion models suitable for small catchments
such as LISEM (e.g., De Roo et al., 1996; Starkloff and Stolte, 2014), WEPP (Flanagan et al., 2001;
Grønsten and Lundekvam, 2006), KINEROS2 (Smith et al., 1995) or EUROSEM (Morgan et al., 1998)
are listed in the literature. In the Czech Republic the 1-dimensional physically based hydrological
model SMODERP (Kavka, 2011) is recommended to use for proposals of erosion control on
agricultural hillslopes. The proposals of erosion control are based on the assumptions of the maximal
allowed lengths of agricultural slopes on the basis of simulated critical hydraulic characteristics of the
surface runoff for formatting rill erosion.

This paper is focused on the monitoring and modelling of the generated surface runoff on small
experimental sites on the small Turá Lúka catchment, located in the Myjava river basin in western
Slovakia. It aims to estimate the effectiveness of soil cover (crops) on reducing the volume of surface
runoff and sediment transport from a hilly agricultural field. The experiment was conducted in two
parts. First, field measurements of surface runoff generated by a rainfall simulator on small
experimental plots were executed. This part of the experiment, which is representative of a plot
scale, was focused on estimating the volume of surface runoff and sediments transported and the
time of the occurrence of the surface runoff under various soil cover (crops). The results of the field
measurements in the plot scale were utilized in the parameterization of a rainfall-runoff hydrological
model used in the second part of the experiment to assess the protective effect of various crops and
agricultural practices on reducing surface runoff in the slope scale. The hydrological modelling was
used to overcome the limitations of the plot measurements, utilizing a rainfall simulator, in terms of
spatial and temporal scales, and extrapolate the estimates of the generated surface runoff to real
topography and design precipitations with the longer durations.

The research aims of the study is to develop a methodology for estimating effectiveness of soil cover
(crops) for flood and erosion control on an agricultural hillslope, based on plot measurements in the
field conditions and hydrological modelling of the formation of surface runoff.
2. Case study area and monitoring site

The small experimental catchment Turá Lúka is located in the northern part of the Myjava Hills and in the adjacent part of the Turá Lúka region (Fig. 1). Within the region the predominant type of land use is intensively cultivated agricultural land, which is concentrated into large fields mutually divided by elongated patches of trees and a network of paved and unpaved roads (Valent et al., 2016). The geology of the area is characterised by flysch massif, soil types are rendzina and cambisols, and topsoil qualifies as loamy soil (based on Novák’s classification). The values of hydraulic conductivity \( K \) of the undisturbed soil samples were in an interval between 1.103 and 162.484 mm/day. Climate is characterised as warm, moderately humid with mild winters, with mean annual precipitation of 650-700 mm and mean annual air temperature ranging between 8 °C – 10 °C.

The small experimental catchment has an area of 0.29 km\(^2\) and is mainly represented by slopes with arable land and an erosion gully with seven small wooden check dams to stabilise the gully. The field is used for agricultural purposes with a rotational crop production management system. The small experimental sites with dimensions of 10 by 10 m were situated in the middle and lower parts of the hill slope close to the erosion gully (see Figs. 1 and 2).
Fig. 2. The experimental sites (10 by 10 m) situated on the middle and lower parts of the hill slope near the erosion gully and the placement of the rainfall simulator in one experimental site.

In the second part of the experiment we moved from the field measurements on the plots to hydrological modelling on the slope. The experimental catchment was represented here by a representative slope profile (the longest flow path upstream of the gully head) with a length of 518 m and a mean slope steepness of 9 %, which was selected on the basis of the field measurements and terrain analysis in GIS. The selected flow path (slope profile) is illustrated in Fig. 3.
Fig. 3. The flow path (slope profile) used for modelling surface runoff by a hydrological model.

3. Materials and methods

3.1 Experimental design and treatments

The experiment consisted of field measurements of surface runoff on small experimental plots using a rainfall simulator; upscaling measured parameters and variables to the slope scale; and hydrological modelling of surface runoff using the physically-based hydrological model SMODERP. SMODERP is a 1-dimensional hydrological model for simulating surface runoff on a hill slope. It was chosen for its ability to simulate surface runoff and its hydraulic characteristics as flow velocity and tangential stress in a very short temporal and spatial resolution. The flow chart of the experiment is presented in Fig. 4.
Fig. 4 The scheme of the experiment consisted of field measurements and hydrological modelling.

Repeated field measurements of the surface runoff (as an indicator of the principal soil threat) and sediment transport (as an indicator of additional soil threat) were provided using artificial rain induced by a rainfall simulator on the selected small plots with various crops and stages of the soil surface. The small experimental sites with dimensions of 10 by 10 m were situated in the middle and lower part of the hill slope close to the erosion gully. The positions of the placement of the rainfall simulator in one experimental site is displayed in Fig. 2.

The selection of the crops depended on the planting management of the agricultural farm in Turá Lúka during three years of the experimental measurements. We focussed on field conditions in which crops were still small, and plant cover was low, because it is well know that at that stage the risk of soil erosion is highest. As a result, our experiments are most representative for the early stages of the May-July wet season. Seven crops (soil cover) of different vegetation stages were tested, i.e., maize in its initial stage (SC1); bare soil, sowed winter crop (SC2); winter crop – 15 cm tall (SC3); bare soil
after tillage, disking the soil (SC4); rapeseed oil plants in initial stage, 10 cm tall (SC5); rapeseed oil plants – 15 cm tall (SC6); bare soil, after the soil aeration (SC7).

The artificial rain was simulated using the Eijkelkamp portable rainfall simulator, which can be used both in the field and in laboratory conditions. The surface area of the test plot is 0.0625 m$^2$ (25 x 25 cm), and the slope of the test area could be a maximum of 40 %. The rainfall simulator consists of a cylindrical reservoir and membrane with capillaries, an adjustable stand, and an aluminium frame. The membrane with capillaries is a calibrated cylindrical reservoir with a capacity of approximately 2300 ml, which is in contact with the membrane. The 49 capillaries generate raindrops, which then fall on the test plot. The surface runoff was measured as accumulated volume during a rainfall simulation by collecting runoff at the lower end of the plot equipped with the flow collection gutter.

Simulations were carried out on different positions of the rainfall simulator on the experimental site (maximum 9 plots on 1 experimental site, see Fig. 2.) In the case without occurrence of the surface runoff (because, e.g., preferential flow) the number of simulations on one experimental site was lower.

The duration of the artificial rainfall was kept constant at 3 minutes at all the locations. This time was limited by the construction of the rainfall simulator and it is representative for a very short intensive rainfall events as they occur in the area in summer. Various intensities of the artificial rainfall were used during the experiment in order to assess their impact on the time after which surface runoff occurs. The intensities used in the experiments were taken from intervals between 3 and 7 mm/min. These intensities, which are quite high, have more or less the same magnitude as a 100 years event of 5 minutes.

In the second part of the experiment, the results were completed by modelling the surface runoff using a physically-based hydrological model, with a focus on particularly estimating the protective effect of the soil covers (crops). To limit the impact of the variable topography, the modelling was undertaken on one representative flow path (slope profile, Fig. 3). For the applicability of the results for the purposes of flood and erosion protection, the rainfalls were represented by their design values with various return periods. Design values of short-duration rainfalls with return periods of
100, 50, 20 and 10 years and with durations equal to the time of concentration were applied as the input rainfalls. The time of concentration is the time needed for surface runoff to flow from the most remote point of the slope profile (start of the slope profile) to the outlet (end of the slope profile).

Except for the volumes of the surface runoff under various crops, the critical lengths of the slopes (the maximum allowed slope lengths) that could be applied for erosion control were modelled.

### 3.2 Field data and sample collection

The field data obtained from the field measurements consisted of volumes of the surface runoff and samples of sediments transported from the artificial rainfalls collected at the lower end of the plots.

Table 1 gives an overview of the measurements, i.e., the dates, soil cover (crop), stage and percentage of coverage, number of simulations, rainfall intensities, total rainfall and the class of initial soil moisture. The various soil covers during the measurements are shown in Fig 5.

### Table 1

Overview of the rainfall simulation experiments.

<table>
<thead>
<tr>
<th>Date</th>
<th>Soil cover, crop (SC)</th>
<th>Stage, % coverage</th>
<th>No. of simulations</th>
<th>Rainfall intensities [mm/min]</th>
<th>Total Rainfall [mm]</th>
<th>Initial soil moisture [class]</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.06.2015</td>
<td>SC1, Maize</td>
<td>Initial stage, 0%</td>
<td>9</td>
<td>6.5 – 7.3</td>
<td>16.1 - 20.7</td>
<td>low</td>
</tr>
<tr>
<td>22.10.2015</td>
<td>SC2, Bare soil</td>
<td>Sowed winter crop, 0%</td>
<td>18</td>
<td>2.7 – 5.4</td>
<td>6.7 - 15.1</td>
<td>high</td>
</tr>
<tr>
<td>06.04.2016</td>
<td>SC3, Winter crop</td>
<td>15 cm tall, 80%</td>
<td>12</td>
<td>3.4 – 5.9</td>
<td>9.1 - 17.1</td>
<td>low</td>
</tr>
<tr>
<td>25.08.2016</td>
<td>SC4, Bare soil</td>
<td>After tillage, disking the soil, 0%</td>
<td>15</td>
<td>3.6 – 7.0</td>
<td>10.4 - 21.1</td>
<td>medium</td>
</tr>
<tr>
<td>30.03.2017</td>
<td>SC5, Rapeseed oil plants</td>
<td>Initial stage (10 cm tall), 40%</td>
<td>20</td>
<td>5.0 – 6.6</td>
<td>15.1 - 19.4</td>
<td>medium</td>
</tr>
<tr>
<td>23.08.2017</td>
<td>SC5, Rapeseed oil plants</td>
<td>10 cm tall, 40%</td>
<td>12</td>
<td>4.9 – 6.7</td>
<td>14.1 - 18.7</td>
<td>medium</td>
</tr>
<tr>
<td>28.09.2017</td>
<td>SC6, Rapeseed</td>
<td>15 cm tall,</td>
<td>16</td>
<td>3.0 – 7.1</td>
<td>9.1 - 24.1</td>
<td>high</td>
</tr>
</tbody>
</table>
Class of the initial soil moisture: 0-20% low, 20-30% medium, more than 30% high

Fig. 5. Examples of various soil cover (crops) during the experiments.

### 3.3 Data analyses

For estimation of the design rainfalls to be used in the hydrological modelling, a simple scaling hypothesis was adopted in order to derive the intensity-duration-frequency (IDF) characteristics of the rain. The methodology applied herein follows the one used in Menabde, et al. (1999) and Yu, et al. (2004). For detailed information on the theoretical background for the multifractal behavior of rainfall, the reader is referred, e.g., to Veneziano and Furcolo (2002); more practice-oriented results can be found, e.g., in Molnar and Burlando (2008).
The dataset consisted of the maximum annual rainfall intensities at the Myjava rain gauge station for
durations of 5 up to 1440 minutes, which were observed during the period 1995-2009. Because the
actual observation period was too short to estimate the IDF curves, we applied a simple scaling
approach, whereby we subsequently used the daily precipitation totals from the period 1988-2014
provided by the Slovak Hydrometeorological Institute to estimate the design values of the daily
precipitation totals for downscaling. The estimation of the design rainfall values was realized in three
steps. First, we derived the scaling exponents at the Myjava rain gauge station for durations of 5, 10,
15, 20, 30, 40, 50, 60, 90, 120, 180 and 1440 minutes for the whole warm season. The resulting value
of the scaling coefficient was 0.725. For the estimation of the design rainfalls for various durations
(Table 2), we downscaled the derived design daily precipitation totals.

Table 2
Estimated values of the rainfall intensities in [mm/min] for different return periods and durations for
the case study region.

<table>
<thead>
<tr>
<th>Duration [min]</th>
<th>100</th>
<th>50</th>
<th>20</th>
<th>10</th>
<th>5</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3.135</td>
<td>2.921</td>
<td>2.547</td>
<td>2.279</td>
<td>1.980</td>
<td>1.502</td>
</tr>
<tr>
<td>10</td>
<td>1.897</td>
<td>1.768</td>
<td>1.541</td>
<td>1.379</td>
<td>1.198</td>
<td>0.909</td>
</tr>
<tr>
<td>15</td>
<td>1.414</td>
<td>1.317</td>
<td>1.149</td>
<td>1.028</td>
<td>0.893</td>
<td>0.677</td>
</tr>
<tr>
<td>20</td>
<td>1.147</td>
<td>1.069</td>
<td>0.933</td>
<td>0.834</td>
<td>0.725</td>
<td>0.550</td>
</tr>
<tr>
<td>30</td>
<td>0.855</td>
<td>0.797</td>
<td>0.695</td>
<td>0.622</td>
<td>0.540</td>
<td>0.410</td>
</tr>
<tr>
<td>40</td>
<td>0.694</td>
<td>0.647</td>
<td>0.564</td>
<td>0.505</td>
<td>0.439</td>
<td>0.333</td>
</tr>
<tr>
<td>50</td>
<td>0.591</td>
<td>0.550</td>
<td>0.480</td>
<td>0.429</td>
<td>0.373</td>
<td>0.283</td>
</tr>
<tr>
<td>60</td>
<td>0.517</td>
<td>0.482</td>
<td>0.421</td>
<td>0.376</td>
<td>0.327</td>
<td>0.248</td>
</tr>
<tr>
<td>120</td>
<td>0.313</td>
<td>0.292</td>
<td>0.254</td>
<td>0.228</td>
<td>0.198</td>
<td>0.150</td>
</tr>
<tr>
<td>180</td>
<td>0.233</td>
<td>0.217</td>
<td>0.190</td>
<td>0.170</td>
<td>0.147</td>
<td>0.112</td>
</tr>
<tr>
<td>240</td>
<td>0.189</td>
<td>0.177</td>
<td>0.154</td>
<td>0.138</td>
<td>0.120</td>
<td>0.091</td>
</tr>
<tr>
<td>1440</td>
<td>0.052</td>
<td>0.048</td>
<td>0.042</td>
<td>0.038</td>
<td>0.033</td>
<td>0.025</td>
</tr>
</tbody>
</table>
3.4 Hydrological modelling of surface runoff

The modelling of the surface runoff from the hill slope and critical slope lengths was provided by the SMODERP hydrological model. The model was developed in 1988 and has been refined over the years by the Faculty of Civil Engineering, Czech Technical University in Prague. This physically-based model includes infiltration processes (Phillips equation), surface runoff (a kinematic wave-based equation), and surface retention in a field up to 1 km$^2$ (Kavka, 2011; Zajiček, 2013).

The parameters of the model, i.e., the saturated hydraulic conductivity, sorptivity, Manning roughness, proportion of the leaf area, and the potential interception, which were developed in laboratory conditions by Kavka (2011), were adjusted (parametrised) in this study by comparing the modelled volumes of the surface runoff with the measured data on the experimental plots (Table 3). The parameter of the surface retention R was parameterised according to the modelled and measured values of the time of the occurrence of runoff. The runoff parameters $x$, $Y$ and $b$ were adapted from Kavka, 2011, and are listed in Table 4.

Table 3
Parameters of the SMODERP model for loamy soils and various soil covers (crops).

<table>
<thead>
<tr>
<th>Soil cover</th>
<th>Satur. hydraulic conductivity [mm.min$^{-1}$]</th>
<th>Sorptivity [mm.min$^{-0.5}$]</th>
<th>Manning roughness [-]</th>
<th>Proportion of leaf area [-]</th>
<th>Potential interception [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare soil</td>
<td>0.28</td>
<td>2.00</td>
<td>0.030</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Maize</td>
<td>0.35</td>
<td>2.84</td>
<td>0.035</td>
<td>0.16</td>
<td>0.13</td>
</tr>
<tr>
<td>Winter crop</td>
<td>0.54</td>
<td>3.61</td>
<td>0.040</td>
<td>0.30</td>
<td>0.20</td>
</tr>
<tr>
<td>Grass</td>
<td>0.71</td>
<td>6.78</td>
<td>0.100</td>
<td>1.00</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Table 4
Surface runoff parameters $x$, $Y$, $b$ for loamy soils (Kavka, 2011).

<table>
<thead>
<tr>
<th>Type soil</th>
<th>Parameter [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$x$</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The values of velocities and the tangential stress of surface runoff which are critical for starting formation of erosion rills (developed by Vrána, 1996) are listed in Table 5. According to these flow characteristics the critical lengths of the slopes (the maximum allowed slope lengths) that could be applied as critical values for flood risk and erosion control are estimated. After reaching the critical length, the slope should be broken by a protective measure, e.g., a protective vegetation strip designed perpendicular to the flow direction.

### Table 5

Critical velocities (v) and the tangential stress (T) of surface runoff (Vrana, 1996).

<table>
<thead>
<tr>
<th>Loamy soil</th>
<th>Without vegetation</th>
<th>Maize</th>
<th>Winter crop</th>
<th>Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>v [m.s⁻¹]</td>
<td>0.248</td>
<td>0.248</td>
<td>0.248</td>
<td>0.8</td>
</tr>
<tr>
<td>T [Pa]</td>
<td>10.79</td>
<td>10.79</td>
<td>10.79</td>
<td>20</td>
</tr>
</tbody>
</table>

### 4. Results

#### 4.1 Effectiveness of the treatment in terms of reducing runoff generation

Fig. 6 gives an overview of the results of the rainfall simulation experiments carried out on the experimental plots. The dependence of the volume of the surface runoff on rainfall intensity under 1) various soil cover (crops), 2) various initial soil moisture contents, 3) the steepness of slope as well as the dependence of the volume of the surface runoff on the sediments transported is illustrated in the graphs. The large variability of the measured volumes of the surface runoff, which was significantly influenced by the soil cover, as well as the initial soil moisture and the steepness of the slope (the lower part of the slope: 9-15%, the middle parts of the slope: 15-20%), is evident. The high initial soil moisture and the soil surface without vegetation had the most important impacts on the high volume of the surface runoff generated on the experimental plots.
Fig. 6. Dependence of the volume of the surface runoff on rainfall intensity and sediments under various soil cover (crops) and conditions of initial soil moisture and steepness of the slope.

The correlation coefficients between the surface runoff (SRF), sediments (SED) and rainfall intensity (RI) were calculated for the seven soil covers (crops) from the field experiments (Table 6).

Table 6

Correlation coefficient between the surface runoff, sediments and rainfall intensity of the plot for the seven soil covers (crops).
<table>
<thead>
<tr>
<th>SC 1</th>
<th>SRF</th>
<th>SED</th>
<th>RI</th>
<th>SC 2</th>
<th>SRF</th>
<th>SED</th>
<th>RI</th>
<th>SC 3</th>
<th>SRF</th>
<th>SED</th>
<th>RI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SED</td>
<td>0.964**</td>
<td></td>
<td></td>
<td>SED</td>
<td>0.568</td>
<td></td>
<td></td>
<td>SED</td>
<td>0.963**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RI</td>
<td>0.422</td>
<td>0.471</td>
<td></td>
<td>RI</td>
<td>0.627**</td>
<td>0.006</td>
<td></td>
<td>RI</td>
<td>0.430</td>
<td>0.333</td>
<td></td>
</tr>
<tr>
<td>SC 4</td>
<td>SRF</td>
<td>SED</td>
<td>RI</td>
<td>SC 5</td>
<td>SRF</td>
<td>SED</td>
<td>RI</td>
<td>SC 6</td>
<td>SRF</td>
<td>SED</td>
<td>RI</td>
</tr>
<tr>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>----</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>----</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>----</td>
</tr>
<tr>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SED</td>
<td>0.908**</td>
<td></td>
<td></td>
<td>SED</td>
<td>0.920**</td>
<td></td>
<td></td>
<td>SED</td>
<td>0.554*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RI</td>
<td>0.419</td>
<td>0.347</td>
<td></td>
<td>RI</td>
<td>0.542**</td>
<td>0.455*</td>
<td></td>
<td>RI</td>
<td>0.467</td>
<td>0.230</td>
<td></td>
</tr>
<tr>
<td>SC 7</td>
<td>SRF</td>
<td>SED</td>
<td>RI</td>
<td>SC 1 – maize (initial stage)</td>
<td>SC 2 – bare soil (sowed winter crop)</td>
<td>SC 5 - rapeseed oil plants (10 cm tall)</td>
<td>SC 3 – winter crop (15 cm tall)</td>
<td>SC 6 - rapeseed oil plants (15 cm tall)</td>
<td>SC 4 – bare soil (after tillage, disking)</td>
<td>SC 7 - bare soil (after the soil aeration)</td>
<td></td>
</tr>
</tbody>
</table>

**SRF**: surface runoff [ml]; **SED**: sediments [g]; **RI**: rainfall intensity [mm/min];

*: P-value <0.05; **: P-value <0.01

Very high values of correlation coefficients about 0.9 (statistically significant on P<0.01) were obtained between the surface runoff and sediment (except for the soil cover 2 and 6). Additionally, in the case of soil cover 2 and 5, there were statistically significant correlations of surface runoff with rainfall intensity.

To specify the effect of the soil cover (crops) as a treatment for reducing the surface runoff, the runoff coefficients as ratios between the volumes of surface runoff and artificial rainfall were calculated. Fig. 7 presents the statistics of the runoff coefficients for low (20%), medium (30%) and high (40%) initial soil moisture conditions in box plots. Fig. 8 presents the same statistics of sediments transported by the surface runoff from the field measurements.
Fig. 7. Box plots of the runoff coefficients for various crops, soil cover and initial soil moisture (SM) conditions.

Fig. 8. Box plots of the sediments for various crops, soil cover and initial soil moisture (SM).

The results of the runoff coefficients illustrate well the effect of different crops or soil covers on the generation of surface runoff. For maize in its initial stage (SC1) the values of the runoff coefficients (RC) are rather high, i.e., with a median of 0.139. This is caused by the very low protection of the soil...
by the crop and, despite the low initial soil moisture, by the soil crust created immediately after starting the rainfall simulations. Very low values of the runoff coefficients with a median of 0.002 for the winter crop (SC3) were achieved because of the good protective function of the crop and the low initial soil moisture. Relatively good results with smaller runoff coefficients were achieved under medium initial soil moisture conditions for the bare soil after tillage (SC4) that was covered with stubble (median RC of 0.052) and the rapeseed oil plants in the initial stage (SC5) (a median RC of 0.031). For the rapeseed oil plants in the initial stage (SC6) and with high initial soil moisture conditions, the values of RC were higher, i.e., with a median of 0.155. The highest values of RC with a median of 0.322 were achieved for bare soil without vegetation and the sowed winter crop (SC2) with high initial soil moisture. On the other hand, in spite of the high initial soil moisture conditions, very low values of RC with a median of 0.0151 were achieved for bare soil without vegetation and no tillage farming (SC7). No tillage farming based on a loosening of the soil significantly increased the soil infiltration capacity.

The sediments transported from the plots are strongly correlated with the volumes of surface runoff. The highest mass of sediments was transported for maize in its initial stage (SC1), with a median of 2.61 g, for bare soil after tillage (SC4) with a median of 3.9 g and for bare soil, sowed winter crop (SC2) with a median of 2.64 g. The lowest mass of the sediments with a median of 0.125 g was achieved for the winter crop (SC3) because of the good protective function of the crop.

The “time to runoff” (the time till the start of surface runoff) illustrated in Fig. 9 represents a very important flooding indicator, which can be used as an indicator in a flood protection system or as a parameter for validating a hydrological model.
The time to runoff is relatively high for low initial soil moisture conditions, i.e., the median of the time to runoff for maize in the initial stage is 108 s and 175 s for a winter crop. For medium initial soil moisture conditions the median of the time to runoff is 99 s for bare soil after tillage and 119 s for rapeseed oil plants in their initial stage. The values of the time to runoff were lower for rapeseed oil plants in their initial stage and with high initial soil moisture conditions, with a median of 44 s. The lowest values of the time to runoff with a median of 32 s were achieved for bare soil without vegetation, a sowed winter crop and high initial soil moisture conditions. On the other hand, in spite of the high initial soil moisture conditions, higher values of the time to runoff with a median of 96 s were achieved for bare soil without vegetation and no tillage farming. No tillage farming based on loosening of the soil significantly increased the soil’s infiltration capacity.

4.2. Effectiveness of treatment in terms of principal soil threats according to the hydrological modelling

In the second part of the experiment, the results were completed by modelling the surface runoff using a physically-based hydrological model, with a focus on particularly estimating the protective effect of the soil cover (crops). The modelling was undertaken on one representative flow path (slope...
profile) of the pilot site (Fig. 3) with the width of 1 m. For the applicability of the results for the purposes of flood and erosion control, the rainfalls were represented by their design values with various return periods and with a duration equal to the time of concentration of 25 min (Table 3).

The parameterisation of the hydrological model was achieved by comparing the measured and modelled volumes of the surface runoff and the time of the runoff occurrences. To avoid extreme initial soil moisture conditions, reference measured data only from experiments under medium values of the initial soil moisture were selected. In the parameterisation process, the hydrological model was repeatedly run on the shortest segment of the slope (of 2 m) permitted by the model in order for the simulations to be comparable to the field conditions of the experimental plots. After approximately one hundred (100) model runs, the best model parameters, i.e., the hydraulic conductivity, saturation, leaf area, interception capacity, and the surface retention, were defined (Table 4).

Except for the volumes and peaks of the surface runoff under various crops at the end of the slope profile, the critical lengths of the slope (the maximum allowed slope lengths) that could be applied as critical values for flood risk and for erosion control were modelled. The results of the volumes and flood peaks of the surface runoff modelled at the end of the slope are presented in Table 7 and 8.

Table 7

<table>
<thead>
<tr>
<th>Total rainfall [mm]</th>
<th>Return period [years]</th>
<th>Without vegetation</th>
<th>Soil cover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Maize</td>
<td>Winter crop</td>
</tr>
<tr>
<td>25.00</td>
<td>100</td>
<td>13.57</td>
<td>7.85</td>
</tr>
<tr>
<td>23.33</td>
<td>50</td>
<td>11.95</td>
<td>6.53</td>
</tr>
<tr>
<td>20.35</td>
<td>20</td>
<td>9.08</td>
<td>4.21</td>
</tr>
<tr>
<td>18.20</td>
<td>10</td>
<td>7.03</td>
<td>2.60</td>
</tr>
</tbody>
</table>
Table 8

Modelled flood peaks of the surface runoff by the hydrological model for design rainfalls under various soil cover (crops).

<table>
<thead>
<tr>
<th>Total rainfall [mm]</th>
<th>Return period [years]</th>
<th>Without vegetation</th>
<th>Maize</th>
<th>Winter crop</th>
<th>Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.00</td>
<td>100</td>
<td>6.967</td>
<td>4.247</td>
<td>1.11</td>
<td>0.000</td>
</tr>
<tr>
<td>23.33</td>
<td>50</td>
<td>6.392</td>
<td>3.532</td>
<td>0.73</td>
<td>0.000</td>
</tr>
<tr>
<td>20.35</td>
<td>20</td>
<td>5.084</td>
<td>2.415</td>
<td>0.22</td>
<td>0.000</td>
</tr>
<tr>
<td>18.20</td>
<td>10</td>
<td>3.86</td>
<td>2.415</td>
<td>0.02</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Fig. 10. Modelled flood peaks of the surface runoff by the hydrological model for design rainfalls under various soil cover (crops).

The results of the hydrological modelling confirmed the protective effect of the soil cover selected. When comparing to the bare soil, the depth of the surface runoff decreased by -5.72 mm (-42%) for maize, and -12.22 mm (-90%) for winter crop in case of the design rainfall with a return period of 100 years; and by -4.43 mm (-63%) for maize, -7.03 m³ (-100%) for winter crop in case of the design rainfall with a return period of 10 years. A similar decrease is evident for the flood peaks. When comparing to the bare soil, the flood peaks of the surface runoff decreased by -2.72 l/s (-39%) for maize, and...
-5.86 l/s (-84%) for winter crop in case of the design rainfall with a return period of 100 years; and by
-1.44 l/s (-37 %) for maize, -3.84 l/s m³ (-99%) for winter crop in case of the design rainfall with a
return period of 10 years.

In addition to the surface runoff, we also modelled the critical lengths of the slope for the purposes
of flood and erosion control. The critical length of a slope is the length where the surface runoff
reaches the critical values of the flow velocity and the tangential stress and where sheet erosion
changes to rill erosion (Table 5). This is the start of riling as a key threshold for flooding risk and the
maximum allowed length of a slope in erosion control. After reaching that value, the length of the
test should be broken by an erosion control measure such as protective vegetation strips (grass or
legumes). Fig. 11 illustrates the values of the critical lengths for the soil cover without vegetation,
maize, winter wheat, and grass. The shortest slope length was estimated for the soil cover without
vegetation and the design rainfall with a return period of 100 years, i.e., from 161 to 67 m. The
longest slope lengths, which were almost without interruption, were estimated for the winter wheat
and grass.

<table>
<thead>
<tr>
<th>SOIL COVER: WITHOUT VEGETATION</th>
<th>SOIL COVER: MAIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st break</td>
<td>2nd break</td>
</tr>
<tr>
<td>201</td>
<td>143</td>
</tr>
<tr>
<td>179</td>
<td>124</td>
</tr>
<tr>
<td>161</td>
<td>110</td>
</tr>
<tr>
<td>161</td>
<td>110</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SOIL COVER: WINTER CROP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st break</td>
</tr>
<tr>
<td>518</td>
</tr>
<tr>
<td>518</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SLOPE PROFILE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation above sea level (m)</td>
</tr>
<tr>
<td>400</td>
</tr>
<tr>
<td>Slope length (m)</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
5. Discussion

For reliably evaluating the effectiveness of soil cover (crops) to reduce surface runoff on a slope in field conditions, the limiting factors (except for small areas of the experimental plots) were the highly variable values of the initial soil moisture and the fact that the actual stage of the soil surface depended on the soil cultivation technology used (tillage, disking or aeration of the soil). Moreover, the selection of the crops tested during the field measurements depended on the planting management of the agricultural farm in Turá Lúka; we were therefore only able to conduct the experiments during certain periods and for certain vegetation stages of the crops. This limitations we avoided by focusing on the field conditions in which crops were still small, and plant cover was low, and under which the risk of floods and soil erosion is the highest.

Another restriction of the rainfall-runoff simulator experiments was a small area of the test plots (0.0625 m²) and a relatively short duration of the artificial rainfalls (3 min). This is a limitation of the small rainfall simulator used. In spite of this, such simulators have been applied worldwide in many other studies mainly for its portability and possibility to provide a large number of measurements during experiments (see, e.g., Thierfeldera, et al. 2005; Parlak, 2012; Iserloh et al., 2013; Palese et al., 2015). However, because of these limitations the results of the field experiments are representative mainly for the beginning phase of the surface runoff on an agricultural hillslope and sheet erosion when it is still not necessary to propose protective measures against floods and soil erosion. We suppose that a protective measure should be designed at the place where the slope reaches its critical length and rill erosion starts to develop.

In spite of the relatively large number of field measurements by the rainfall simulator, it was possible to generalise the effect of various soil covers on reducing the surface runoff only to some extent because of variable soil surface and soil moisture conditions on the plots during the experiments. Measurements of the surface runoff generated from artificial rainfalls in field
conditions enable the repetition of runoff processes under similar rainfall intensities but such
simulations are time-consuming and are usually only carried out under a limited rainfall,
topographical, and soil conditions to answer specific research questions or hypothesis (Fiener et al.,
2011). To overcome these limitations, hydrological or erosion models could be applied to account for
a wide range of climatic and physiographic properties. (e.g., Adams, et. al., 2005).

Accordingly, the hydrological modelling presented a very important part of the experiment in that it
was thereby possible to generalize more reliable results and also to indicate possible flood and
erosion controls based on the estimating the maximum allowed length of the slope. The physically-
based hydrological model SMODERP was chosen for its ability to simulate surface runoff and its
hydraulic characteristics as flow velocity and tangential stress on a slope in a very short temporal and
spatial resolution, as well as the critical (maximum allowed) length of the slope.

The parameterisation of the hydrological model was achieved by comparing the measured and
modelled volumes of the surface runoff and the time of the runoff occurrences. To avoid extreme
initial soil moisture conditions, reference measured data only from experiments under medium
values of the initial soil moisture were selected. The limitations of the parameterisation of the model
came out from the fact that the parameters were estimated by the method of trial and error and
only for medium initial soil moisture conditions. Because our field data were limited to certain
vegetation stages we expect that the model parameters can be valid only for limited field conditions,
i.e., in which crops were still small, and plant cover was low. As a result, these parameters are most
representative for the early stages of the May-July wet season and for the conditions of the highest
flood risk in the pilot area.

The parametrized model was used for simulations of the surface runoff from the design rainfalls. The
results of the hydrological modelling confirmed the protective effect of the soil covers (crops)
selected. The critical lengths of the slope were estimated from these simulations based on the critical
values of the flow velocities and the tangential stress of runoff on a slope. After these values are
reached, flood and erosion control measures should be proposed, e.g., protective strips or protective
vegetation covers. The results can be applicable to flood protection control in the same region and
for similar topographical and soil conditions. It is important to emphasize that we focused on flood protection possibilities for the soils using methods based on land management; technical measures such as, e.g., water channels above the field or terraces were not considered.

6. Conclusions

The results of the volumes of the surface runoff measured confirmed the high dependency of the runoff on the initial soil moisture conditions, the soil cover and soil stage. Initial soil moisture higher than 40% and the soil surface without any vegetation had the most important effects on the volume of the surface runoff generated on the experimental plots. Almost for all experiments the high correlation between the volume of surface runoff and sediments transported from the experimental plots was confirmed. The effect of different soil covers (crops) on reducing the volumes of surface runoff was expressed by the runoff coefficients, which were estimated for all the measurements on the experimental plots. Very low values of the runoff coefficients with a median of 0.002 for the winter crop were achieved because of the good protective function of the crop and the low initial soil moisture. The highest values of RC with a median of 0.322 were achieved for bare soil without any vegetation and the sowed winter crop with high initial soil moisture.

The time before the occurrence of surface runoff, which represents a very important flooding indicator, was relatively high for low initial soil moisture conditions and a winter crop. The values of the time to runoff were lower for rapeseed oil plants in their initial stage and with high initial soil moisture conditions, i.e., a median of 44 s. The lowest values of the time to runoff with a median of 32 s were achieved for bare soil without any vegetation, a sowed winter crop, and high initial soil moisture conditions.

The results of the hydrological modelling confirmed the good protective effect of the winter wheat. In the comparison with the bare soil, the depth of the surface runoff decreased by -5.72 mm (-42%) for maize and -12.22 mm (-90%) for winter crop in the case of the design rainfall with a return period of 100 years; and by -4.43 mm (-63 %) for maize, -7.03 mm (-100%) for winter crop in the case of the
design rainfall with a return period of 10 years. The flood peaks of the surface runoff at the end of
the slope profile (flow path with the width 1 m) decreased by -2.72 l/s (-39%) for maize, and -5.86 l/s
(-84%) for winter crop in case of the design rainfall with a return period of 100 years; and by -1.44 l/s
(-37 %) for maize, -3.84 l/s m$^3$ (-99%) for winter crop in case of the design rainfall with a return period
of 10 years.

In addition to the depth, volumes and flood peaks of the surface runoff, we also modelled the critical
lengths of the slope for the purposes of flood and erosion control. This is the maximum allowed
length of a slope in erosion control. The shortest slope length was estimated for the soil cover
without any vegetation and the design rainfall with a return period of 100 years. The longest slope
lengths, which were almost without interruption, were estimated for the winter wheat.

**Acknowledgements**

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No 1/0710/15.

**References**

physically based hydrological model to investigate runoff processes in a hillslope. Hydrol. Proc.
19, 2209–2223.

Adams, R., Elliot, S., 2006. Physically based modelling of sediment generation and transport under a

variation: Comparison between compacted and non-compacted soil. Geoderma 134, 97–108.
https://doi.org/https://doi.org/10.1016/j.geoderma.2005.08.016


Fang, X., Cleveland, T., Garcia, A.C., Thompson, D., Malla, R., 2005. Literature review on timing parameters for hydrographs. (No. 0-4696–1). Austin, TX.


JRC technical reports, JRC, EC, 205 pp.

Thierfeldera, Ch., Ame´zquita C. E., Stahra, K., 2005. Effects of intensifying organic manuring and tillage practices on penetration resistance and infiltration rate, Soil & Tillage Research 82, 211–226.


### Table 1

Overview of the rainfall simulation experiments.

<table>
<thead>
<tr>
<th>Date</th>
<th>Soil cover, crop (SC)</th>
<th>Stage, % coverage</th>
<th>No. of simulations</th>
<th>Rainfall intensities [mm/min]</th>
<th>Total Rainfall [mm]</th>
<th>Initial soil moisture [class]</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.06.2015</td>
<td>SC1, Maize</td>
<td>Initial stage, 0%</td>
<td>9</td>
<td>6.5 – 7.3</td>
<td>16.1 - 20.7</td>
<td>low</td>
</tr>
<tr>
<td>22.10.2015</td>
<td>SC2, Bare soil</td>
<td>Sowed winter crop, 0%</td>
<td>18</td>
<td>2.7 – 5.4</td>
<td>6.7 - 15.1</td>
<td>high</td>
</tr>
<tr>
<td>06.04.2016</td>
<td>SC3, Winter crop</td>
<td>15 cm tall, 80%</td>
<td>12</td>
<td>3.4 – 5.9</td>
<td>9.1 - 17.1</td>
<td>low</td>
</tr>
<tr>
<td>25.08.2016</td>
<td>SC4, Bare soil</td>
<td>After tillage, disking the soil, 0%</td>
<td>15</td>
<td>3.6 – 7.0</td>
<td>10.4 - 21.1</td>
<td>medium</td>
</tr>
<tr>
<td>30.03.2017</td>
<td>SC5, Rapeseed oil plants</td>
<td>Initial stage (10 cm tall), 40%</td>
<td>20</td>
<td>5.0 – 6.6</td>
<td>15.1 - 19.4</td>
<td>medium</td>
</tr>
<tr>
<td>23.08.2017</td>
<td>SC5, Rapeseed oil plants</td>
<td>10 cm tall, 40%</td>
<td>12</td>
<td>4.9 – 6.7</td>
<td>14.1 - 18.7</td>
<td>medium</td>
</tr>
<tr>
<td>28.09.2017</td>
<td>SC6, Rapeseed oil plants</td>
<td>15 cm tall, 50%</td>
<td>16</td>
<td>3.0 – 7.1</td>
<td>9.1 - 24.1</td>
<td>high</td>
</tr>
<tr>
<td>18.10.2017</td>
<td>SC7, Bare soil</td>
<td>After the soil aeration, 0%</td>
<td>6</td>
<td>4.8 – 6.1</td>
<td>13.1 - 21.1</td>
<td>high</td>
</tr>
</tbody>
</table>

Class of the initial soil moisture: 0-20% low, 20-30% medium, more than 30% high
Table 2

Estimated values of the rainfall intensities in [mm/min] for different return periods and durations for the case study region.

<table>
<thead>
<tr>
<th>Duration [min]</th>
<th>100</th>
<th>50</th>
<th>20</th>
<th>10</th>
<th>5</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3.135</td>
<td>2.921</td>
<td>2.547</td>
<td>2.279</td>
<td>1.980</td>
<td>1.502</td>
</tr>
<tr>
<td>10</td>
<td>1.897</td>
<td>1.768</td>
<td>1.541</td>
<td>1.379</td>
<td>1.198</td>
<td>0.909</td>
</tr>
<tr>
<td>15</td>
<td>1.414</td>
<td>1.317</td>
<td>1.149</td>
<td>1.028</td>
<td>0.893</td>
<td>0.677</td>
</tr>
<tr>
<td>20</td>
<td>1.147</td>
<td>1.069</td>
<td>0.933</td>
<td>0.834</td>
<td>0.725</td>
<td>0.550</td>
</tr>
<tr>
<td>30</td>
<td>0.855</td>
<td>0.797</td>
<td>0.695</td>
<td>0.622</td>
<td>0.540</td>
<td>0.410</td>
</tr>
<tr>
<td>40</td>
<td>0.694</td>
<td>0.647</td>
<td>0.564</td>
<td>0.505</td>
<td>0.439</td>
<td>0.333</td>
</tr>
<tr>
<td>50</td>
<td>0.591</td>
<td>0.550</td>
<td>0.480</td>
<td>0.429</td>
<td>0.373</td>
<td>0.283</td>
</tr>
<tr>
<td>60</td>
<td>0.517</td>
<td>0.482</td>
<td>0.421</td>
<td>0.376</td>
<td>0.327</td>
<td>0.248</td>
</tr>
<tr>
<td>120</td>
<td>0.313</td>
<td>0.292</td>
<td>0.254</td>
<td>0.228</td>
<td>0.198</td>
<td>0.150</td>
</tr>
<tr>
<td>180</td>
<td>0.233</td>
<td>0.217</td>
<td>0.190</td>
<td>0.170</td>
<td>0.147</td>
<td>0.112</td>
</tr>
<tr>
<td>240</td>
<td>0.189</td>
<td>0.177</td>
<td>0.154</td>
<td>0.138</td>
<td>0.120</td>
<td>0.091</td>
</tr>
<tr>
<td>1440</td>
<td>0.052</td>
<td>0.048</td>
<td>0.042</td>
<td>0.038</td>
<td>0.033</td>
<td>0.025</td>
</tr>
</tbody>
</table>
Table 3

Parameters of the SMODERP model for loamy soils and various soil covers (crops).

<table>
<thead>
<tr>
<th>Soil cover</th>
<th>Satur. hydraulic conductivity [mm.min⁻¹]</th>
<th>Sorptivity [mm.min⁻¹⁻¹]</th>
<th>Manning roughness [-]</th>
<th>Proportion of leaf area [-]</th>
<th>Potential interception [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare soil</td>
<td>0.28</td>
<td>2.00</td>
<td>0.030</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Maize</td>
<td>0.35</td>
<td>2.84</td>
<td>0.035</td>
<td>0.16</td>
<td>0.13</td>
</tr>
<tr>
<td>Winter crop</td>
<td>0.54</td>
<td>3.61</td>
<td>0.040</td>
<td>0.30</td>
<td>0.20</td>
</tr>
<tr>
<td>Grass</td>
<td>0.71</td>
<td>6.78</td>
<td>0.100</td>
<td>1.00</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Table 4

Surface runoff parameters $x$, $Y$, $b$ for loamy soils (Kavka, 2011).

<table>
<thead>
<tr>
<th>Type soil</th>
<th>Parameter [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$x$</td>
</tr>
<tr>
<td>Loamy</td>
<td>10.552</td>
</tr>
</tbody>
</table>
Table 5

Critical velocities (v) and the tangential stress (T) of surface runoff (Vrana, 1996).

<table>
<thead>
<tr>
<th>Loamy soil</th>
<th>Without vegetation</th>
<th>Maize</th>
<th>Winter crop</th>
<th>Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>v [m.s(^{-1})]</td>
<td>0.248</td>
<td>0.248</td>
<td>0.248</td>
<td>0.8</td>
</tr>
<tr>
<td>T [Pa]</td>
<td>10.79</td>
<td>10.79</td>
<td>10.79</td>
<td>20</td>
</tr>
</tbody>
</table>
Table 6

Correlation coefficient between the surface runoff, sediments and rainfall intensity of the plot for the seven soil covers (crops).

<table>
<thead>
<tr>
<th>SC 1</th>
<th>SRF</th>
<th>SED</th>
<th>RI</th>
<th>SC 1</th>
<th>SRF</th>
<th>SED</th>
<th>RI</th>
<th>SC 1</th>
<th>SRF</th>
<th>SED</th>
<th>RI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SED</td>
<td>0.964**</td>
<td>0.568</td>
<td></td>
<td>SED</td>
<td>0.568</td>
<td>0.006</td>
<td></td>
<td>SED</td>
<td>0.963**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RI</td>
<td>0.422</td>
<td>0.471</td>
<td></td>
<td>RI</td>
<td>0.627**</td>
<td></td>
<td>0.006</td>
<td>RI</td>
<td>0.430</td>
<td>0.333</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SC 4</th>
<th>SRF</th>
<th>SED</th>
<th>RI</th>
<th>SC 5</th>
<th>SRF</th>
<th>SED</th>
<th>RI</th>
<th>SC 6</th>
<th>SRF</th>
<th>SED</th>
<th>RI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SED</td>
<td>0.908**</td>
<td></td>
<td></td>
<td>SED</td>
<td>0.920**</td>
<td>0.455*</td>
<td>0.554*</td>
<td>SED</td>
<td>0.542**</td>
<td>0.455*</td>
<td>0.467</td>
</tr>
<tr>
<td>RI</td>
<td>0.419</td>
<td>0.347</td>
<td></td>
<td>RI</td>
<td>0.542**</td>
<td></td>
<td>0.455*</td>
<td>RI</td>
<td>0.467</td>
<td>0.230</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SC 7</th>
<th>SRF</th>
<th>SED</th>
<th>RI</th>
<th>SC 1 - maize (initial stage)</th>
<th>SC 2 - bare soil (sowed winter crop)</th>
<th>SC 5 - rapeseed oil plants (10 cm tall)</th>
<th>SC 3 - winter crop (15 cm tall)</th>
<th>SC 6 - rapeseed oil plants (15 cm tall)</th>
<th>SC 4 - bare soil (after tillage, disking)</th>
<th>SC 7 - bare soil (after the soil aeration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRF</td>
<td></td>
<td></td>
<td></td>
<td>SC 1 - maize (initial stage)</td>
<td>SC 2 - bare soil (sowed winter crop)</td>
<td>SC 5 - rapeseed oil plants (10 cm tall)</td>
<td>SC 3 - winter crop (15 cm tall)</td>
<td>SC 6 - rapeseed oil plants (15 cm tall)</td>
<td>SC 4 - bare soil (after tillage, disking)</td>
<td>SC 7 - bare soil (after the soil aeration)</td>
</tr>
<tr>
<td>SED</td>
<td>0.987**</td>
<td></td>
<td></td>
<td>SC 1 - maize (initial stage)</td>
<td>SC 2 - bare soil (sowed winter crop)</td>
<td>SC 5 - rapeseed oil plants (10 cm tall)</td>
<td>SC 3 - winter crop (15 cm tall)</td>
<td>SC 6 - rapeseed oil plants (15 cm tall)</td>
<td>SC 4 - bare soil (after tillage, disking)</td>
<td>SC 7 - bare soil (after the soil aeration)</td>
</tr>
<tr>
<td>RI</td>
<td>0.443</td>
<td>0.350</td>
<td></td>
<td>SC 1 - maize (initial stage)</td>
<td>SC 2 - bare soil (sowed winter crop)</td>
<td>SC 5 - rapeseed oil plants (10 cm tall)</td>
<td>SC 3 - winter crop (15 cm tall)</td>
<td>SC 6 - rapeseed oil plants (15 cm tall)</td>
<td>SC 4 - bare soil (after tillage, disking)</td>
<td>SC 7 - bare soil (after the soil aeration)</td>
</tr>
</tbody>
</table>

**SRF**: surface runoff [ml]; **SED**: sediments [g]; **RI**: rainfall intensity [mm/min];

*: P-value <0.05; **: P-value <0.01
Table 7

Modelled depth of the surface runoff for the flow path (518 m x 1 m) by the hydrological model for design rainfalls under various soil cover (crops).

<table>
<thead>
<tr>
<th>Total rainfall [mm]</th>
<th>Return period [years]</th>
<th>Without vegetation</th>
<th>Maize</th>
<th>Winter crop</th>
<th>Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.00</td>
<td>100</td>
<td>13.57</td>
<td>7.85</td>
<td>1.35</td>
<td>0.00</td>
</tr>
<tr>
<td>23.33</td>
<td>50</td>
<td>11.95</td>
<td>6.53</td>
<td>0.77</td>
<td>0.00</td>
</tr>
<tr>
<td>20.35</td>
<td>20</td>
<td>9.08</td>
<td>4.21</td>
<td>0.14</td>
<td>0.00</td>
</tr>
<tr>
<td>18.20</td>
<td>10</td>
<td>7.03</td>
<td>2.60</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Total rainfall [mm]</td>
<td>Return period [years]</td>
<td>Without vegetation</td>
<td>Maize</td>
<td>Winter crop</td>
<td>Grass</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------</td>
<td>---------------------</td>
<td>-------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td>25.00</td>
<td>100</td>
<td>6.967</td>
<td>4.247</td>
<td>1.11</td>
<td>0.000</td>
</tr>
<tr>
<td>23.33</td>
<td>50</td>
<td>6.392</td>
<td>3.532</td>
<td>0.73</td>
<td>0.000</td>
</tr>
<tr>
<td>20.35</td>
<td>20</td>
<td>5.084</td>
<td>2.415</td>
<td>0.22</td>
<td>0.000</td>
</tr>
<tr>
<td>18.20</td>
<td>10</td>
<td>3.86</td>
<td>2.415</td>
<td>.02</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Table 8

Modelled flood peaks of the surface runoff by the hydrological model for design rainfalls under various soil cover (crops).
Fig. 1. Location of the Myjava River basin in Slovakia and location of the pilot site: the Turá Lúka catchment.

Fig. 2. The experimental sites (10 by 10 m) situated on the middle and lower parts of the hill slope near the erosion gully and the placement of the rainfall simulator in one experimental site.

Fig. 3. The flow path (slope profile) used for modelling surface runoff by a hydrological model.

Fig. 4. The scheme of the experiment consisted of field measurements and hydrological modelling.

Fig. 5. Examples of various soil cover (crops) during the experiments.

Fig. 6. Dependence of the volume of the surface runoff on rainfall intensity and sediments under various soil cover (crops) and conditions of initial soil moisture and steepness of the slope.

Fig. 7. Box plots of the runoff coefficients for various crops, soil cover and initial soil moisture (SM) conditions.

Fig. 8. Box plots of the sediments for various crops, soil cover and initial soil moisture (SM).

Fig. 9. Time before the occurrence of surface runoff for various initial soil moisture conditions.

Fig. 10. Modelled flood peaks of the surface runoff by the hydrological model for design rainfalls under various soil cover (crops).

Fig. 11. The critical slope lengths for various soil cover (crops) and design rainfalls with different return periods.
Title: Infiltration via submerged drains to reduce peat oxidation, subsidence and GHG emissions of peat soils in agricultural use

Article Type: VSI: Testing soil conservation

Keywords: peat soil, peat oxidation, subsidence, loss of SOM, GHG emission

Corresponding Author: Mr. Jan JH van den Akker, Ir.

Corresponding Author's Institution: Alterra Wageningen UR

First Author: Jan JH van den Akker, Ir.

Abstract: Decline of organic matter in peat soils directly threatens one of the main ecosystem services of peat soils: the storage of carbon. In the EU the decline in SOM by oxidation of peat soils in agricultural use is about 45 Mton per year, which causes a CO2-emission of about 90 Mton per year which is almost the CO2-emission of Belgium. Oxidation of peat soils used in dairy farming in the western peat area of The Netherlands causes subsidence rates up to 13 mm.y⁻¹ and emissions of CO2 to about 27 t.ha⁻¹.y⁻¹. In 2003 experiments started with subsurface irrigation by submerged drains to raise groundwater levels to reduce peat oxidation and so subsidence and GHG emissions. Subsidence and so CO2 emissions were reduced with about 50% and the trafficability improved. In 2011 we started a pilot in the Krimpenerwaard area with the main objective to determine the impact of submerged drains on reducing subsidence to confirm these earlier findings. The use of submerged drains in the pilot in the Krimpenerwaard proved to raise groundwater levels and so conserve peat soils reducing peat oxidation and so subsidence and CO2 emissions and loss of organic matter by 30 – 50%. However, long term monitoring is needed to derive sound proof of these findings.
Coverletter

Dear Editor, dear Estela Nadal,

Herewith we submit our contribution entitled "Infiltration via submerged drains to reduce peat oxidation, subsidence and GHG emissions of peat soils in agricultural use" to the Special Issue "Testing soil conservation".

Thank you for the efforts you put into this Special Issue.

With kind regards,

Jan van den Akker

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Title:

Infiltration via submerged drains to reduce peat oxidation, subsidence and GHG emissions of peat soils in agricultural use

Abstract:

Decline of organic matter in peat soils directly threatens one of the main ecosystem services of peat soils: the storage of carbon. In the EU the decline in SOM by oxidation of peat soils in agricultural use is about 45 Mton per year, which causes a CO\textsubscript{2}-emission of about 90 Mton per year which is almost the CO\textsubscript{2} emission of Belgium. Oxidation of peat soils used in dairy farming in the western peat area of The Netherlands causes subsidence rates up to 13 mm.y\textsuperscript{-1} and emissions of CO\textsubscript{2} to about 27 t.ha\textsuperscript{-1}.y\textsuperscript{-1}. In 2003 experiments started with subsurface irrigation by submerged drains to raise groundwater levels to reduce peat oxidation and so subsidence and GHG emissions. Subsidence and so CO\textsubscript{2} emissions were reduced with about 50\% and the trafficability improved. In 2011 we started a pilot in the Krimpenerwaard area with the main objective to determine the impact of submerged drains on reducing subsidence to confirm these earlier findings. The use of submerged drains in the pilot in the Krimpenerwaard proved to raise groundwater levels and so conserve peat soils reducing peat oxidation and so subsidence and CO\textsubscript{2} emissions and loss of organic matter by 30 – 50\%. However, long term monitoring is needed to derive sound proof of these findings.

Keywords: peatsoil, peat oxidation, subsidence, loss of SOM, GHG emission
1. Introduction

Description of soil threat

Decline of organic matter in peat soils directly threatens one of the main ecosystem services of peat soils: the storage of carbon. Peat soils cover more than 420 million ha worldwide equivalent to 3% of the Earth’s land surface (Strack, 2008) and contain 20-30% of the world’s soil organic carbon (Moore, 2002). Joosten (2009) estimated the total C stock in peat soils in the world to be 445700 Mton C. This makes peat soils one of the major stocks of C in the world, even more than in the atmosphere. Byrne et al., (2004) reported a total area of peat soils of 34 million hectares in the EU Member States and Candidate Countries with an estimated total C store in peat of 17 Pg (17000 Mton) or about 20-25% of the carbon in soils of the EU. Of the 34 million hectares about 5.80 million ha is drained of which 3.60 million ha is in agricultural use as cropland (0.95 million ha) or grassland (2.65 million ha) (Schils et al., 2008).

The Netherlands have nowadays about 290,000 ha peat soils of which 223,000 ha in agricultural use, almost completely as grassland. About 92,000 ha of the 223,000 ha have a clay layer of 15 – 40 cm, and about 9,000 ha a sandy layer. About 40 years ago a strong modernization and mechanization of dairy farming started. This required improvement of drainage conditions and bearing capacity of peat soils in agricultural use and therefore in large areas ditchwater levels were lowered several decimetres. Today about 84,000 ha has a shallow (around 30 cm); 117,000 ha an intermediate (around 60 cm) and about 22,000 ha a deep (> 90 cm) ditchwater level. The lowering of ditchwater levels caused a strong increase of subsidence of the peat soils. In the first 5 to 10 years the yearly subsidence is caused by decomposition (oxidation) and peat compaction by shrinkage above groundwater levels and by consolidation below groundwater levels. After this period the major part of subsidence is caused by peat oxidation. The major part of peat soils in the Netherlands is in use as permanent pasture with ditchwater levels of 60 cm minus surface or lower. Organic soils above groundwater level are exposed to the air and decompose (peat oxidation). This causes a subsidence of 8 – 12 mm per year and emission of greenhouse gasses. Subsidence of one centimeter per year equates to an emission of about 22 tons of CO$_2$ per hectare per year (Van den Akker et al., 2008). Van den Akker et al. (2008) calculated an emission of 4.25 Mt CO$_2$ per year for the agricultural peat soils in the Netherlands. Per ha this is about 19 tonne CO$_2$ per year. The total CO$_2$ emission per year by oxidation of peat soils is about 2.5 % of the national anthropological CO$_2$ emission of the Netherlands.
In the Netherlands every 10 years ditchwater levels are lowered and so adapted to the subsidence. In this way an adequate drainage level is maintained for modern dairy farming. However, in this way also groundwater levels are lowered every 10 years with 5 to 10 cm. Many houses and farm buildings are built on wooden piles. In time the upper part of these piles are exposed to oxygen and start to rot. In this way subsidence causes damage to infrastructure and buildings. Because the subsidence is not the same everywhere, water management becomes ever more complex and expensive. Many wetlands become difficult to preserve as "wetland" because subsidence of adjacent drained agricultural land results in 'islands of peat' surrounded by lower elevation agricultural lands. The higher wetlands drain towards the lower agricultural land, become too dry and degrade. In a time with rising sea levels, it is also not wise to allow subsidence rates of one cm per year. When drainage of peat soils started in the Middle Ages, the surface level was several meters above sea level. Nowadays surface levels are 2 – 3 meters below seawater level due to subsidence and seawater level rise. During centuries peat lands had downward seepage, however, due to continuously lowering water levels to follow the ongoing subsidence this downward seepage starts to turn around in upward seepage. This upward seepage is in many cases nutrient rich (N and P) and sometimes even brackish, causing increasing problems with water quality.

Raising groundwater levels to diminish peat oxidation

In Figure 1 relationships between subsidence rates and ditchwater levels and groundwater levels are presented. Data was available from literature on ditchwater levels and on subsidence of peat soils in the northern part of the Netherlands and a set of data based on own measurements of ditchwater levels, groundwater levels and subsidence of 14 parcels in 5 locations during more than 30 years. The subsidence ranges from 3 to 23 mm and depends strongly on ditchwater and groundwater levels. Note the effect of a thin clay cover. Due to the fact that this clay cover is not prone to oxidation, the subsidence is about 6 mm less than of a peat soil without a thin clay cover.

*Here Figure 1*

From Figure 1 we learn that water management is the key to conservation of peat soils. A logical solution to diminish the subsidence of peat soils is to raise ditchwater levels. However, this results in too wet conditions for an economic viable dairy farming. It should be noted that a viable dairy farming is needed to maintain the important cultural historical landscape in the
heart of the Netherlands (the so called Green Heart). Moreover raising ditchwater levels is less
effective than most people think, because in summer the evapotranspiration of the pasture is
higher than the infiltration from the ditch. This results in groundwater levels that are
substantially lower than the ditchwater level, and so the subsidence is still considerable. A
more effective way to raise groundwater levels in summer without raising ditchwater levels
could be subsurface irrigation using drainage tubes below ditchwater levels. Because the
drainage also drains the soil in wet periods it is even possible to raise ditchwater levels 0 – 20
cm without causing too wet conditions for dairy farming. Figure 1b shows that raising of the
deepest groundwater level towards a ditchwater level of e.g. 60 cm below the soil surface can
reduce subsidence substantially.

To test whether subsurface irrigation with drainage tubes will indeed reduce subsidence of
peat soils we started several pilots with submerged drains. The RECARE Case Study in the
Krimpenerwaard is at the moment the only pilot that is still going on and monitored to test
the long term functioning of this solution. In the Case Study we compare a part of a parcel with
and without submerged drains.

2. Case Study area

Berkenwoude (51° 57’ N, 4° 43’ E, -1.7 meters above sea level) is situated in the centre of the
peat land area Krimpenerwaard (27 km²) and has been permanent pasture for centuries.
Nearby the rivers these peat soils are covered with a 20 – 40 cm thick layer of heavy clay. Peat
depth is 6 to 8 meters. The distance between ditches is about 30 – 40 meters and about 15% of
the total area is open water. Ditchwater levels are 50 – 60 cm below ditchwater level. The area
is typical for about 100,000 ha of peat soil in agricultural use in the Western part of the
Netherlands.

Geology & Soil formation

The Krimpenerwaard is part of a river delta area of the rivers Rhine and Meuse and Scheldt
behind a row of dunes along the shore of the North Sea. The low area behind the dunes was
covered by swamps and lakes. From time to time there were intrusions from the sea. Thick
layers of fen peat could formed because of the slow subsidence by tectonic movement and sea
level rise. The whole western and Northern part of the Netherlands was covered by fen peat.
After a while raised bogs started to grow covering the fen peats. Later on large areas of peat
were lost by intrusions of the sea. At the end of the Middle Ages people started to exploit and
drain large areas of peatland for agricultural purposes and later on also for fuel and to extract
salt. Also the Krimpenerwaard had a raised bog. Nowadays the sphagnum moss peat is
completely disappeared in the Krimpenerwaard. The Krimpenerwaard is surrounded by rivers.
Due to the subsidence of the drained peat and due to sea level rise and so higher river water
levels the Krimpenerwaard was yearly flooded in the areas nearby the rivers and sometimes
completely. During the floods clay was deposited on the peat soils (see figure 1). The more clay
in the topsoil or as a layer on the peat soil, the less vulnerable the soil is for oxidation and
subsidence. In the 12th and 13th century BC the Krimpenerwaard was surrounded by dikes
and became a polder. In the first centuries thereafter the land subsided slowly below the river
water level and the ditchwater had to be pumped out by windmills and later on with steam
engines, later on replaced by electricity driven pumps. Nowadays the surface level is about
1.70 m below average sea level

Climate

The climate in this region is Atlantic and temperate. Mean annual temperature is 10.2 °C and
mean annual precipitation 754 mm.

In the period 1950 – 2012 the temperature increased about 1.4 °C, which is about twice as
much as the average increase worldwide. This faster increase is caused by an increase of
western winds and decrease of aerosols in the atmosphere of The Netherlands and less clouds
in case of winds from the east and south. The precipitation in the coastal area is increasing due
to higher water temperatures of the North Sea.

3. Materials and methods

3.1. Experimental design and treatments

In this case study we test and demonstrate the use of submerged drains to infiltrate
ditchwater into the parcel to raise summer groundwater levels to conserve peat soils (see
Figure 3).

Here Figure 3

Here Figure 4
The set-up of the experimental site is presented in Figure 4. Ditchwater and shallow and deep groundwater levels are measured each 8 hours. Water is pumped in and out at the North and South dam to keep the ditchwater level constant at 40 cm below the mean soil surface level. The ditchwater level in this part of the polder is about the same as in the experimental set-up. To determine the subsidence rate soil surface levels altitudes are measured every two meters in three cross sections in early spring at each measuring field, so in total 51 point the altitude was measured. However, we have to consider that nearby the ditch the altitude is disturbed by the annual cleaning of the ditch. Therefore we skipped the points nearby the ditch, so the mean altitude of the reference and the part with the submerged drains was determined based on 45 points. We measure in early spring because in that period the soil is wet and has been in general almost saturated during winter. This means that the peatsoil is swollen to more or less at its maximum. During a year this is a period with the most stable altitude without almost no reversible shrinkage of the peatsoil. The altitudes were measured every spring in the period 2011 – 2016. The groundwater levels were monitored in 2011 and 2012.

Soil Properties

The soil is classified as Terric Histosol (FAO classification). The top soil consists of clayey decomposed peat on top of about four meters wood-sedge and reed-sedge peat. Soil properties are presented in Tables 2 and 3. The mean deepest groundwater level is at the end of the summer about 65 cm below the average soil surface level.

4. Results

The groundwater levels and the subsidence are considered to be target variables: in summer the infiltration via submerged drains should raise the groundwater level towards the ditchwater level of 40 cm below soil surface and in winter lower the groundwater level towards the ditchwater level. The subsidence should be diminished as much as possible.
The target is to raise groundwater levels by infiltration via the submerged drains towards the ditch water level. The ditch water level is kept constant at the reference level of -2.21 m NAP. NAP is the reference level in The Netherlands and refers to the mean seawater level in the North Sea nearby Amsterdam. The average altitude of the soil surface is -1.80 m NAP. In a dry summer the groundwater level can lower to about 65 cm below soil surface and the soil is up to that depth subjected to air (oxygen) and so biological decomposition. Raising the groundwater level to ideally the ditch water level with submerged drains will diminish the oxidation considerably. In figure 5 the groundwater levels in 2011 and 2012 are presented.

Measurements of altitude and subsidence

The altitude of 45 points in three cross sections is measured in early spring every year since 2011. The results are presented in figure 6 and 7 for respectively the western and the eastern parcel.

Based on the trendlines the subsidence of the reference and the part with the submerged drains of the western parcel is respectively 3.5 and 2.8 mm per year. In the eastern parcel the subsidence of the reference is 3.6 mm per year and in the part with submerged drains 2.4 mm per year. The ditchwater level is -2.21 m NAP. This means that the ditchwater level is about 40 cm below the mean altitude of the soil surface of the western parcel and about 47 cm below the mean altitude of the eastern parcel. Based on the period 2011 – 2016 the correlation coefficients of the trendlines is in the range of 0.32 – 0.63, which is not very high. We hope to improve these correlation coefficients in the future by continuation of the monitoring of the altitudes.

5. Discussion
According to a map with the annual subsidence in the period 1984–2002 of peat and clay soils in the Krimpenerwaard (Grontmij, 2006) the average subsidence is in the range of 4–6 mm in this area of the Krimpenerwaard. The lower value in this range is a little bit higher than the measured subsidence in the parts of the parcels without submerged drains. In the western parcel the use of infiltration via submerged drains results in a reduction of the subsidence with 0.7 mm per year (20%). In the eastern parcel this reduction is 1.2 mm per year (30%). These reductions are less than we found in two parcels at the experimental farm Zegveld (Van den Akker and Hendriks, 2017, Van den Akker et al., 2017). The subsidence of parcel Zegveld 3, with a ditchwater level of about 55 cm below soil surface, was in the period 2004–2015 on average 5.2 mm per year. The use of submerged drains resulted in an average subsidence of 2.5 mm per year, so a reduction of 2.7 mm (50%). The fact that the measuring period in Zegveld was 12 years resulted in much higher correlation coefficients of the trend lines than in the Krimpenerwaard, which had just a measuring period of 6 years. At the experimental farm Zegveld we had in the period 2004–2015 also a parcel Zegveld 13 with a ditchwater level of about 20 cm below soil surface with and without submerged drains. With such high ditchwater levels the use of submerged drains results in too wet parcels and so less favourable for dairy farming, however, in this experimental setup we expected to derive in this way a strong reduction in subsidence. The subsidence of parcel Zegveld 13 without submerged drains was on average 3.0 mm per year. The use of submerged drains resulted in an average subsidence of 0.9 mm per year, so a reduction of 2.1 mm (70%).

According Van den Akker et al. (2008) one millimetre subsidence equals 2.26 Mton CO$_2$ emission. With this equation the CO$_2$-emissions of the parcels are calculated in Table 4. Based on the C-losses of the soil by the CO$_2$-emissions also the soil organic matter (SOM) losses are estimated.

6. Conclusions

The use of submerged drains to raise groundwater levels and reduce peat oxidation and so subsidence and CO$_2$-emissions and SOM losses proves to be a promising technique. However, at the moment we have just a few sets with monitoring data of the subsidence during at least six years. At the moment there are several locations with pilots with parcels with and without submerged drains in which altitudes are measured during just a few years. It is recommended...
to restart these altitude measurements to derive more data on the reduction of subsidence by
the use of submerged drains during a longer period.

Acknowledgements
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References
Byrne KA, Chonjicki B, Christensen TR, Drosler M, Freibauer A, Friborg T, Frolking S, Lindroth A,
Current Carbon Stocks and Trace Gas Fluxes. Carbo-Europe Report, Christensen TR, Friborg T
(eds.)


Schieland en de Krimpenerwaard, Rotterdam, The Netherlands.
https://www.schielandendekrimpenerwaard.nl/ons-werk/ruimtelijke-ordening/waterkansenkaart-krimpenerwaard

Schils, René, Peter Kuikman, Jari Liski, Marcel van Oijen, Pete Smith, Jim Webb, Jukka Alm,
Zoltan Somogyi, Jan van den Akker, Mike Billett, Bridget Emmett, Chris Evans, Marcus Lindner,
Taru Palosuo, Patricia Bellamy, Jukka Alm, Robert Jandl and Ronald Hiederer, 2008. Review of
existing information on the interrelations between soil and climate change (CLIMSOIL). 208 p

Strack, M., (editor). Peat lands and Climate Change, published by International Peat Society,


Title:
Infiltration via submerged drains to reduce peat oxidation, subsidence and GHG emissions of peat soils in agricultural use
Van den Akker, JH; Hendriks, RFA

TABLES

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Table 1. Weather station Rotterdam, long term means, 1981 – 2010
Table 2. Measured values of organic matter and clay content and VanGenuchten-parameters derived from measurements.
Table 3. Measured values of physical and chemical soil properties.
Table 4. Subsidence and CO₂-emissions and SOM-losses of four parcels with a part with submerged drains and a reference part without submerged drains. In the location Krimpenerwaard the distance between the drains is 6 meters and in the location Zegveld 4 meters. We assumed a C-content fraction of SOM of 0.55.
Infiltration via submerged drains to reduce peat oxidation, subsidence and GHG emissions of peat soils in agricultural use

Van den Akker, JJH; Hendriks, RFA.

FIGURES

Figure 1. Derived relationships between (a) subsidence and Ditch Water Levels and between (b) subsidence and Deepest Ground Water Level (GWL) in meters below Soil Surface (m –SS).

The Deepest GWL is calculated as the mean of the three deepest groundwater levels measured in 14 days intervals in the period 1992 – 1998 (Van den Akker et al., 2008).
Figure 2. CO2-emissions of peat areas in The Netherlands in ton/ha/year and soil map of the Krimpenerwaard.
Figure 3. Prevention of deep groundwater levels in peat soils by infiltration of ditch water via submerged drains. This will halve the oxidation of peat soil. Note: a rise of the mean deepest groundwater level with about 20 cm will reduce the subsidence with 5 mm and the CO2-emission with 11 tonne CO2 per ha per year (Van den Akker and Hendriks, 2017, Van den Akker et al., 2017).
Figure 4. Sketch of the set-up of the experimental site. Width of the parcels is about 30 m, length of each section (with and without submerged drains) is about 145 m. Distance between the drains is 6 m.
Figure 5. Groundwater levels in 2011 and 2012 in the western parcel in the reference and in the part with submerged drains at about 1/3th of width of the parcel (see figure 4). Both years were relatively wet years, certainly 2012. Nevertheless in dry periods the groundwater levels in the part with submerged drains was 10 to 15 cm higher than in the reference. In wet periods the maximum lowering of the groundwater levels by the drains was about 20 to 30 cm.
Figure 6. Altitude and subsidence of the western parcel in the period 2011 to 2016. The subsidence of the reference is 3.5 mm per year. The subsidence of the part with submerged drains is 2.8 mm per year in this period.
Figure 7. Altitude and subsidence of the eastern parcel in the period 2011 to 2016. The subsidence of the reference is 3.6 mm per year. In this period the subsidence of the part with submerged drains is 2.4 mm per year.
Title: Effectiveness of different grasses to improve carbon capture efficiency, yield, nutrient uptake and trafficability on a cultivated peat soil

Keywords: Timothy; Reed canary grass; Tall fescue; Peat soils; Nutrient removal; Greenhouse gases

Abstract: The storage of organic carbon (C) in peatlands is a major contributor to the stocks of C in the world. Loss of organic matter from drained peat soils is a threat both to the farmer, due to the surface subsidence associated with the organic matter loss, and to the atmosphere receiving CO2 and N2O emitted from the soil. To find alternatives for the farmer to prolong the use of these soils, a field experiment was established in 2014 on a drained and cultivated fen peat in southern Sweden. The aim of the project was to test if reed canary grass and tall fescue perform better on peat soils compared to the commonly grown timothy grass, without an increase in greenhouse gas emissions. In the experiment we compared yield, nutrient uptake, penetration resistance and loss of organic matter measured as greenhouse gas emissions (CO2, N2O and CH4) from 6 m x 12 m plots (4 replicates) cultivated with timothy (control), reed canary grass and tall fescue. The yield (two cuts) of timothy was significantly lower than the yield from reed canary grass and tall fescue in 2016 and lower than reed canary grass in 2017. The yield level increased during the three years with a total dry matter yield in 2017 ranging between 11.7 Mg ha-1 yr-1 for timothy, 13.5 Mg ha-1 yr-1 for tall fescue and highest for reed canary grass with 14.3 Mg ha-1 yr-1. The higher yield in 2017 compared to 2016 could be due to the higher fertilization level in 2017 (2 applications with 50 kg N ha-1 compared to one in 2016). The total removal of all macro nutrients were higher in reed canary grass and tall fescue compared to timothy in both cuts. Reed canary grass removed totally 173 kg N ha-1 yr-1, tall fescue 169 kg N and timothy 121 kg N. This can be compared to the fertilization rate in 2016 that was only 50 kg N ha-1. No differences in trafficability measured as penetration resistance could be shown. Greenhouse emission measurements were conducted with automatic dark chambers (CO2) in 2016 and manual (CO2, N2O and CH4) dark chambers 2016 and 2017 during the snow free season. Differences in CO2 emissions between treatments were small, N2O emissions were low in the range from close to zero up to 300 µg m-2 h-1 and the CH4 emission rates were very small and in general negative. The
carbon capture efficiency, the ratio of C in above ground biomass plus roots and emitted CO2-C measured by the automatic chambers, was estimated for the growing season (May-October) in 2016. The efficiency was lowest for timothy (0.61) and higher for reed canary grass and tall fescue (0.70 and 0.70 respectively). Reed canary grass and tall fescue are promising alternatives to the commonly grown timothy on peat soils regarding yield, nutrient removal and carbon capture efficiency.
Abstract

Click here to download Abstract: abstract.docx
The yields (two 10 m² plots) remain lower than the 23
years from re-introduction and even lower than the 6.

The yields are recorded during the year with a total dry yield ranging from -1 to -1 for tomato and -1 to -1 for sunflower. The highest yield could be due to the utilization level of 2 kg of nutrients with 50 kg of N ha⁻¹ compared to 2016. The yield comparison could be very similar for both crops and grass and even higher for reed grass. This can be compared to fertilization rates only 50 kg.
The ability measured as penetration and ventilation during the snow season. The oxygen emissions were tested for the season (May-1 to August) and ventilation was lower for tomato and 0.70 and 0.70 respectively for reed grass and tall grass. Reed grass and tall grass commonly grow on peat soils regardless of yield, nutrient removal and carbon capture during the season.

Conclusions:

Kebede: 

20021999
The yields of red canary grass and fall meadow moth y are shown between treatments
and nutrients are removed by earthworms.

Highlights (for review)
Effectiveness of different grasses to improve carbon capture efficiency, yield, nutrient uptake and trafficability on a cultivated peat soil.

Berga, Berga, Sabine Jordan, Lisbet Norrgård.

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*Manuscript.

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The storage of carbon (C) in a nation is a major carbon stock. Carbon stocks in the world are estimated to contain approximately 3% of the world's organic carbon (Moor et al., 2009). The total carbon in the world is estimated to be 475 Gt C, as per EU Member States and Candidate Countries, Byrne et al. (2004) reported 34 Gt C are agricultural crops, with a total of 17 Pg organic carbon in Europe and 13.8 Pg carbon in agriculture and cropland (0.95 Pg grassland (2.65Pg)) as per 2008.

Peat are estimated to change in terms of use and carbon. The pressure for land in Europe has resulted in a reduction in Europe and to make a table for agriculture and other land love and.

As a new type of peat became more in countries, any in Poland, when over 85% of the land and area in agriculture, money.


The subsidence can be divided into the main category and (2) shrinkage by drying and (3) fog due to ice crystals. The subsidence is very similar to the actual type of inflation, intensity, and type of year, and other. The type of subsidence is a major category of CO$_2$ andarto. The house gas SCHEL and exclude the last steam SO$_2$ and from use change along any organ. They also...
carbon to manage carbon stocks is to increase stocks in soy and other crops, and to encourage carbon content in grasslands and other ecosystems.

To stop agricultural contamination through fertilizers, they turn to increasing agricultural productivity in many cases through the use of phosphorus, e.g., Rezvany and Rao, 1983) to cultivate and improve birds as are. On many peats, weing is possible due to the difficulty to maintain a high static water table. In cases where it is possible to regulate water tables, e.g., love and care, 2017) it is to be used as a strategy to slow down agriculture by the farmers in Eureope (RENTE, 2013a) to slow down agriculture by the farmers in Europe (LAND) and to mention the importance of reducing emissions and agriculture, 2013b) to mention the importance of reducing emissions and agriculture.
The common grass grown in Sörn is mostly for animal feed other than masty for livestock (1961) both regarding and traffic ability. Reeducarily (Phalaris L. is a tall and grassy-stalked as a 1961 crop if classes and classes (183) are and classes for age.101 The animal thickens to test if the canary grass and tall commonly grass without an ease of growth and classes participate in the measurement of gases (CO$_2$, N$_2$O and H$_2$S) (108).

Material and method

The Broodbäck case site (60.028 N, 17.43 E) is a more Bäcken site and a land in Sörn. This
The region in the image is of interest to note that there is a short food supply in that area (Berg 2008). The mean air temperature is °C and the mean precipitation is mm. The temperature at 50 cm is °C. The land is mainly covered by 20% forest. The area is mainly cultivated. To describe the site, several samples are formed outside each crop. The soluble pH according to Pohl (1922) and the electrical conductivity (water solution content) were measured by burning at 105°C after ignition.

The area is covered by 20% forest. The taxonomic name is Euic. The oil Taxonomy 20% is Euic.
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c ommonl y  g row �in �� a ��a , B � R e e �c a �� r y  �a ss ��a ��
��  F e �� �F ). Due  t ���e mer g e n c e  R C ��a nd ��
sown in ��e  sprin g  o 2 015. �� �� � c e ived 5 �� kg N, �� k ��
phosphorus �� a nd 37 �� potas sium ��rtili z e �� c t a in �� sprin �� 2016 using ��k g ��- 5 - ��
ar a ��la P ��g �). The  �rtili z a �� on in �� �� �� b y
��a �� c a �� �� �- 5 - �� one  in Apr (45 �� /ha ��
one  fte r the irst cut of ��� �� n J ��y (454 �� g ��).

2.4 Field d ��� ield sa mp ��l sa nal y sis
The  �mpl �� � C O2 N2 ��a nd C H4 c a �� i e �� durin �
y ��m �� 12 ��  with c ��rk c ��s  (Mosier  a nd
Mack, 1980) �� C irc ��  p ��y vin y  c hlo �� ��c oll a rs with a
163
The area is approximately 13 cm. The columns are situated on grass and for gas sampling, the grass was cut to create the sampling. For measurement, 

<table>
<thead>
<tr>
<th>CH4</th>
<th>N2</th>
<th>CO2</th>
</tr>
</thead>
</table>

At sampling outside, volumetric content and temperature were recorded every 30 min with a WET sensor and vice versa. A polytechnic with a cone of 2 cm and a scale was used. Measurements were repeated in each.

...
The above ground yield measured at 0.25 square meter with an error of 0.25 mm.

The assay is for 3-year yields to enter the yield.

Carbon and nitrogen content is analyzed using a C N analyzer (CN2000, LICOR).

Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) are determined using ICP-OES duration by Li et al. (2013) total nutrient movement from the yield and the concentration of nutrient dry biomass.

Soil samples in (0-20 cm) in July 2016 and in (20-40 cm) in September (20-40 cm) were pooled to a sample size and sieved with a 2-mm sieve. Soil C and N content were analyzed by LECO, according to SS-IS-10694 for Ca and SS-IS-1321 for P. Plant nitrate content was measured according to method no G-287-02 R and ammonium content according to method no G-102-93 Rev.8.
2.5 Gas analyses

The gas sample was manually stored in a dark room and then kept in an airtight container for some time after sampling using a gas collection cylinder and a vacuum-sealed vial. The GC was equipped with a capillary column and connected to a splitless injector. The gas analyses were performed using a gas chromatograph (Clarus 580, Perkin Elmer, USA) with a capillary column and connected to a splitless injector. The gas analyses were performed using a gas chromatograph (Clarus 580, Perkin Elmer, USA) with a capillary column and connected to a splitless injector.
ca and ed injection are used. The GC is operated in a flame heated by a flexible fiber first, N\textsubscript{2} and CO\textsubscript{2} by a electron capture detector. CH\textsubscript{4} is monitored at 1 ppmv and 20 ppmv; N\textsubscript{2} at 1 ppmv and ppmv and CO by a detector for the same concentration at 300 ppmv and 900 ppmv are used. The system is for CO analysis given high resolution analyzers. The system is manually in a using a HMR ion in R and a measurement not in R is used. The means influence to the soil from the atmosphere.
264 CO$_2$ concentration and assimilation A

265 used to move naturally that could by ambient CO$_2$ concentration and assimilation.

266 Manually measured CO$_2$ and N$_2$ and CH$_4$ flux by pressure measurement analysis and estimated easily as analysis.

267 Resultion

3.1 Nitrogen assimilation 3.1

285 concentration

286
The % ses w e % cut two % e r y y e a % except in 2015 whe c a %r y %a %ss %n and %e r e sowned and c ould onl y
%e sted %e %me %S %i g %e %y. %y ield leve %durin %e 2017 %n g %e e %1 % 1 h a
-1 -1 %e h ��� y i e ld in 2017 c ompare %to 2016 c ould % e %h %r %rtili z a on %in 2017 %a %e c a %r
r 50 %e fie lde x e riment with tall %u e %hig %st %e c a %r y %a ss %
14.3 % 1.
10.1 % 1.
14.3 % 1.

The %rtili z a on %e %n 2017 %a %n 2016 c o mpare %thi %rtili z a on %n 2017 %c a
(2.5 + 2) c ut %nd %n 2017 %n 16.4 a n %18.8 Mg -1 -1 %rtili z a on ��� ��+ 60 %he
y ield %n our e x e riment %sig nific a ntl y %han %y ield %m %e d c a %r y %a ss %nta %c
2 %s c in 2016 a nd %tha %e d c a %r y g r a ss in %n %a %e ��e n e x e riment %
with %e d c a %r y %a ss (��ad %e e %2013a ) %y ��e y i e �� in a 2 c
s y stem w e %11 Mg h a (8 + �� ��rtili z e with 60 kg N
-1 -1 16 % 1 (8 + ��rtili z e ��
-1
-1
-1
-1
-1

11.1 (10.1 - 12.1) 11 Mg in

2016 ��a nd 14.3 1.
2016 ��a nd 14.3 1.

Re e d c a %r y g r a ss %y �� 11.1 (10.1 - 12.1) 11 Mg
2016 ��a nd 14.3 1.

Rec e d in a fie ld e x e riment on %a %s oil  in S e r g lund a % B e r g ��
2012) a nd w a %g %c a %ntl y %g r


than that yield (8.8). This is in agreement with older field trials where an average mass yield of cane was measured for both grass and tall fescue crops. Macro and micro-chemical analysis in both 2016 (tables 3) and 2017. Concentrations are comparable to Danish field experiments with grass grown on sand (2017) and Swedish experiments with canary grass in both cuttings. 

3.2 nutrient removal by the ses The total macro-chemical (ferrous higher in canary grass and tall fescue compared to grass as was removed in 169 kg N and 121 kg. This can be attributed to the utilization in 2016 as only 1 kg N
The phosphorus (16-25 P on the me  a on  P R e on potassium many higher by the Rtilization and cec a fic y that can ec yield leve ls and fodder qua ty The aer ��egr a �� e ��e ��f r om �� �� cing �� nt es. Iy �� e eks after ic cut, t oil wa al y for m inal N content a a e P and a 4). e small cence in ent lels no cleac on that the grea dife e in removal by the gbed aer ec ynt lels in o o o S oil al y �� e��r e at e on ��me ��c ��rve st for �� tops i and �� nta on �� �� a able. There are no cence etwee e tre ae ��c ontent in ��� �� hig r onium c in topso il e c a r y ��ss ��s, ��mpare ��y ear. 3.3 y ��

The a onysis e in ��horizon -20 c signifi cantly low e for mot h y in J but a other mea ��ent o cca sions ��5 ). I to �� whe n lking in the fie ld a more g ous owth in reed
3.4 Discussion

2 emission scenario was manually measured (Fig. 1 and with a computer program in 2016 and compared to the average with a computer measurement due to the increase in -measured with a computer made around a clock on the 3 week period and manually measured before measurement and only added when necessary to be calculated. In 2016 we were estimated in CO2 emissions through a computer on the 3 week period and manually measured with a computer with the 3 week period before measurement and only added when necessary.
During 2017 CO emissions were only done with manual calculations (Fujitani et al. 2011) and these results are significant compared to standard CO2 emission calculations. The CO emissions were very small and linearly decrease (Berglund & Berglund 2011) and CO2 emissions were in general for the current situation between crops and seeds planted in 2013 at Norrström, and soil temperature around 20°C in 2016 and...
close to zero update and and 

sim to values in finish field experiments with 

crops and grass m-2 h-1. In 2017 N2 was significantly lower than grass m-2 h-1). On yon comparing the effect of crops on nitrogen and methane emissions in 2018) on untilize generally (Bunthorpe et al. 2013). It was not until 2016 untilize on crops can and stay high. Higst N2 was recorded after the crop was cut on 7 S e ask in Experiment in 2017 could be easily in as soon as possible. High N2 in 2017 were recorded after the crop was cut on 7 S e ask in Experiment in 2017 could be easily in as soon as possible. Berglund and Berglund (2011)
The carbon efficiency C in a grass plus roots and above-ground C uptake by the grass, were estimated for the growing season (May - October in 2016). The efficiency was estimated to be zero for the canary grass grown on a pea and rye mixture, and 0.61 for heather and and 0.70 for these grasses to a mixture of a cereal and traditional grasses grown in 2017. The grass yield with than % similar to 2016, the mixture could achieve the carbon capture efficiency I and efficiency on above yields could become in an environmental cycle of recycling. Re-cycling of re-cycling re-cycling re-cycling re-cycling in 2013 and 2012;
The main concerns of this system are:

- The yield can be increased by using more fertilizers and by changing the planting density.
- The carbon entry is minor compared to the common growth yield, and the nutrient removal and carbon entry are highly efficient.

Recovery of a canary grass and tall moth y in carbon generation. Small amounts of oxygen are low in energy.
This study was funded by the European Framework Programme.

Agreement no 603
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Rksdal mårler Rolf leren från Närland ör sök en t Rksdal: 4, Väodil i. Um. Bgl. 

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gflu xen C K., Friborg (c) , Cen- rep ort.

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gflu xen C K., Friborg (c) , Cen- rep ort.

Inér H., Riehm H., Domi, Ös Jensen die

chemi ianaly al Grundl in für d Bert iung

des Nährstoff der BII Chii.
K. Kiim - Kledt et al. Grnhouse gases for med ani lls: A ril A und Nagent 5--
Kl e, B. Bglund K., Bglund, Ö., l. S., l. jalan, M., �� Fut uro cult ev es Nl di s cl managem ent or ro l gr i ons? Env ironment al Sci �� Po li s - 93.
Kl e, D. J., H. ��� lk e, E.L., �� Wi ne Erodi ty Org ani c il Sc i . Soc . A m. J ��ri - ��
��r �� Lomakk a, A. As son, �� ��� Hv i tir i im mi y and qua l i ty r ed in y gr es a stone g ry cro p. B i��s a n d B ioen gy , 11, 333-��
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ande r Ü ., ���R g r es i cult ev i mi t i g e s gr nhous g i ons fr aba ndoned p e -
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 t ��r �t s  i ��p ��t  o r E u r o p e ; �� R ��� L u x e m��, pp. ��-
V on Po st ��1922.  ��i g � G eol ��is ��t i v e ��t e r i �� �� nog r � � des �� t t i l v unna r e sul t a t  ( � U �� ��t e y  ��s �� ��� i mi nar y  r e sul t a t  (U �� 1-37.
WRB �� 2001.  Lec t ���t e s  on t he ��i l s  ��t h e  Worl ( W �� �� e s ��t �� �� �� ��r t �� �� R ��
Zhou, X ��t  � ., 2011.  ��t s �� ed CO ��t ��r u ��n C O ���t �� �� ��t e r i s t i ��pho ��c ��c ��o r ��i ��r ound ��c a ��or ��b i ��r b i ��r g y  ��op ( P hal a r i ��und �� )  ��der  v �y i �� w ��i ��m�� C �� B i ��y �i ��r g y �� - ��

Table 1. Soil profile properties at the field experiment site at Broddbo, Sweden. Determination of soil type, humification degree (von Post, H1-H10), pH (H$_2$O), electric conductivity (EC) and loss on ignition (LOI), n=4 (Standard error).

<table>
<thead>
<tr>
<th>Soil horizon (cm)</th>
<th>Soil type</th>
<th>Humification degree von Post</th>
<th>pH (H$_2$O)</th>
<th>EC (µS/cm)</th>
<th>LOI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>Fen peat</td>
<td>H10</td>
<td>5.55</td>
<td>105</td>
<td>86.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.09)</td>
<td>(8.38)</td>
<td>(0.2)</td>
</tr>
<tr>
<td>20-40</td>
<td>Fen peat</td>
<td>H8-H10</td>
<td>5.73</td>
<td>50.4</td>
<td>85.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.16)</td>
<td>(5.46)</td>
<td>(1.19)</td>
</tr>
</tbody>
</table>
Table 2. Micro nutrient concentration (mg/kg dry matter) in the biomass of timothy (T), reed canary grass (RCG) and tall fescue (TF) during harvest in 2016. Different letters indicate significant differences between treatment means (p < 0.05) for each cut.

<table>
<thead>
<tr>
<th></th>
<th>First cut 2016-06-23</th>
<th>Second cut 2016-09-21</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T</td>
<td>RCG</td>
</tr>
<tr>
<td>Cu</td>
<td>4.1 a</td>
<td>5.2 b</td>
</tr>
<tr>
<td>Fe</td>
<td>37.0 a</td>
<td>42.1 a</td>
</tr>
<tr>
<td>Mn</td>
<td>72.5 a</td>
<td>106.6 b</td>
</tr>
<tr>
<td>Zn</td>
<td>30.4</td>
<td>33.5</td>
</tr>
</tbody>
</table>
Table 3. Macro nutrient concentration (% of dry matter) in the biomass of timothy (T), reed canary grass (RCG) and tall fescue (TF) during harvest in 2016. Different letters indicate significant differences between treatment means (p < 0.05) for each cut.

<table>
<thead>
<tr>
<th></th>
<th>First cut 2016-06-23</th>
<th>Second cut 2016-09-21</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T</td>
<td>RCG</td>
</tr>
<tr>
<td>N</td>
<td>1.57</td>
<td>1.78</td>
</tr>
<tr>
<td>P</td>
<td>0.24</td>
<td>0.26</td>
</tr>
<tr>
<td>K</td>
<td>1.42</td>
<td>1.34</td>
</tr>
<tr>
<td>Ca</td>
<td>0.51</td>
<td>0.53</td>
</tr>
<tr>
<td>Mg</td>
<td>0.17 a</td>
<td>0.26 b</td>
</tr>
<tr>
<td>C</td>
<td>43.7</td>
<td>46.0</td>
</tr>
</tbody>
</table>
Table 4. Analyses of mineral nitrogen (NH$_4$ and NO$_3$) and available K and P (K-AL and P-AL) in topsoil (0-20 cm) 13$^{th}$ of July 2016, and mineral nitrogen both in topsoil and subsoil (20-40 cm) 22$^{nd}$ of September 2017. Different letters indicate significant differences between treatment means ($p < 0.05$) within each year.

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>NH$_4$ (mg kg$^{-1}$)</th>
<th>NO$_3$ (mg/kg)</th>
<th>K-AL (mg/100g)</th>
<th>P-AL (mg/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timothy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-20</td>
<td>43.5</td>
<td>ab</td>
<td>39.5</td>
<td>a</td>
</tr>
<tr>
<td>20-40</td>
<td>27.0</td>
<td></td>
<td>29.3</td>
<td></td>
</tr>
<tr>
<td>Reed canary grass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-20</td>
<td>38.5</td>
<td>a</td>
<td>51.3</td>
<td>b</td>
</tr>
<tr>
<td>20-40</td>
<td>29.7</td>
<td></td>
<td>25.7</td>
<td></td>
</tr>
<tr>
<td>Tall fescue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-20</td>
<td>47.8</td>
<td>b</td>
<td>43.3</td>
<td>a</td>
</tr>
<tr>
<td>20-40</td>
<td>33.0</td>
<td></td>
<td>27.3</td>
<td></td>
</tr>
</tbody>
</table>
Table 5. Mean penetration resistance (MPa) in the top soil (10-20 cm) measured 2016 and 2017. Different letters indicate significant differences between treatment means (p < 0.05) on each measurement occasion.

<table>
<thead>
<tr>
<th></th>
<th>2016</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timothy</td>
<td>0.61a</td>
<td>0.64</td>
<td>1.06</td>
</tr>
<tr>
<td>Reed canary grass</td>
<td>0.69b</td>
<td>0.66</td>
<td>0.89</td>
</tr>
<tr>
<td>Tall fescue</td>
<td>0.70b</td>
<td>0.69</td>
<td>0.91</td>
</tr>
</tbody>
</table>
Table 6. Mean emission of CO$_2$ (mg m$^{-2}$ h$^{-1}$), N$_2$O and CH$_4$ (µg m$^{-2}$ h$^{-1}$) from plots with timothy, reed canary grass and tall fescue during the growing season 2016 and 2017. Different letters indicate significantly different emission ($p < 0.05$) in pairwise comparison. Capital letters indicate where the treatment effect also is significant in the model.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N$_2$O</td>
<td>Timothy</td>
<td>179 a</td>
<td>71 A</td>
</tr>
<tr>
<td></td>
<td>Reed canary grass</td>
<td>85 b</td>
<td>75 A</td>
</tr>
<tr>
<td></td>
<td>Tall fescue</td>
<td>152 ab</td>
<td>126 B</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>Timothy</td>
<td>10</td>
<td>-33</td>
</tr>
<tr>
<td></td>
<td>Reed canary grass</td>
<td>-60</td>
<td>-34</td>
</tr>
<tr>
<td></td>
<td>Tall fescue</td>
<td>-33</td>
<td>-37</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>Timothy</td>
<td>1326 a</td>
<td>730 A</td>
</tr>
<tr>
<td></td>
<td>Reed canary grass</td>
<td>684 b</td>
<td>795 B</td>
</tr>
<tr>
<td></td>
<td>Tall fescue</td>
<td>1295 a</td>
<td>825 B</td>
</tr>
</tbody>
</table>
Figure Captions

1. Figure 1: Biodiesel trial: experiment and pea t
2. Figure 2: Manual sampling of indoor gases using VC collators (auto and soil CO$_2$ exc system from C scientific &)
3. Figure 3: Dry matter/ha of moth, reed canary grass, and teasels 2015 (c/cut and 2017 (c/6 & c/cut)
4. Figure 4: Soil measure N, CH$_4$, and CO$_2$ emissions with c/ears shown standard of the system at moth years and 2016.
5. Figure 5: Soil measure N, CH$_4$, and CO$_2$ emissions with c/ears shown standard of the system at moth years and 2016.
F, N, O, CH, and CO. The cut occurred at 5 cm during the growing season 2017.
Case study number:
County:
Networks:

Affiliation(s):
Wageningen Mental Research, The Netherlands

Principal soil area:

decline of organic matter in mineral soils

Additional soil area:
soil contamination decline of groundwater quality, soil compaction

electrication and demonstration:
1. Introducing grass and control increase soil organic matter grass cover in maize
2. Manual separation
3. Incubation of biomass

Contribution:
Reportings:
WP 6.3 Activities

Mon 18-

version: 04
date: 08-Jan-

Decay of soil organic matter (SOM) in agricultural and degraded soils has been widely recognized as a major threat to sustainable soil management because of the importance of soil functions and ecosystem services (et al., 2015). The decline in soil organic matter (SOM) in agricultural and degraded soils has been widely recognized as a major threat to sustainable soil management because of the importance of soil functions and ecosystem services (et al., 2015).
The loss of organic matter observed by face and observed in previous projects is due to a combination of factors, such as long-term and continued monoculture of maize on specific fields, intensive potato cropping in the area, strict legislative dictates at to a combination of factors, such as long-term and continued monoculture of maize on specific fields, intensive potato cropping in the area, and water quality. This was also explicitly recognized in the project proposal. The information collected as a scientific field experiment. This period is also to show to see effects on soil fertility, but implementation by face is less well known. Implementation by face is the agricultural practice implemented in this region already tested and described in the long-term. The information on the land management is already known. As a consequence of the setup of this collaboration, the information is collected and shared on the effectiveness of the agricultural practices, and the experience of national government financing over the period 2014-2024. For this period information will be used. The setup of the information collection is not implemented. In the project, information collected from different sources as described above was used. Wageningen Environmental Research employed the information on soils and satellite water company assigned the monitoring of nitrogen within REA and with foundation Huur a chairman appointed to collect information on the maize yield, the fields of the face participating in the subsidy arrangement every year, the provinces: the provincial authority instructs the measurement of organic matter in the face. As a consequence of the setup of this collaboration, the information is collected and shared on the effectiveness of the agricultural practices, and the experience of national government financing over the period 2014-2024. For this period information will be used.
The soils in the Olden-Eibergen Case Study and developed in coastal sands and clayey and loamy sediments deposited by the small stream. Most soils are podzols or cambisols; nutrient-poor soils developed in sand. The area also has patches of anthroposols, soils enriched in Medieval times with manure and organic residues. Phosphate and nitrogen levels in these soils are generally high.

Climatic information on the study site is developed from the meteorological stations of Hupsele and Stuhol, at respectively 2 and 15 km distance from the case study area. Mean monthly temperatures between 2 and 17 °C. The long-term annual precipitation is between 800 and 825 mm, with the lowest amounts in spring, and the highest in autumn. The 30-year average annual precipitation deficit is between 200 and 240 mm.

3.1. Experimental design and treatments

A number of 30 fields currently participating in the implementation of measures to improve the soil organic matter status of the fields (Figure 2). These measures include plowing of grass as a cover crop in a standing maize crop, manure separation and the incorporation of wood chips and other organic residues. Grass plowing is implemented since 2014 (Figure 3); manure separation and the incorporation of external biomass (wood chips, leaves, grass clippings from the vees of ads and wate) since 2016 (Figure 4). The measures designed to measure the status of fields in the area. The measures are not designed to determine the effect of the specific treatments. Such the measures show the participation of the fields, the implementation of measures and help to quantify the problem.

The implementation of measures followed within the World of the RapProject (Table 1). The following soil parameters monitored to assess the effectiveness of the measures:

1. Ammonium concentration in the upper groundwater (µg / l): this parameter is used to assess effects on the sub-objective 2 - De nitrification to the groundwater.

Additionally, in fields of four fields:

2. Organic matter content in the topsoil (25 cm): this soil parameter clearly indicates the status of soil organic matter in the topsoil. It is used to assess the effect of the mediation measures on all the objectives of the experiments.
Figure 2 Fields of farmers participating in the implementation of measures to support SOM status (orange) and locations of groundwater quality monitoring (black dots).

Figure 3 Fields of the farmers participating in the field trials for the RECARE project, and fields with grass undersow in maize cropping. The land use reflects the situation in 2015.
Figure 4 Fields of the farmers participating in the field trials for the RECARE project, and fields with grass undersow in maize cropping. The land use reflects the situation in 2017. The total area testing undersowing (“onderzaai”), thick fraction (“dikke fractie”) and additional biomass (“biomassa”) is resp. 39, 67 and 93 ha. In some fields a combination is used.

Table 1 Key characteristics of the pilot fields.

<table>
<thead>
<tr>
<th>Field</th>
<th>Area (ha)</th>
<th>Soil type</th>
<th>Land use (2015) and prior land use</th>
<th>Years with grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td>383197-JS</td>
<td>3.37</td>
<td>Fimic Anthrosols (50%)/Umbric Gleysols (50%)</td>
<td>Maize since 2003</td>
<td>0</td>
</tr>
<tr>
<td>383205-JS</td>
<td>1.26</td>
<td>Gleyic Podzols</td>
<td>Maize since 2012; grassland from 2008-2012</td>
<td>4</td>
</tr>
<tr>
<td>146548-JZ</td>
<td>2.69</td>
<td>Gleyic Podzols/Umbric Gleysols</td>
<td>Maize since 2004</td>
<td>0</td>
</tr>
<tr>
<td>383198-JS</td>
<td>2.52</td>
<td>Gleyic Podzols</td>
<td>Grassland since 2000 One maize rotation in 2012</td>
<td>15</td>
</tr>
</tbody>
</table>

3.2. Field data and sample collection
Monitoring on upper groundwater

Nitrate concentrations in the upper groundwater monitored on behalf of the drinking water company Vitens Ieis, Noij and Roelsm, 2016

The aim of the monitoring activity is to test if measures in a area have an effect on the average nitrate content of the upper groundwater. This is relevant as the deep groundwater is used for the production of drinking water. The monitoring is carried out between 2014 and 2018. The nitrate concentration is measured in the upper groundwater on 70 locations in the area in November of each year. The sampling locations were selected in a stratified random sampling design. The stations are defined by soil type, groundwater regime and land use. In the sampling design the various treatments, gases under, thick manure in the area were not taken into account.

NDVI

NDVI was obtained from DMC images, processed and hosted for The Netherlands since March 2012 by the website www.geonmonitor.nl. The DMC images are multispectral, providing data on the green, red and NIR bands. Processed images of calculation of spectral reflectance, geocodification, mosaicking and filtering have a spatial resolution of 25 m and a temporal resolution of ca. one week. The availability of images depends on the cloudiness. NDVI images were collected for 33 fields of the four pilot fields in the study area, of which 6 under maize cropping. The images cover the period of 15 March 2012 till 8 September 2016. Between 16 and 34 images per year available for this period.

3.3. Laboratory analyses

Organic matter

The soil organic matter content was determined in the laboratory of ERMTR and using loss on ignition at 550 °C and a standard NEN 5754. Nitrate

The nitrate content of the groundwater samples was determined in the Wageningen UR according to the concentration method and time in protocol KB 3001 for non-acidified samples. The laboratory and the analysis method were accredited by the Dutch Council of Accreditation see www.acn.nl, registration number 342 for details on the method.

3.4. Data analyses

Fall the spatial average, median and range were calculated, and the changes in these parameters between the years. For these calculations the method described in Bruis and De Gijt 2011 was used.

NDVI

For each field the spatial average, median and range of the NDVI values of pixels with the same ID within the field boundaries. The NDVI expresses the amount of green biomass in multiple systems of vegetation. In this use the NDVI is used to detect the effect of gases under and possibly also the other two mediation measures on the production of maize and gases and on the soil ant Available Water Capacity (PAWC). This soil parameter expresses the maximum amount of plant extractable water which can be held in the soil. Maximum NDVI V and green-up slope (rate of NDVI increase) appears to be a good indicator of soil available Water Capacity (By et al., 2016). These indicators were calculated for the treated and untreated conditions in maize fields.

NDVI
4.1. Treatment effectiveness in terms of targeted variable(s)

**Figure 5** Soil organic matter content in agricultural fields in sample in 2003 and 2010 (bottom). The number of fields is indicated in the right of the figure. Source of the data: Project “Gezond zand” (healthy sand) (Rienks and Leever, 2014).
Figure 6 Development of SOM in two fields with permanent grassland (grey) and maize cropping (coloured) of two pilot farmers in Haarlose Veld - Olden Eibergen, The Netherlands.

**Untreated conditions**

The content of fields under continuous maize cropping of four pilot farmers until the implementation of soil management measures is considered to reflect 'untreated conditions' for the purpose of the RAR Project. At the moment of writing 2016 observations from the fields of two pilots are available.

Field 383198-J is located for 50% of its surface on a Fimic Anthisol, a soil which has been enhanced in organic matter since medieval times. This is not reflected in the content of the field, since field 383198-J was managed by the same farmer had comparable or even slightly higher contents, as this field is located on a Gleyic Eutroch, which by definition has lower organic matter contents in the topsoil. However, the last mentioned field was grassland until 2012, which may explain the slightly higher contents, which are close to the reference values found in permanent grassland (1-4.4%), see Reference conditions).

**Treated conditions**

In 2013 and 2014 grass growing was implemented on field 383198-J respectively. In 2015 this measure was combined with the application of thick fiction of cattle manure on both fields, and in 2016 another measure was added: in addition of wood chips. Since only two observations since the start of the implementation, no conclusions can be drawn about the effectiveness of the measures yet.

The observations on SOM content of field 383205-JZ show a decrease in SOM content between 2004 and 2009, but the farmer indicated not to be certain about the measurement of the 9% in 2004. From 2009 to 2012 the SOM content slightly increases, but the increase is small.
Maize yield

Maize yield was not measured by the pilot face until 2014. The reason is that the maize is used as a feed crop for the own cattle, and not sold on the market. Since the start of the implementation of measures as part of the project, maize yield started to increase. For the pilot fields only observations for 2014 are available (Table 2).

Table 2 Maize yield in pilot fields. Source data: J. Stokkers and J. Zieverink, farmers in Haarlose Veld Olden-Eibergen.

<table>
<thead>
<tr>
<th>Field</th>
<th>Treatment</th>
<th>Year</th>
<th>Maize yield (ton/ha) (fresh)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2013-14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guss underow</td>
<td>Wood chips</td>
<td></td>
<td>14.8 ±5% DM</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2014-2016</td>
<td>39.7 ±5% DM</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2013-14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guss underow</td>
<td>Wood chips thick f</td>
<td></td>
<td>11.2</td>
<td>Low yield as a result of an inappropriate guss variety for the underow.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2016</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2. Treatment impacts on non-targeted variable(s)

NDVI index of greenness

Reference conditions

NDVI values of permanent gussland are considered as reference conditions for the measure guss underow in maize, since the permanent gussland constitutes a full guss cover of the soil throughout the year.

The NDVI values of the fields with permanent gussland and fields with maize cropping of the pilot fields in the monitoring period are shown in Figure 7. On the fields with maize cropping guss underow was applied since 2013-2014. The course of the NDVI values in time shows the effect of the seasons, with high NDVI values in summer and low values in autumn and winter.

Permanent gussland can be distinguished from fields under maize cropping by high values of the NDVI in spring and autumn. Also, maximum NDVI values in the growing season (May-October) are high for permanent gussland in most years.
Figure 7 NDVI values of fields of the pilot farmers (32 under permanent grassland, 4 under maize cropping). Source of the data: www.groenmonitor.nl.

Unshaded and shaded conditions
NDVI values of maize fields before the implementation of grass undersown are considered as unshaded conditions, since the management, soil type and groundwater conditions are the same in both conditions. Since NDVI is influenced by precipitation, the comparison of values between years is a correct correction for precipitation.

The expected effect of grass undersow would be a higher NDVI after the sowing in June compared to the unshaded situation, and relatively higher values during the winter when maize is harvested and the undersows still provide vegetation. This effect cannot be observed for the pilot fields with maize cropping since 2014 (Table 3).

Table 3 NDVI in June-March in fields with maize cropping.

<table>
<thead>
<tr>
<th>Field</th>
<th>without grass undersow (-2014)</th>
<th>with grass undersow (2014-)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>stdev</td>
<td>average</td>
</tr>
<tr>
<td>146548</td>
<td>0.51</td>
<td>0.22</td>
</tr>
<tr>
<td>146551</td>
<td>0.56</td>
<td>0.10</td>
</tr>
<tr>
<td>383197</td>
<td>0.51</td>
<td>0.21</td>
</tr>
<tr>
<td>383205</td>
<td>0.55</td>
<td>0.15</td>
</tr>
<tr>
<td>Average</td>
<td>0.53</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Table 4 Average nitrate concentrations (mg NO\textsubscript{3}/L) as a function of year and land use (between brackets: standard deviation).

<table>
<thead>
<tr>
<th></th>
<th>Area (ha)</th>
<th>Number of samples per year</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arable</td>
<td>129</td>
<td>30</td>
<td>56 (8)</td>
<td>43 (6)</td>
<td>50 (7)</td>
</tr>
<tr>
<td>grassland</td>
<td>177</td>
<td>40</td>
<td>75 (11)</td>
<td>46 (11)</td>
<td>40 (5)</td>
</tr>
<tr>
<td>Whole area</td>
<td>306</td>
<td>70</td>
<td>67 (7)</td>
<td>45 (4)</td>
<td>44 (44)</td>
</tr>
</tbody>
</table>

4.3. Treatment effectiveness in terms of principal soil threat
4.4. Treatment impacts on additional soil threats
a r r a n g e m e n t o n a g s c u l t u r e p c i c e s t o i m p r o v e s o i l o a n i c m a t t e r w i t h t h e g i o n a l a n d n a t i o n a l g o v e r n m e n t . W e t h a n k t h e f a c e a n d d i c t o r o f t h e F o u n d a t i o n f o r t h e c o n t r i b u t i o n . C o n s u l t a n t a g e n c y R O M3 D i s t h a n k e d f o r t h e i s u p p o r t t o t h e e x c h a n g e o f i n f o r m a t i o n a b o u t t h i s e x e h a n g e w i t h t h e f a c e a n d F o u n d a t i o n . T oo n e s s e l s f r o m t h e w a t e r c o m p a n y V i t e n s f r o m W a g e n i n g e n v i c e r n a l r e s e a r c h a c k n o w l e d g e d f o r s h a r i n g t h e r e s u l t s o f t h e g u n d w a t e r m o n i t o r i n g i n t h e a a .

R e f e r e n c e s

A y a , L y l e , G. , L e w i s , M. , O s t e n d o , , 2 0 1 6 . e n o l o g i c m e t e c s d e v e d f r o m M O D I N D V I a s i n d i c a t o r o f a n t A v a i l a b l e W a t e r - C o o y . I n d i c . 6 0 , 1 2 6 3–1272.

B r i n k , C. e n R. j . j . R i e t 2 0 1 6 . N i t a t m o n i t o r i n g l a n d b o u w p j e c t O v e j s s e l m e e t e n d e s 2 0 1 1 – 2 0 1 5 . C o n c e p t a p p o r t a g e .

S u s , D. j . e n J . j . G i j t e 2 0 1 1 . D e s i g n-b a s e d G e n e r a l i z e d l e a s t s q u a r e s e s t i m a t i o n o f s t a t u s a n d t i n d o f s o i l p p e i e s f r o m m o n i t o r i n g d a t a . G e o d e a 1 6 4 -4 1 7 2-�� 2 0 0 6 C o m m u n i c a t i o n f r o m t h e C o m m i s s i o n t o t h e C o u n c i l , t h e e p e a n e c o n o m i c a n d s i c i a l C o m m i t t e e o f t h e R e g i o n s . 2 0 0 6 2 3 1 f i n a l T h e m a t i c e t e g r y f o i l P r o t e c t i o n , B r u s s e l s .

B r o l s m a , T o n , A . R e i j n e v e l d , 2 0 1 7 . e d e m c h e c h t b a a i d i n N e d e a n d o v e d e p e o d e 2 0 1 2 - 2 0 1 5 . ��f i n s A g , W a g e n i n g e n , T h e N e t h e a n d s 2 0 1 2 C o m m i s s i o n t o t h e e p e a n e c o n o m i c a n d s i c i a l C o m m i t t e e a n d t h e C o m m i t t e e o f t h e R e g i o n s , T h e i m p l e m e n t a t i o n o f t h e i l T h e m a t i c e t e g r y a n d o n g o i n g a c t i v i t i e s . 2 0 1 2 4 6 f i n a l O f f i c i a l J o u n a l o f t h e e p e a n U n i o n , B r u s s e l s .

G e l d e g e n o o t s c h a p , 2 0 1 2 . B E R K E L L A N D �� H R�� – Cu l t u u i s c h e g e b i e d b e s c h j v i n g . 1 6 2 p p .

H i l h o t e n V e o o p , 2 0 0 9 . Op b o n g s v a n g g e w a s n a m a i s . R a p p o n n 5 1 . e i e n e n s e n , A n i m a l i e n c e G u p , L e l y s t a d .

L a l R 2 0 0 4 ��i l c a c o n s e q u e s t ti o n i mp a c t s o n g l o b a l c l i ma t e c h a n g e a n d f o o d s e c u t y . 3 0 4 , 1 6 2 3–1627.

L u g a t o , , m a p a , F . , a n g o s , �, M o n t a n a l l a , L . , J o n e s , A . , 2 0 1 4 . e n t i a l c a c o n s e q u e s t ti o n o f e a b l e s o i l s e s t i m a t e d b y m o d e l l i n g a c o m p e h e n s i v e s e t o f m a n a g e m e n t p c i c e s . G l o b . Ch a n g . 2 0 , 3 5 5 7–67.

M o m a , F . , a n g o s , a n d m a p a , F . 2 0 1 5 . D e c l i n e i n o a n i c m a t t e r i n m i n e l s o i l s I n : o l t e , J . , T e s f a i , M. a n d Øy g a n , L . a d s . i l i n – T h a t s , f u n c t i o n s a n d e c o s y s t e m s e c i c e s . R A A R a j e c t R e p o t 0 5 , D e l i v e r b l e 2 .1 . p . 6 2 -79.

U s t i a n , , L e h ma n n , J . , O g l e , , R e a y , D. , R o b e s o n , G. , i t h , , 2 0 1 6 . C l i ma t e-s m a r t s o i l s . N a t u r e 5 3 2 , 4 9–57.

R A A 2 0 0 8 . R A A P - e p p o r t 1 7 4 8 , 2 8 -29.


Manuscript Number: CATENA7335

Title: Conservation agriculture and cover crop practices to regulate water, carbon and nitrogen cycles in the low-lying Venetian plain

Article Type: VSI: Testing soil conservation

Keywords: soil organic carbon; sustainable land management practices; ecosystem services; water balance; soil cover; modelling.

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Corresponding Author's Institution: University of Padua

First Author: Carlo Camarotto

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Abstract: Sustainable land management (SLM) practices, aimed at balancing competitive agricultural production and environmental protection, have been encouraged throughout the EU through policy and subsidisation. Adoption of SLM practices that regulate biogeochemical cycles requires further study, especially given the effects of local pedo-climatic variability. Conservation agriculture (CA) and cover cropping (CC) as opposed to conventional agriculture (CV), were carried out in field experiments and modelling studies in order to mitigate the loss of soil organic carbon (SOC) and water and air pollution. All experimental treatments utilised a three-year crop rotation (maize, soybean, and wheat), and crop residues remained either atop the soil surface (CA) or were incorporated with tillage operations (CC and CV). As of March 2016, 17-month recordings from three soil-water monitoring stations per treatment (9 in total) were combined with climatic data to estimate water and N fluxes in the root zone. Carbon fluxes were quantified considering SOC and biomass contents. The biogeochemical model DNDC was employed to evaluate long-term (105-yr) C dynamics and quantify greenhouse gas (GHG) emissions as affected by SLM practices and climate conditions. Experimental results showed significant differences in crop production between treatments, with lower average yields in CA (5.4 Mg ha-1) than in CC (7.9 Mg ha-1) and CV (8.5 Mg ha-1). Continuous soil cover in CA and CC determined the soil-water balance through increased evapotranspiration and reduced percolation (-30%) relative to CV. On the other hand, CC and CV tillage operations significantly affected NO3-N concentrations, with higher soil solution concentrations in tilled (CV = 74.6 mg l-1; CC = 58.1 mg l-1) than in untilled (CA = 14.0 mg l-1) systems. Model results emphasised that SLM practices responded differently in the short and long terms due to initial inertia to C changes and lower N2O fluxes, followed by higher SOC sequestration, and increased N2O emissions. These results demand time-dependent studies that weigh agro-environmental benefits provided by SLM practices against management alternatives to find a suitable compromise for stakeholders.
Padova, 30/01/2018

Dear Editor,

On behalf of my co-authors I submit a manuscript entitled "Conservation agriculture and cover crop practices to regulate water, carbon and nitrogen cycles in the low-lying Venetian plain" for publication in Catena as a research paper in the Virtual Special Issue "Testing soil Conservation". This work, that has been conducted in the framework of the EU FP7 RECARE project, focusses the attention on some sustainable land management practices (the continuous soil cover with cover crops and conservation agriculture), examining the key drivers leading to soil organic carbon and nitrogen dynamics that affect degradation and/or rehabilitation processes. The work gives a comprehensive view of impacts and benefits in the short and long term, combining experimental results with modelling scenarios.

We are confident that the manuscript will provide new insights on the understanding of land use and management dynamics and the effects on soil functions.

Yours sincerely,

Carlo Camarotto

Department of Agriculture, Food, Forestry and Environment - FFE, University of Padova, Italy

The stint of the agricultural extension service - agricultural and horticultural - Agraria Legna Italiany

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Manuscript

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Abstract

Sustainable land management (SLM) has been adopted to enhance agricultural productivity and competitiveness, as well as to improve environmental protection through EU and subsidy adoption. Adoption of SLM practices that balance biological cycles requires specific efforts. Conservation agriculture (CA) and cover cropping can improve soil and air quality through experiments and studies. Experiments are conducted under specific conditions (e.g., maize, area, a crop examined during the soil and air quality (SOLAS) project). SILO is employed to evaluate medium-term carbon and quantify GHG emissions. SLM can reduce emissions (-3% to C V). On the other hand, C C and C V show significantly lower emissions. Systems that SLM are different in short and long terms due to a combination of high solution concentration (C V = 74.6 µl-1, C C = 58.1 µl-1) and low N rates, followed by SOC change. The environmental conditions are provided by SLM, contributing to a guarantee for stakeholders.
1. In order to grow interest in Europe to reduce the danger of climate change (for example, Shashuk, 2015). The REDD (REDD+) and a new environment theme (soil, water and biodiversity, and rural and cultural landscapes (e.g., forests and grasslands, and agriculture lands)) are expected to increase. That is known that every 10 cm of cover (e.g., cover crops) and nitrogen fixation (e.g., legumes, 2003) are important to reduce nitrogen leaching by agreements (Campbell, 2007) and quantity (e.g., secondarily efficient cover crops versus other). Concerning is a systemic agricultural system that increases the efficiency by improving and diverse system (e.g., updating biological systems, 2015). It is receive another way to reverse the decline in important ecosystems, such as SOC completion, or increasing the amount of income, food and education on a long term (Ruhlstein et al., 2015). Alternatively, C crops are directly by struc...
Page 5
And recording through LACCA (https://ecare-93939939.eu/) to generate RIS content.

By integrating environmental fields with societal systems service by conservation agriculture and cropping (CCAC) and making systems compositional and regulation on biomass and regulating terrestrial conditions.
2. Material and methods

2.1. Study area

The experiment was conducted in the western part of Slovenia (45° 2.908' N, 15° 26.780' E, Pieve fractioned by a small river table of height about 250 cm in summer to -70 cm in winter). The soil is silt-loam Endoglycy Cambisol (ESC0, 1990) and medium fertility due to relatively low pH (pH 6.5) (Table 1). The site is characterized by annual rainfall of 733 mm that is uncertain about 80% in one year (129 mm in January in a specific place) between January (-8.8° C minimum age and July (30.6° max. temperature of 848 m above sea level) and produce evapotranspiration exceed by more than 10% in May and to be with maximum in July (4.8 mm day-1).

2.2. Experimental design and treatment

126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151
The multisonar system contains continuously storing temperature (°C) and volumetric content (m^3/m^3) at depths (10, 20, and 40 cm) and moisture content in soil samples at a frequency of 3 data collected every day.

The system controls the storing to a station (CA and CC) via GSM technology. The sensors used are a temperature sensor, a moisture sensor, a pir sensor, and a microcontroller. Soil samples were collected at the end of the 17th trial (April 2016 - August 2017). Water collected by lysimeters was analyzed in the laboratory for nitrate content.

Yield and simple examples were determined at 65 °C for cedared conditions and 72 h for drying. Around crops, sampling was done before the start of CA and soil incorporation in CC. Sample dry weight was determined after 2 h at 65 °C.

To evaluate the ecosystem cover by crops and undisturbed ecosystem SOC, a six-year interval was chosen appropriate for the slow reaction of SOC to land use changes. Terrestrial campaigns were carried out, the first in spring 2017. Soca, a hydraulic walker is used to undisturb (0–10 cm, 10–30 cm, and 10–50 cm) area before sampling in each field. Time was identified by integrating signals with Real-Time Kinemetrics (c...c...c... The soil samples were cut into 0–10 cm, 10–30 cm, and 10–50 cm, as well as...
<table>
<thead>
<tr>
<th>Page</th>
<th>Text</th>
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<td>[57x760]a �� ��c a l ana l y s i �� �� a l of 108  undis turbe ��� ����� 3 tre a �e �s ×  2 da �� ×  3 la y e rs × �</td>
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<td>181</td>
<td>[57x705]om ��h �� bulk ��� y w a � c a lcula t e d� T��ter �� �g a�� c a rbon a nd nit rog e �c ���� ��</td>
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<td>182</td>
<td>[57x678]other  � a c � on (on e-thi rd)  �a �-��� a nd sieve d ��� h 0.5  �  ��� Flash c ombus ��n</td>
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<td>183</td>
<td>[57x650]C NS e ��ntal a n a l y s e ��a �� Ma x � Ana l y s e ��y steme �� L a nge �� ��� DE)  w a � e mpl o y e d</td>
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<td>[57x622]following  the ����� inorg a �� c a rbon with a �a c id �e-� e a �e ��T�qua nti f y  �� S OC ���</td>
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<td>[57x595]���c ould � c onfou n ��b y  �� e f �c ts � � � a � on bulk ��� y � w e  used t� e quivale nt s�l</td>
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<td>186</td>
<td>[57x567]mass method (V a nde n B y �a rt a nd ��� ��� F inall y � soil  tex ��  w a ��� rmine ��r</td>
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<td>[57x539]�� ��c tom e t r y  (Malve � Maste �� e ���, Mal �rn I �� ��� Malve �� � �of 2-�  sieve d</td>
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<td>[57x512]�mpl e �that �d b e e n p r e vious l y dispe rse ��� �% �� um ��x a ��phospha ���� ion and sha k e n</td>
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<td>[57x484]for  12 h a t 80 rpm.</td>
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$P(t)$ is the vertical geotechnical contact boundary (60 cm depth) and $C_N(t)$ is the conceptual ground content following the test conditions.

$N_{\text{balances}}$ (kg m$^{-1}$) are expressed as terms that include air content (volatile nitrogen and carbon) and changes in soil between the beginning and end of the experiment.

$N_{\text{uptake}}$ and $N_{\text{leach}}$ (kg ha$^{-1}$) are inputs (crop, and ley) and uptake and leach nitrogen (kg ha$^{-1}$) puts (crops, ley).

The model, tested six ecosystem sub-models to simulate soil carbon (e.g., SOC dynamics, CO$_2$ emissions) and nitrogen (e.g., NH$_3$ emissions, nitrogen leaching, transport and transformation in the plant-soil system). The model, tested six ecosystem sub-models to simulate soil carbon (e.g., SOC dynamics, CO$_2$ emissions) and nitrogen (e.g., NH$_3$ emissions, nitrogen leaching, transport and transformation in the plant-soil system).
and turgor, and can be successfully applied to crop models (e.g., temperature and infiltration, crop species and systems, and nutrient uptake).

2.6. DNDC model validation

Parameter validation is necessary to accurately and effectively simulate soil conditions. A field experiment was conducted over six years (2011-2016), with yields, total accumulation, and annual moisture content in the root zone used to validate the model. Prediction uncertainty and system effects were calculated using the C model, and U results were compared with observed outcomes. To test the model's performance, different outcomes and field conditions were evaluated with a significance test (e.g., data were good approximated with = 0.95 and U)
The six-year field experiment was by measured over every ecosystem and statistical values (Fig. 2). Only in recent years (2013–2018), and older, a slight estimation was most dry years of, and (average infanta 548 mm in), and the actual estimation was SGC concordance in and treated a high degree efficiency \( F = 0.67 \) and low values (Fig. 3). The only estimation was SGC topsoil in and treated cases to achieve shallow depth (10 cm, and less accurate in CAC and a greater depth and 50 cm) \( F < 0.54 \) and for before and after, specifically). The 50 cm in a case is difficult to estimate in DC and where the water table is. The comparison between observed and simulated concentrations at the factory. On average \((-0.35)\) where the "R" word), A2 ("Separated word"), and B1 ("Sustained word"), each of which are calculated by ent C \( \text{CO}_2 \) concentrations (2). The error rates selected, each of which is specified at a specific concentration.
The conditions were modelled using a static simulator and an Inf a... at the soil conditions by a small est AIC (Akaike’s Information Criteri... and post-hoc 3-way comparisons were made, following the analysis to norma...
3.1. We observed unusual contamination in the study area (March - December 2016; January - August 2017). While reaction rates were significantly higher in both years, the total amount of event was higher during the period in 2017 (about 30%). Soil erosion was observed during July - August, in 45 counties in 2017. As expected, greater levels were seen with a generalized increase in the period and a median about 2 cm. So, expected higher amounts for the non-chemical crop - heavy soils (Figure 4). Among the agents, Dicamba is negligible except in the long-term control when the temperature is higher in CV than CC and CA. In sum, the condition is observed on field treatment and soil quality in the topsoil. For example, %C is higher than %C at 0-30 cm and significantly less %C at 0-30 cm contrast, soil moisture in CC is much higher than in CA difference that was found after November 2016. The soil moisture was significantly higher in CC during the monitoring period. Soil temperature varied across the study area, mostly with a high values. High temperature was noted at an average depth (+0.1 cm in C than in CV).
and C_C ended A_S an, a treat ex gibl e

...; temperature average 1.4 °C CA and CC (data not shown).

... and cyg yield over total association (main crops and cover crops) during two-year period significantly across treatments. I think CC slightly produced o (...1, more than C (...1, and C_CC increased (24.7 ha)).

Wheat yield was among treatments. Yields averaged Mg ha and be between a minimum 6.29 Mg ha in CC and a maximum 6.68 ha in CA. Around wheat, similar treatment association size didn't (minimum) in CC and Mg ha (maximum in CA) significantly (p < 0.05) versus curve. Wheat yield was (4.05...1) in CC and (9.97...1, on average. Made a round crop with residues and significantly high in CC and C (15.8...1 on average that in CA (14.2...1).

B_C and CA treatment significantly (p < 0.05) between CA and 4.88 Mg ha respectively). The gibl e cover crop on CC was notable and in contrast that in C where sowing delayed to close and managed cut once a maize crop decrease germination and delayed distinctly.
During April to October, precipitation totals led to exceedances by 349 mm (by contrast January-August precipitation was 350 mm). This highlights the high mandate for crops 2017, especially during the winter when coupled with low (35 mm). The entant found in cereal crops treated by (C and C) treated compared to percolation (178 mm on average) where a in cereal values (78.6 mm on average) increased show significantly in C than C and C). In 2017, sub-catch water passed for the crop and cereal demand hitherto in 2016 negative percolation.

3.4 SONLY

Soil only simulation in 2016 was good in C and C (Fig. 1).

During the 2016 cropping and March treatment measured less than \( \frac{1}{10} \) and increased marginally to the y peak in \( \frac{1}{10} \). Among treatments, N was C and CV in both years. The curve 2016 ground after values were similar across the treatments, with significant values in C A and to C and C (0.01). However, winter treatments were those found in the winter treatments.

5. NITROGEN BALANCE

Every treatment (fertilisation and input) were similar among the treatments; however, the changes mainly stemmed from plant uptake, leaching (N leaching), and N (N uptake) (C showed the most N net leaching -N in 2016 and). Nitrogen low -N became C and C 3.5 kg ha\(^{-1}\).
...
by CC (2.41 kPa h⁻¹), and C (4.10 kPa h⁻¹) in 2017, essentially at C (6.04 kPa h⁻¹) and a significantly lower value in CC above in CC, a result of biological and ecological factors (e.g., heritability). Alternatively, ammonia emissions are high in CC and in 2017 (b). In the case of N₂ emissions, they too are high in C relative to CC and + and C, respectively. Methane (e) provided by the cattle is high in CC and C and (e) (v) and a average 4.6 and 6.5 kPa h⁻¹, and a result of biological and ecological factors (e.g., heritability). As for precipitation, no significant increase was found as the average age increased in CC and A and C (130 kPa h⁻¹). In the case of CO₂ uptake, a significantly higher value in CC than in CC while solar cell efficiency (F 9) decreased during the simulation period (in the last simulation period of C A and C). As for precipitation, no significant increase was found as the average age increased in CC and A and C (130 kPa h⁻¹).}

We mode with LRW and we actual system for short periods (i.e., LRW and C A and C) stock in C and C A and C as C and C decreased significantly to que S. Moreover, the simulation S OC stock in C V and C for the entire simulation (i.e., simulation).
than did the CC and CV areas. Scaling accumulation...
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and growth (Pinto et al., 2017), and to a lesser extent, water management essential to the biotic and hydraulic regulation system.

In crops, poor cover growth leads to windows for cultivar growth. The primary goal in intercropping with crops is to mediate root zone nutrient leaching (Over-Köhnke, 2008). However, this goal is only partially achieved due to growth with residual residues and nutrient losses. Over time, these treatments significantly reduce the standing residue (Over-Köhnke, 2008), which is already reduced by age and disintegrated. Therefore, the processes that regulate the biotic and physical systems, and in particular, the ecosystem and ecosystem by nutrient cycles, are the primary processes that determine the environmental context, the mariable ecosystem integration, and the regulation processes. Model simulation dictated 

Conservation and cropping do regulate atmospheric emissions. For both the (Bryan et al., 2008) and in age treatments. Modeling simulations are not realistic in the context of the nutrient cycle in crops and maize growth. According that incor porated crops residues in 

significantly reduce the atmospheric emissions (Paradisi et al., 2004), partially due to the lack of nutrient cycling.
that differe ced a consi stently on N. The cer to with solv ing a system a high e residual term whi ch is a cced ter include s N a ir l evels (volatil e n and nitric oxides) a nd c ange in cont ent the " stabilize e g nering a nd en d the e p idemic. S ites in content a signi ficantly a e e S L systems, a high e residual term a t e t t a e d b y An educ a tion in N eSSI s %, relative to actiona ls y stems, a e g a on ef forts w e a p di cte d in CA. Ver, our a c on found a robust a on fir mat e studi e s on N O, a nd ew er fe e diment that is evident the nee for more a c hieve N a merica l lux e.

In the, N e rse d mar k e y with high e eSSI s C than in C V a nd , whi ch con fir m a high e unc e rta inty as socia ed G studi e s a nd nee f lon g-term m ing ex irments (Kna c e a). Dur ing p e re DC simulate a s e sti n g that a

a s y stems are a c c e ng S OC in y e a rs KG C -1 on a rage). S OC cied s, p di cte d with DC model, a g ree w ith ex irments a s hig hli ghted that e e a mong tre a e found in 0-30 c y e rs a t gre a t depths a re alrea d a re by other a uthors (Lu e a �� P owlson e t a; P iccoli a l. 2 016 S OC cied e ntly in no s a tre a e onl y, a nd in e a ge a nd C C e a ents.This sugge s o propose c e to e a se c a rbon sequ eстра e g oduce ove��Re tention e c re sidues on the ac e a nd a e e ope ra e ove S OC cied in e toppe y e CA, e side incor e t ploug e for S OC a c c e on in e y e rs in C V a nd C C (G ova e a l. �� e nto S OC cied e long ter should e ig r e d��r a g e (2005), for exampl e found that S a c c e ted a a a
aage  followed a S-shape development that started after 50 years. Along-term DC model shows that once SOC is anchored dynamically in CA soil, then age trends and climate will strengthen SOCs and C pools. On the contrary, activity silts in line to conservation agriculture (Piccoli et al. 2017) were transitory in SOC in CA over 100 years after 50 years simulation. In the high SOC sequence, C pools are not an ideal solution for GCO2 emissions. Above all, considering agriculture fields, needs P-coarse and Gs high in C than in CA and C-somes and eases N assimilates. Above over e. C-somes category is e. C microbe affects on a field and C-ness e. microbe. In the opposite, a pectoma e. SOC in C-e microbe by the gate.

Eve, y a e a to e a ter m c a bil by c an g e. Ciors e in trend sim a and observed in previous studies e. European (Lu e et al.).

5. Conclu- tion

The e vluation of a inabl e a ge c s p c c to Region confirms lack a “pec-ctoma age”, that one ca pable a g just cestent e y system I ndeed, a inabl e land a c estes by a cess, gulate the e- quality mul- y e ver C a �� the.

F, a o e y system e o in e short and me- terms m be ove r lon g t e rm. Above a, hig h e lses once uncertainty can introduce by variable c- matic conditions a e. e e con with t l m a y ent.

The e ximent, curva on and cov e crops e. a a c c din g a �� ons, e y system e c a or a me span. The for- me is e e a e- ent e fects on e- quality a nd c on e on.

For x eriment, c orva on and c ove erops c. a e a c c din g a �� ons, e y system e c a or a me span. The for- me is e e a e- ent e fects on e- quality a nd c on e on.
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Berg tol d, J., Ramsey, S., y, L., Wa a J., vie economic considerations for over crops as a conservation practice. Rene... Food Syst. 1-

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C F., Z ng C., Wa K., Zhou, Z., ng J., ess bio ge o cme ef c and st management account for a wheat-ma c p p e g system u the DC... Biogeoscience -107.
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**Notes:**

- The table contains data points extracted from the document. Each row represents a specific data entry, and columns likely correspond to different variables or measurements.
Figure 1. Trends of specific criteria during the period 2018—2020 model mean values (columns a) are defined for sets A1, B, A2, and y. Novicet trends.
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Click here to download Table: Tables.docx
The Second World

...the world's economic growth (3% per year), low population growth (0.27% per year) and introduction of efficient technology. The current economic and cultural situation is with a substantial decrease in economic capital income.

The Second World

Cultural identity is entangled with the world's hierarchy of nations and international action less likely.

The labelled

Economic growth (1.65% per year) and material wealth

The sustainable world

Changing economic structure, the material aspect

Over years and environmental concern. This is a global concern regarding environmental and social stability and in introducing clean technologies. The global population will achieve this situation by 2100.
Aboveound biomass production of the... 14.10 (1.10) 12.93 (0.40) 10.73 (0.30) 11.10 (0.40) 24.66 (1.00) 12.41 (0.40) 10.48 (0.50) 16.47 (0.00) 17.03 (0.00) 29.33 (0.00)

Winter wheat production

Summer cover crop

Winter cover crop
Water balance in the monitored fields April - December annual standard accounts.

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\hline
\text{January} & 286 & 510 & 642 & 75 (±110) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 4.8 & 8 & 8.0 \\
\text{February} & 286 & 462 & 662 & 45 (±60) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 8.0 & 8 & 8.0 \\
\text{March} & 286 & 589 & 662 & 63 (±70) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 8.0 & 8 & 8.0 \\
\text{April} & 286 & 622 & 662 & 73 (±80) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 8.0 & 8 & 8.0 \\
\text{May} & 286 & 510 & 622 & 54 (±70) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 8.0 & 8 & 8.0 \\
\text{June} & 286 & 598 & 648 & 71 (±80) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 8.0 & 8 & 8.0 \\
\text{July} & 286 & 598 & 648 & 71 (±80) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 8.0 & 8 & 8.0 \\
\text{August} & 286 & 598 & 648 & 71 (±80) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 8.0 & 8 & 8.0 \\
\text{September} & 286 & 598 & 648 & 71 (±80) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 8.0 & 8 & 8.0 \\
\text{October} & 286 & 598 & 648 & 71 (±80) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 8.0 & 8 & 8.0 \\
\text{November} & 286 & 598 & 648 & 71 (±80) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 8.0 & 8 & 8.0 \\
\text{December} & 286 & 598 & 648 & 71 (±80) & 30 & 6 & 6 & 8 & 6 & 191.8 & 3 & 9.1 & 104.8 & 8 & 4.8 & 8 & 8.0 & 8 & 8.0 & 8 & 8.0 \\
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GWP values relative to CO₂: N₂O = 28.5.
Figure 2

Predicted grain yield (kg C ha$^{-1}$) vs. Observed grain yield (kg C ha$^{-1}$) for CA, CC, and CV treatments. The linear regression equation is $y = 0.9553x + 66.861$, with $R^2 = 0.9023$. Points represent data from different treatments, with CA in blue circles, CC in red squares, and CV in yellow triangles.
Figure 3

Predicted SOC (g 100 g\(^{-1}\)) vs. Observed SOC (g 100 g\(^{-1}\))

- CA
- CC
- CV

Equation: \( y = 0.5712x + 0.4578 \)

\( R^2 = 0.7965 \)
Figure 7
Click here to download high resolution image
Figure 9

Click here to download high resolution image
Abstract: Soil pollution is one of the main environmental concerns at a global scale, and different measures have been proposed for its prevention and remediation. In this paper we evaluate two measures - amendment addition and tree planting - applied to remediate soils contaminated by trace elements (TE). The Guadiamar study site (SW Spain) is a well-known example of a large-scale cleaning and remediation program intended to rehabilitate about 3000 ha of soils affected by a mine-spill in 1998. Firstly, we present the results of a long-term experiment in which two types of amendments - sugar beet lime (SL) and biosolid compost (BC) - were added to the spill-affected soil. Three different treatments were established: SL, BC, and NA (non-amended control). The experiment has been running since 2002 and new soil samples were taken in 2016. In general, the amendments increased soil pH and total organic carbon, and reduced TE availability. The available TE concentrations (CaCl2 extraction) decreased drastically with time in all cases, but the evolution differed among treatments. The treatment effectiveness was evaluated by measuring plant biomass, TE concentrations in plant shoots, and soil-plant transfer. Secondly, we present results detailing the effects of seven tree species (three - Populus alba, Celtis australis, and Fraxinus angustifolia - were deciduous and four - Quercus ilex, Olea europaea, Ceratonia siliqua, and Pinus pinea - evergreen) on remediated soils. In 2014 (about 15 years after planting) we measured TE concentrations in leaves and roots and related them with TE concentrations (total and available) in soil. There were significant differences among the studied tree species in the uptake and accumulation of TE in leaves and roots. Soil pH differed among tree species and with respect to adjacent non-planted sites. There was a negative exponential relationship between soil pH and availability of Cd, Cu, and Zn. The bioconcentration factor (BCF, root:soil) and the translocation factor (TCF, leaf:root) were calculated to evaluate the potential of each tree species to stabilize TE in soil. Finally, we propose the phytoremediation of TE-contaminated soils as a three-stage process, including addition of soil amendments, planting of trees, and monitoring of TE dynamics.
This studies the threats of the R. similis (Pantanal and R. media in Europe and Spain), SOPOI.

We evaluate the media to understand the biodiversity of the area. Firstly, we evaluate the long-term experiment in two years. Secondly, we evaluate the effects of the species. Finally, we propose to use media on soil contaminants, including soil arson, floods, and plant tissues. The study is a report of the world and scope of the journal.

We believe that the results of the study will improve knowledge of the treated area.
Contamination sources

- Amendment addition
- Tree plantation
- Monitoring and evaluation

Phytoremediation of soils contaminated by trace elements

Stop contamination

Residual contamination
Tree mortality
Highlights

In this study we propose a three-stage phytoremediation approach

1. Soil amendments addition is effective at increasing soil pH and reducing TE availability
2. Tree planting stabilizes TE in soil, mainly through their retention in the roots
3. Long-term monitoring of potentially toxic elements in the ecosystem is obligatory

The Guadiamar Green Corridor (Spain) is a large-scale phytoremediation case study
Abstract

Soil erosion is one of the main environmental concerns at a global scale, and measures to mitigate soil erosion and media protection are proposed. The Guardamar site (SW Spain) is a large-scale example of a small-scale research in which a tree cultivation intended to mitigate weathering by trees is run in different conditions. Three treatments shed: SLB and -amendment treatments. The experiment was run under environmental conditions such as pH, nutrients, and total carbon, reducing TE availability and increasing the cation concentration (CaCl₂).
Soil pollution is one of the main environmental problems affecting human health. It affects the site in the European Union and poses a significant cost equivalent to 2% of its GDP (Paige et al. 2014). The site is affected due to the effects of past and present contamination. That affects agriculture and viticulture as well as the ability to use contaminated land for certain land uses such as environmental protection.
include a priority in the EU age (in 2015) so the event is a priority in the people on the European Soil Strategy (European Commission, 2012).

Phytemedia is a low-cost, and friendly phytoremediation, as plants and other organisms to toxify, and both organic and inorganic contaminants, especially the total (Atal et al., 2017; Watanabe et al., 2017).

Among the phytemedias, phytoavailability is the first for management or it can be contaminated by trace elements (Mendez and Ruiz, 2008). This approach is a way to decrease the plants to zize mutants in the area, thus certify the transfer through the soil. The implementation of phytoindicators are at the moment to test changes in the same system (Mendez et al., 2008; Bolan et al., 2011).

As the first step in phytemedias, one should move to the cells, in the state of certain chemical properties, for example carbon amendments, second, to certify the system for example carbonate amendments, a certain physical characteristics, for example carbon.

As the first step in phytemedias, one should move to the cells, in the state of certain chemical properties, for example carbon.

Conclusively, the system for example carbonate amendments, a certain physical characteristics, for example carbon.
In recent years, the introduction of plants, extensive root systems and shoots, high amounts of aeria tissue. The plants are able to absorb salts in solutions and can act as a nutrient source for their development (Mendez and Ar, 2008). Moreover, successful establishment leads to a diversity and/or activity of the plant root community, which can contribute to the quality of the soil (Sestak and La, 2015; Šiel-R, 2015, a, b).

Finally, effective remediation measures must be taken, which is necessary to carry out research and contaminant dynamics within the system and risk testing introduced into food systems. In research on this subject, several land remediation experiments across the country (Ereç, 2018) focused on obtaining surface soil that evaluated the effectiveness at two cutout complementary stations.
The example of large-scale mediation

Specific methods to test effects of this type on soybean leaves;

TE visualization in this site for 14 years after the first attempt to evaluate the corresponding TEs on soybean stems; another paper to studies in applying both measurement methods, we studied the commonly in pH and TE availability effects on gaseous carbon, and i) through soybeans.

2.1. Study area

The study site and experiment are affected by the following: (i) Apr 1998, and a collar, releasing ca 6 × 6 m3 slurry containing about 4,000 kg with a mixture of lime, CaO, and PE in 1999; the eae, 2018, after several layers, another treated by a treated by the able and uses, to minimize the alee.

The effect of the above can be added, and the use of large-scale cases by mediation (Domínez & et al., 2015) are critical for the site biodiversity and ecosystem.
The climate is Mediterranean, with mild winters and hot, dry summers. The average temperature is 17ºC, with a minimum of 5.2ºC in January.

The city of Guardamar is part of the Pyrenean Pyrites Basin (IPB), which contains important volcanic deposits in western Europe. This area, along with the Guadarrama Range, is rich in terrestrial and aquatic species, as identified in the global, 1999; López-Pamio et al., 2000.

The soil in this area is characterized by the Mediterranean zone, highly heterogenous due to a high diversity of topography and morphology. Very calcareous and non-calcareous types, with high vegetation, are present. These are represented by the Rhodoxeralf, with very high vegetation and psephobryum areas. These are under huge beech forests.
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GGC and with and the use of a 2010). In,
we are with and tree planting. We are
effects are tree planting for different trees (one "trees") and availability in,
and the other one "open non-tree ones"
This study on a site about how the GGC (37° 2' N, 6° 15' E) randomly selected and replicated to each event each time for forested in the tree in total) is for S3). Three species (alba
(Ce), and
inusus colonia and are
gree (Quercus excelsa and Cerasus silvatica, and pinea) (area after
autumn we are finally full extended leaves as the point in the outer canopy these tree to composite tree. We collected the forest floor after ter) as a part 25x 2 cm quadrats around each tree and these to make one composite tree. We collected roots as a point around the tree and these to make one composite tree. We collected
samples roots to composite tree and depth. The samples for forest floor roots,
2014.
theory as
The oil sample is dried, condensed, and sieved (<100 µm). Prior to concentration, the sample is ground to <60 µm. Soil water, using a CRIOScope pH 2002 probe, in sample solution (1:10 KCl). Total carbon (C in soil) is determined following combustion with an ammonium sulfate alkali and B-catalyst.

Soil CaCl$_2$-extractable concentrations are determined in 0.01 M CaCl$_2$ at a ratio of 1:10 for 3h (subsamples 2000) and analysis of pseudocentrate in and extrants, sample (60 µm) is digested 1:3 with $\text{O}_3$ in a closed oven.

Laloty Porolitho ETHOS lestonlestone lestonl Italy) Plant analysis for 15 with 1 M HCl, followed by a 1-x washing with 3% water and then oven-dried at 105°C. Plant analysis is performed and then ground and passed through a 500-µm sieve. Plant extracts are made by simultaneous oxidation with concentrated $\text{O}_3$ in a microwave.

The concentration in samples and digests and CaCl$_2$ extracts were measured by inductively coupled plasma-atomic emission spectroscopy (ICP-OES) with a Varian ICP-MS, coupled with atomic absorption (AA).

The quality of analysis are samples. For soil ERM-C and obtain series from to. For plant analysis were obtained recovery rate between 90 and 103%.
The results and discussion

3. Results and Discussion
The main target is to achieve pH 2 and cecability of a plant (2001). Next, the soil and discuss the effects of the media on measurement—amendment and planting—soil and cecability.

3.1.1. Effectiveness of Amendment Additions

The site of the Victoria experiment site is very acidic (pH around 3.5, for 1); therefore, an amendment in pH significantly affects TEs and soil close, and values were for at least 12 years without any amendment aimed to increase (no significant change in values are different samples). It is less effective than SL for a specific case. Therefore, to the strong acidity and high concentrations of the availability of TE and the potential toxicity risk of these elements to be high.
The effectivene
s is thus evaluated by...
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...ents e c y e a mendme a a e d. e n e d a ta (14 ye a rs...

...fter the first a mendment to the a nd-term f c on soi l media a... Although e e c n ess a me e in c on tox y and contamination is undoubted, is a int e st i...c r e a e a c onc e e with a s sa sig e a media a...

...ctive ess of the ing ef e r e i on- a fter a a c ion a... Dur ing in 2014), timea oil a t for e sted e x e rimen e g om 2.6 to 6.05. The c onc e e with s...rbs c e a nd tre e a e with Ce c a nd Olea e s, showe d in t e med i a t e pH va e Fig 3...e x essed in mg c -1) The re no signi fic a nt ere e a studi e d tre e c ies be e n t im and the ope tes, indica a ge...The As a nd P a b y in c on tox y c on e tre e c ies b e low...tec con c on 1.1.). T g r �� lues und e r...
some trees gave an extensive education in Cd, Cu, and Zn abilities (Figure 317). Therefore, these species are convenient for plant and heavy metal ability and had lower capability in amphibians (Pinus and Eucalyptus) (Pinheiro et al., 2013). In contrast, these trees are easily treated with co-chelator and propylenthiolamine and cycled, and chlorobacterial communities are able. The carbon is one of the main threats to quality agriculture (Sanderson et al.) The fate in aquatic ecosystems, are concerned with soil carbon status, but it is still an open question of TE-cycled land. 3.2. Soil organic carbon
A high content of organic leads to easier carbon treatment and both their carbon to the environment and their ability (Ferreira et al., 2011). Therefore, carbon is one of the main threats to quality agriculture (Sanderson et al.)
We evaluate the effectiveness of carbon storage and tree density to ease carbon, and since the media mainly used - carbon, specifically, as associated additives, increasing (such as tree movement and community) (see Figure 3.2.1).

Effective addition of deficit capacity is generally a major factor in Mediterranean areas; 2% deficit is for decreasing age, 2002) being initial values of the content in the site around 1% to kg in 2002, Figure 5. (partly due to the changing and moving consequence) The carbon content both of easy significantly, consequently, non-amended (Figure 5.2.3) during the long-term (2011 and BC effects on the content significantly (by 16% from initial value), from 2011 to 2017). Figure 5). The time is the carbon content associated with for these sites (in L-untreated) the carbon in TOC found for these using in these years.
The as a ease ease matte los a ese the co covering catering the A w e-lopped the grea gtation cover ing the movement e qua ty on the other medium e The movement e che c onditions by g TE conc en trations, cro bial comm ec e com pos e -tol e nt g as. B e ece a, 15) Ia ees, educ on con cal the e om munity struc e the e c myc myc y fun gal comm y, e a sin g e y ge c diver sity -wha che max u le with. Tre e c a l condi ons (iel-R a h, 2016a).  

The effective ess eing  

The tre nd for the and an d pro ced by physi a cal con ditions (iel-R a h, 2016a).  

363 by a ac in SLs much hig er than in others (Mar jen e a 2003). The movement e che c onditions by g TE conc en trations, cro bial comm ec e com pos e -tol e nt g as. B e ece a, 15) Ia ees, e educ on con cal the e om munity struc e the e c myc myc y fun gal comm y, e a sin g e y ge c diver sity -wha che max u le with. Tre e c a l condi ons (iel-R a h, 2016a).  

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However, this significant due to high significance. The average 3 a center (15.7 g -1 reyele aca

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Effects of nutrients. In general, bacteria growing in amended soil (except in some cases BC; for 2011, 2015 in Table S3) and nutrient concentrations are generally for long, 1989, except as in Lamark and Poa species. The extreme concentrations for Lamark illustrate total yields and of C, for example, BC F Poa species about F for SL 48% with BC. There we significant increases among species. In tran spectrum soil, Cd and Zn are elevated, especially BC F; instead, species show y less mobility BC y. Amendment a to TE reduce TE transfer to TE abundance y plants are TE in species issues and for these sentenced to low risk for the food web, ion. Extraction by each growing reason (they are stressed o grazing diminish availability by each).
I gene, BCF values among trees, shrubs, and grasses.

1). The TCF for Fe (mean 0.58) than for lead (0.24).

Among studies, C showed higher BCF values for root > 1) for some species, especially P. Accumulated contaminated 2 concretion of 5.8 for Zn in P. t. TCF values are relatively (be 0.5) for Pb, Cu, and As, while they are one for Ca and Zn in some species (max TCF 5.8 for Zn in P. t. TCF criterion is the plants are especially P. t. TCF < endoze and Zr, Bolan only). In this area, some species that TCF are widely used to TCF in roots, and C can C cad < BCF roots BCF values are for Fe and P. e. the higgest BCF for Fe and C e. The planting tree can very easily measure for Fe media - s of D. Dickinson, 2005) and how, a tree especially P. t. TCF capacity to C in the section. So the section should
3.4.1.3. Entrapment phytoremediation

The contaminated media site of Gua diamante is considered a case study with the extraction of toxic elements and their containment in the area and treatment of the water from the system. In Gua diamante, the cost of a significant economic blow, and the spillage of sludge to a contaminated area has been cleaned up by transporting the sludge to an open pit. These open pits have economic costs of about 58 million euros (Aston et al., 2011). The use of green plants for the potential in carbon sinks (such as willow and meadows) and the establishment of TE and ichnometry with geographical coordinates. These data are used for the entry and exit of toxic elements (As, Pb, Ca and Fe) by the elements themselves. The establishment of trees and shrubs for the TE and ichnometry with geographical coordinates. This third entry involves the entry into the TE system and the location of the information.
biose composition and as sing ability and as sing capacity to the community by toxic and by C quez and Ibadi these are genetic and with costs these could be by transport and by a a on any social use cause it continues and Commissi, 2015).

Advances assoc with -ese -a dual
educon and the me to aee and leaching a ee can accelerate by a s (Rutte et a 2010) In ease a ge animals, and arm enhancement low-solub y cse for ee en organic and is utmost portability. The solub y of these could with sensible is zed thus acting a a a e bomb' (Ma 2010) More over, it ssa rry to verify adequa ce and ec ec dif ferent to a on a s, a po a on a s, and p esistence o a aent ec ts ove a ee The a on t a end on land and c matologica onditions (Me e 2003) Fi thi a son, a a a r a ry a e c t e a and wild ation to ensure sensible a and wild ation the ne e for a on a and.
in the first years were some mortalities, mainly due to girdling and drought during the term of Mediterranean and coming years (2010). I believe a different shrub (naturally and added) can be used for a further use of domestication (c. subdivided) or of a solid (convention), others, in other cases, when this amount of public money cannot be added, I reiterate, these plants grow for C for energy production and combustion can be centrally evaluated (e.g., 2017), showing that this energy can be used for new and older.

The question of the trees' sustainability is crucial for the ability to conserve. Forests (Fraxinus, Ceratonia, and Populus) are pH adapted and are thus able to reduce C and Z, whereas pines (Pinus) and quercus (Q.) identify C and thus increased the mobility of TE in the energy for the trees are the same for TE must stabilize (M. 2017) study showed high C in their and a (but Populus) extract from roots and leaves, thus into the criteria for the new and further (but Populus 2017)
The presentation contributes to the growth with other issues such as biodiversity. The paper includes tree areas as "islands of biodiversity" and suggests the importance of the carbon storage in the atmosphere. Those associations can contribute to the transformation and other processes in tree species, and can illustrate microbial-assisted mechanisms are essential.

The hypothesis - and evaluation - is crucial to achieve the effective media storage - in the case of Bolan (2011). The existing costs in Guadalupe's case (As and Pb), propose that those proposals are important. As and Pb, the effective solutions, propose that those solutions are effective.
site should identify in e-cleaning to reduce risk and protect quality, 2017). Site maintaining are cheaper, with reduce toxicity and-term potential toxic in the cy system, soil, plants and animals) as a factor B. For the action on toxic media on other contaminated some centers be to cleaned (see news by Bale et al., 2016; Antoniadis et al., 2016). A simple and cost-effective approach, although in Guardamiga case expansion is made to extensive. With this very high, the growth and survival of plants should be further reduced. The site contamination plants (not only availability nurse right pose a critical for quality and utility cities lands. As quality is a very important status in the systems diversity such as reducing pH and zinc, tree species can toxic and TE in leaves and fruit (not risk). See contamination site by specific quiries search. The acquisition to to and on the effect on ecosystem operates. The permitting of site is a learning process.
4. Conclusion

Soil contamination by Tis a major environmental and ecological issue, following the experience acquired during the diagnosis approach (Spain) and the stage aimed at optimising organic amendments and particularly effective for pH reduction and improving Tis ability to accumulate Se stage is testing, to stabilise mainly in roots. There are different trees specific in ability for media and in absorbing thus, stage is followed long-term ability in and coincides with and unination. The continuous evaluation of the situation as a part of the cycle.

Oil Plant, I.R. S.C., specifically J. M. Segregati for assistance and I.R. N. Sali analysis seen for the oil and the simple... Thanks University of Seville for the ownership plan...

References


Ali, M. K. Khan, M. S. and Ali, M. K. Khan (2001).... C. A. Alcocer J., and R. Page, M., and... J. C., Lopez-Padamo, M. P., and R. R. Rubi, J., and... Marquez P., and... Sanz Quezada, A. and... Lopez, M., and... Jeglas, J., and... Seoane, S., and... Ok, M., and... Seoane, S., and... Sebastian, M., and... C. and... Ace... Soil... Phytotoxicity and translocation and... S. and... C. and... Lezama, J. V., and... Marañón, P., and... Effects on plant and... E. and... Orta... and... F. and... Earth.

309, 36-46.
Communicating from the Community on Economic and Social Committee and Regional Committee. B (4), 1–35.


Ávila, J.M., Ávila, P., Ávila, B. & Ávila, C. 2010. And canals is a hotspot for a river basin. Geod 261, 133–


P 30 shed February AVAILABLE at http://lexp-use/data-elements/EN/TXT/P/...LEX:52012DC0...accessed on October 2015.


J.O. Feder, Macpherson 1999. The tailing blank. Scurr. a...42, 3-11.

Houba V.J.G., Hinghoff, E.J.M., Sikhor and W., Sowel analysis of core during using 0.01% chloride agent. Community Anal. 31, 1299–1320.


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Figure 3
Figure 5
Figure 6
Phytoremediation of soils contaminated by trace elements

Contamination sources → Amendment addition → Tree plantation → Monitoring and evaluation

Stop contamination

Residual contamination
Tree mortality
Figure 1: Comparison of available CaCl₂ extract trace element concentrations (mean ± standard deviation) before and after amendments (L, A, B, C) bio compost in comparison with unamended soils (mean ± standard deviation). Each year signifies a significant difference between the elements indicated (p < 0.05). Each treatment except the control is significantly different with respect to the purity - 10% 2016).

Figure 2: Mean and standard deviation of pH (10 cm depth) in trees after contamination and comparison with adjacent sites (2014 samples) F = 0.1, and p = 0.05. The values are significantly different, as indicated by different letters (p < 0.05). Each treatment except the control is not significantly different with respect to the purity - 10% 2016).

Figure 3: Relationships at the tree and the ability of Cd, Ca, and Zn in a 10 cm and comparison with adjacent sites (2014 samples).

Figure 4: Soil total organic carbon and comparison with adjacent sites (2014 samples).

Figure 5: The pleume trees after contamination should be at the stage: treatment, tree, and control. Trace elements should be monitored.

Figure 6: Soil total organic carbon in trees, a supercritical 10 cm and comparison with adjacent sites (2014 samples).

Figure 7: The pleume trees after contamination should be at the stage: treatment, tree, and control. Trace elements should be monitored.
Title: Assessment of sugar beet lime measure efficiency for soil contamination in Mediterranean Ecosystem. The case study of Guadiamar Green Corridor (SW Spain).

Article Type: VSI: Testing soil conservation

Keywords: Soil contamination; trace elements; remediation; lime amendment

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Abstract: Contamination is identified as one of the main threats for soil conservation worldwide. Availability of high-quality information on soil contamination, its impacts and effects is still required at the global level. Well documented case studies provide valuable information to understand long-term trends associated to management of contaminated soils. The temporal evolution of contamination and associated factors have been studied in the Guadiamar river basin, after a mine wastes spill of about 6 hm3 of acidic waters and toxic sludge enriched with trace elements. An extensive database have been compiled, harmonized and standardized from the numerous and heterogeneous sectorial studies and monitoring carried out in the area since 1998 to present, and furtherly applied to the spatio-temporal analysis of individual and mixed soil remediation measures effectiveness as a case of pilot for data exploitation. Variables consider six ecosystem compartments (soil, water, sediment, air, plant and animal biomass), management (remediation measures applied along time and space), land use and cover, and present and predicted Mediterranean climate. A pilot developed on remediation effectiveness considered 11 different treatments along time, including mixed addition of compost, red clays and sugar beet lime. Further analyses assessed the effectiveness of sugar beet lime for reduction of Cadmium in different land uses and type of soils. The created database provided a relevant resource for the management of the Guadiamar area and other similar cases in terms of assessment and prediction of the system responses to the medium and long-term, as well for the development of decision support tools, decision making and policy advice in terms of promising, effective remediation strategies.
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Blanco-Velázquez, FJ*; Muñoz-Vallés, S¹; Anaya-Romero, M¹.

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Contamination is identified as one of the main threats for soil conservation worldwide. Availability of high-quality information on soil contamination, its impacts and effects is still required at the global level. Well documented case studies provide valuable information to understand long-term trends associated to management of contaminated soils. The temporal evolution of contamination and associated factors have been studied in the Guadiamar river basin, after a mine wastes spill of about 6 hm³ of acidic waters and toxic sludge enriched with trace elements. An extensive database have been compiled, harmonized and standardized from the numerous and heterogeneous sectorial studies and monitoring carried out in the area since 1998 to present, and furtherly applied to the spatio-temporal analysis of individual and mixed soil remediation measures effectiveness as a case of pilot for data exploitation. Variables consider six ecosystem compartments (soil, water, sediment, air, plant and animal biomass), management (remediation measures applied along time and space), land use and cover, and present and predicted Mediterranean climate. A pilot developed on remediation effectiveness considered 11 different treatments along time, including mixed addition of compost, red clays and sugar beet lime. Further analyses assessed the effectiveness of sugar beet lime for reduction of Cadmium in different land uses and type of soils. The created database provided a relevant resource for the management of the Guadiamar area and other similar cases in terms of assessment and prediction of the system responses to the medium and long-term, as well for the development of decision support tools, decision making and policy advice in terms of promising, effective remediation strategies.

Keywords: Soil contamination, trace elements, remediation, lime amendment.

Introduction:

Contamination is recognized as one of the main threats for soil conservation worldwide (Jones et al. 2012, Gómez-Sagasti et al. 2016, Tóth et al. 2016a). Well documented case studies provide valuable information to understand long-term trends associated to responses and behaviour of contaminated soils under different driving factors, management and/or restoration actions, and thus to design suitable soil and land management to recover their functionality and supported biodiversity, while recovering or maintaining the ecosystem services they provide (Tóth et al. 2013, Schwilch et al., 2016). Nevertheless, availability of high-quality information on soil contamination, its impacts and effects is still required at the global level (Tóth et al 2016b, EEA 2014). In the last decades, research institutes, universities, government agencies and even industry have produced large pools of local, regional and national datasets comprising physical, chemical, hydrological and taxonomic information on soil, often combined with data on landforms, land cover and uses, climate and policies. However, this information is often dispersed and fragmented, or heterogeneous in terms of spatio-temporal scales, units, methodology, formats and even language and described under non-unified criteria, and sometimes only partially available through a wide range of repositories and digital databases. In this regard, international organizations and global partnerships have promoted the compilation, standardization, harmonization...
and sharing of data concerning soils and their characteristics (i.e., the JRC-ESDAC LUCAS topsoil 2009
database). In this sense, the EU FP7 project RECARE (“Preventing and remediating degradation of soils in
Europe through land care”) aims to develop and select innovative sustainable land management
measures to combat threats to key soil functions and to restore them, as well as to evaluate the
effectiveness of such measures in terms of soil functions and ecosystem services, costs and benefits in
European scale. The Trace Elements and their toxicity such as potential pollutants, is a global problem
with high significance for different reasons (ecological, evolutionary, nutritional, environmental).
Contamination is identified as the main threat for soil conservation in the case study of Guadiamar (SW
Spain) of RECARE.

In April of 1988, a mine accident spilt about 4 hm$^3$ of acidic waters and 2 hm$^3$ of toxic sludge enriched
with heavy metals into the Agrio and Guadiamar rivers basins, reaching more than 4,200 ha of
agricultural and pasture land and notably affecting soil properties, vegetation and fauna. It was
estimated that around 16 000 tons of zinc and lead, 10 000 tons of arsenic, 4000 tons of copper, 1000
tons of antimony, 120 tons of cobalt, 100 tons of thallium and bismuth, 50 tons of cadmium and silver,
30 tons of mercury, 20 tons of selenium and other metals were released (Grimalt et al., 1999). It was
considered the first largest in Europe and the second largest of the 59 major mine spills in the world
(Nikolic et al., 2011). In addition, the accident had catastrophic ecological and socio-economic
consequences such as 73.000 kg of death fishes, death of shellfishes in the water courses and many
others (amphibians, birds and mammals). Soils were contaminated by the TE dissolved in the acidic
water and by the sludge. The TE of acidic water reacted with soil components and becoming retained
through different processes and, in the case of sludge, it entered the soil through pores and cracks, with
the consequence of the increase in the total content of TE in the soils (Madejón et al. 2018). After the
spill, the affected area was subjected to a large-scale management project that included the removal of
sludge and the topsoil, the subsequent application of organic and inorganic amendments, the
afforestation with native shrub and tree species, and the protection of the area by declaring it as
“Protected Landscape Guadiamar Green Corridor” on April 2003. The total cost of the remediation
program, including the purchase of the land, rose up to €165 million, being paid with public funds
(Arenas et al., 2003).

The main trace elements severely contaminating the superficial layer of soil and water in the Guadiamar
case study area were As, Cd, Cu, Pb, Tl and Zn (Cabrera et al., 2008). While concentrations of available
As and Pb in soil and plants have decreased over time, the levels of Cd and Zn in leaves of trees used as
bio-indicators (i.e. poplar leaves) are still relatively high (Madejón et al. 2013). Hence, long-term
monitoring of the potential toxicity of residual contamination is needed, particularly in regards of Cd,
due to its mobility, toxicity and frequency in contaminating events (Voegelin and Kretzschmar, 2003;

The aim of this research is to evaluate the effectiveness of sugar beet lime amendment in terms of
reduction of Cadmium and cost. The specific objectives of this study are(1) Develop an harmonized
database for the site characterization, taking into account the local environmental conditions in an
European context (2) Identify simulation scenarios of remediation measures (3) Evaluate the spatio-
temporal efficiency of sugar beet lime amendment in terms of reduction of Cadmium and economic
factors.

Further research will consider the validation of the present methodology in other European climate
zones and the inclusion of new input and output variables to improve accuracy of results

Materials and methods

Study area

The Guadiamar Green Corridor is established along the Guadiamar basin, occupying about 2,700 ha,
with around 60 km long, and 0.5–1.1 km wide across extensive agricultural and rural lands, connecting
the Sierra Morena Mountains and the coastal Doñana Park (Fig. 1). Climate is Mediterranean, with mild
rainy winters (about 500 mm mean annual rainfall) and hot, dry summers. The mean annual daily
temperature is about 17ºC, with a maximum temperature of 33.5ºC in July and a minimum
temperature of 5.2ºC in January. The predominant soils in the area belong to the great groups
Xerofluvent, Xerochrept, Haploxeralf and Rhodoxeralf.
Previous to the mine accident the Guadiamar valley was mainly occupied by croplands (sunflower, fruit orchards) and pasture lands. After the spill-contamination, soils have been remediated and the land afforested with native shrub and tree species (Domínguez et al. 2008, 2010a). Currently the main use is for the conservation of biodiversity and the establishment of an ecological corridor connecting the Doñana National park (to the south) and the Sierra Morena Mountains (to the north).

Geologically, the mine area, located on the south-eastern edge of the Iberian Pyrite Belt, is situated on the northern edge of the Guadalquivir Tertiary basin, where transgressive Miocene sediments cover Paleozoic materials. The lower course of the Guadiamar River is underlain by Miocene blue marls and yellowish calcareous sandy silt, although most of the flood-plain is carved in Pleistocene alluvial terraces and Holocene deposits. The alluvial deposits of the Guadiamar fluvial system consist of silt, sand and gravel. Gravels are dominant, though quartz sands are locally abundant. Three terrace levels can be recognized along the affected valley segment. The high terrace is preserved only in the northern area, near the confluence of the Agrio and the Guadiamar rivers, whereas it is totally eroded to the south (Gallart et al., 1999; López-Pamo et al., 1999). The soils in the study area correspond to the Mediterranean edaphic zone, which is very heterogeneous due to a highly variable lithology and mesoclimate.

Data standardization and harmonization

Massive production of data has resulted in heterogeneous and fragmented datasets needing to be compiled and harmonized, operationalized to be re-used, allowing a non-planned long-term assessment, trends and conclusions extraction, as well as their application to other less monitored or managed case studies. To this aim, we developed a two-folded strategy, considering compilation, standardization and harmonization of a semi-structured macro-database, as well as the creation of a well-structured database shaped under standardized criteria as a first approximation for its direct exploitation with multiple objectives.

The creation and use of the case study environmental database were carried out through three well defined steps, as follows: 1) Data selection, analysis of contents and database compilation; 2) Standardization of formats, harmonization of contents and development under a common framework, and 3) Statistical analyses, development, application and validation of predictive models as a pilot of information exploitation.

Data standardization and harmonization followed three well-defined steps: (i) the previous curation of compiled data, according to their metadata or to the associated scientific publications, (ii) the standardized formats used in the different information packages compiled, and (iii) the analysis and harmonization of the contained variables in terms of nomenclature, and particularly in terms of
methods and units, so that the database thus produced was ready to be compared and integrated into European and global databases. Standardization of formats, harmonization of contents and development under a common framework were carried out according to the criteria and standards established for the preparation of the European Hydropedological Data Inventory (EU-HYDI) (Weynants et al. 2013), the ENVASSO project, the SDBm thesaurus PLUS (FAO-CSIC), the Harmonized World Soil Database (FAO / IIASA / ISRIC / ISS-CAS / JRC, 2012) and the INSPIRE directive (Regulation EU 1312/2014; thematic Data specifications for Soils), although other initiatives such as the World Soil Information Metadata Service (ISRIC, Holland) or the Linked Thesaurus Framework for Environment (LusTRE; CNR, Italy) were taken into account. For the nomenclature of new variables, these same criteria were applied, adapted to each case.

In this regard, harmonisation of methods and units was particularly required. In the case of units, direct transformation was possible in most of the cases, and only the application of a simple factor (bulk density) was necessary in several records. In the case of methods, differences were found for pH, carbon, and total, pseudototal and soluble trace elements determination. In these cases, previously defined and validated conversion factors were applied; i.e., the factors defined in the Annex 3 of the European Hydropedological Data Inventory for soil carbon content (JRC 2013), and the factors defined by Zingg (2014) for soluble trace elements. In other few cases, particular regression analyses were carried out to find suitable conversion factors applicable to the case study soils (Martínez-Masero 2017).

To this aim, statistical analyses were performed with R software (R Core Team, 2017). As well as, the land use classification was translated of “Land Use and Vegetation Cover Map of Andalusia” to Corine Land Cover according to INSPIRE normative, following criteria established for Muñoz-Rojas (2012).

We selected 4 land uses most representative and their soil amendments applied for to evaluate the reduction of cadmium in soil. In addition, the type of soil was a criterion for selection of samples and selected calcareous fluvisol such as most representative soil (Soil Map of Andalusia).

Figure 2 Land use 1999 (left) and soil types (right) of the Guadiamar Green Corridor
**Parameters analyzed and monitored**

In this study, biological, chemical and physical parameters have been measured. According to ENVASSO, there are a number of parameters necessary to measure in any research project. Normally pH and total organic carbon are the elements most analyzed in all countries and some trace elements. Of all trace elements present in relatively low concentrations in the earth’s crust, there are 17 that are considered as very toxic and readily available in many soils in concentrations that exceed toxicity levels, these are: Ag, As, Bi, Cd, Co, Cu, Hg, Ni, Pb, Pt, Sb, Se, Sn, Te, Ti and Zn (Galán, et al., 2008). The EPA (US Environmental Protection Agency) includes thirteen trace elements as priority pollutants: antimony, arsenic, beryllium, cadmium, chromium, copper, mercury, nickel, silver, lead, selenium, thallium and zinc.

In the Guadiamar study, the thirteen priority elements and other elements, oils and fats, Chlorophyll, Barium, etc., have been measured. However, when carrying out the database, only the Cadmium was taken into account, since in this case it is the most significant element in the investigation. This project, comparing with other European projects such as packaging and the EU-HYDI, has made a differentiation. The trace element that has been considered as more significant by mobility, toxicity and frequency of occurrence (Cadmium), has been separated according to the medium in which it has been measured (Air, Soil, Water, Vegetation, Animals, Sediments) and according to the characteristics of that particular medium. There are other studies that differentiate the analysis of Cadmium depending on the medium, but these studies do not reach as much detail as that of Guadiamar (Chintaka et al, 2016).

### 2.3. Definition of soil amendments and scenarios

According to the produced information, although residual contamination still remains and relatively high Cd and Zn contents in leaves of trees used as bio-indicators (i.e. poplar leaves) are still found (Madejón et al. 2013), management actions have leaded to low levels of soil contamination by trace elements in general.

To the assessment of the medium-term effectiveness of selected techniques for soil remediation, the created structured database was used and spatio-temporal trends regarding the effectiveness of selected remediation techniques were analysed. To this aim, cadmium was selected as contamination factor related with contamination regulation ecosystem service, due to its toxicity, mobility and frequency in contaminating events (Voegelin and Kretzschmar 2003, Deckert 2005, Aguilar 2008).

A total of 54 remediation techniques appeared associated to sampling points in the database (Table 1 Annex I). By means of data mining techniques, a total of 413 sampling points in common soils (graves, sands, silts and clays) of the alluvial plain, with significant similarity in terms of geomorphology, land use and affection along the Corridor were selected due to their representativeness, comprising a final list of 11 remediation techniques with sugar beet lime: T12, T23, T28, T29, T30, T33, T38, T40, T42, T48 and T52. Finally, the land use selected were 4: 211 (Non-irrigated arable land), 244 (Agro-forestries areas), 311 (Broad-leaved forests) and 321 (Natural grasslands). Analysis of means and variance were applied to compare trace elements values associated to such techniques and land use for a time period of 3 years from the accident.
3. Results and discussion

3.1. Data Compilation

An environmental database of 55 Gb of total information in 12322 files have been created, comprising both spatial and alphanumeric information has been compiled, 176991 records and 910 variables in alphanumeric, tabulated information, in addition to numerous datasets stored in spatial formats. Variables consider soil profiles description, basic, physical and chemical properties, content of trace elements in soil, water, sediment, air, plant and animal biomass, soil biological activity, associated biodiversity (soil nematodes, river zooplankton, phytoplankton, periphyton, aquatic macroinvertebrates and fishes, among others), management (remediation measures applied along time and space; Fig. 4), land use and cover, and present and predicted climate (Table 2).
Figure 4. Distribution of remediation measures across the Guadiamar Green Corridor during the period 1998-2002

<table>
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<tr>
<th>Type</th>
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<td>Soil physical properties</td>
<td>Coarse fragments (&lt;2 mm); Coarse sand; Fine sand; Clay; Silt; Bulk density; Water content.</td>
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<tr>
<td>Soil chemical properties</td>
<td>pH (1:1) H$_2$O; pH (1:1) CaCl$_2$; Electrical conductivity; Total carbon content; Organic carbon; Calcium carbonate; N org.,</td>
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<tr>
<td>Trace elements content in soil</td>
<td>As, Cd, Co, Cu, Fe, Hg, Mn, Ni, Pb, Sb, Ti, Zn (pseudototal); As, Cd, Cu, Fe, Mn, Ni, Pb, Zn (soluble); Others: Ag, Al, Ba, Be, Bi, Cr, Cs, Cu, La, Mn, Mo, Nb, Ni, Sb, Sc, Ti, V, W, Y (pseudototal); Al, Co, Sb, Ti (soluble).</td>
</tr>
<tr>
<td>Trace elements content in sludges</td>
<td>As, Cd, Cu, Fe, Hg, Mn, Ni, Pb, Ti, Zn (pseudototal)</td>
</tr>
<tr>
<td>Trace elements content in sediments</td>
<td>As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Ti, Zn (pseudototal)</td>
</tr>
<tr>
<td>Other contaminants in sediments</td>
<td>Total S</td>
</tr>
<tr>
<td>Trace elements content in water</td>
<td>As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Ti, Zn (pseudototal)</td>
</tr>
<tr>
<td>Trace elements content in vegetal biomass</td>
<td>As, Cd, Co, Cr, Cu, Fe, Mo, Mn, Ni, Pb, Sb, Ti, U, V, Zn; Others: Bi, Sn, Th.</td>
</tr>
<tr>
<td>Nutrients in vegetal biomass</td>
<td>N, P, K, S, Ca, Mg, Na</td>
</tr>
<tr>
<td>Trace elements content in animal biomass</td>
<td>As, Cd, Cu, Fe, Mn, Ni, Pb, V, Ti, Zn.</td>
</tr>
<tr>
<td>Other contaminants in soil</td>
<td>S (pseudototal; soluble); others: Soluble cyanides (CN−)</td>
</tr>
</tbody>
</table>

**Soil biological activity**

- Basal respiration rate; Potential nitrogen mineralization rate; Potential nitrification rate; NO2 (gas) production; Denitrification; Urease activity (dry soil); Dehydrogenase activity (fresh soil, dry soil, 80% FC); Acid phosphatase activity (fresh soil, dry soil, 80% FC); Alkaline phosphatase activity (dry soil); Arylsulfatase activity (dry soil, 80% FC); beta-Glucosidase activity (dry soil, 80% FC); Microbial chemical toxicity (CE50); Microbial mean chemical toxicity; Microbial resistance; Microbial mean resistance.

**Soil biodiversity**

- Nematodes abundance (density) and abundance (45 taxa).

**Management: amendments**

- Fe-rich cly materials, Sugar beet lime; Biosolid compost; Manure.

**Climate**

- Monthly temperature (Current, Future); Monthly precipitation (Current, Future)

**Soil land use**


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**Table 2. Geodatabase processed for the Guadiamar Green Corridor assess during the last 20 years.**

The compiled data comprised a totality of 49 information packages, as follows: Base cartography (BC) for spatial standardization purposes included 10 information packages concerning lithology, landscape and land use and cover maps. Environmental monitoring and assessment (EM) data included 36 information packages corresponding to those studies carried out during the most active assessment period, between 1998 and 2002 (Montes and Carrascal, 2008), as well as those data produced by the research group SoilPlant (IRNAS-CSIC) between 1999 and 2016 provided by the authors (Table 3). Finally, 3 information packages regarding present climate and climate change scenarios (CL) data and maps were also compiled. This database included variables concerning site and soil characteristics, contamination (concentration trace elements -TE-), soil biological activity, biodiversity, management and climate (Table 3, Annex II).

**3.2. Data standardization and harmonization**

Main conversion factors applied were referred to soil organic carbon content (SOC), pH and trace elements (TE) in soils.
For the harmonization of SOC obtained from different analysis methodologies, the conversion factors defined in Appendix 3 of the European Hydropedological Data Inventory were used (JRC 2013). No correlation factors were found in the bibliography respecting the pH and ET determination methods. Thus, the conversion factors for pH was obtained from statistical correlations (Pearson correlation) and regressions between the data obtained by different methods (at the same sampling point and at the same time), and a conversion equation was obtained to be applied in the study area. pH determined with pH-meter with glass electrode in two different solutions, H₂O with a soil:water ratio of 1:1 and CaCl₂, with a soil:CaCl₂ ratio 1:1 were compared. Person analysis (N=306) found significant correlation made between both procedures (Fig. 4).

In the case of TE content in soils, the harmonization was not possible in all the cases, since the analytical methods applied were specified to extract differentiated fractions of ETs in soils. Methods determining available fraction of Cd (0.05 M EDTA, 0.01 M CaCl₂, 0.1 M CaCl₂, 1M NH₄NO₃) with the pseudo-total Cd extraction methodologies (aqua regia, ISO 11466) and with the methodology of total extraction of Cd (Sequential Extraction Tessier 1979) were compared. Pearson analysis found a significant correlation between Cd content determined by extraction with 0.05 M EDTA and extraction with aqua regia for the studied area (P<0.0001, ρ: 0.8542). The best fitting in the regressions analyses was polynomial (P <0.0001, R²: 0.7479) (y = 0.21122 x² + 1.21718 x +1.59574).

<table>
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<tr>
<th>ORIGIN_FILE</th>
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<th>Units</th>
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<td>F_ZINGG_2014</td>
<td>Digestion with &quot;aqua regia&quot; (concentration of ClH and HNO₃); determination by spectrometry (ICP-OES, optical emission spectrometry with inductive coupling plasma)</td>
<td>mg/kg</td>
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<tr>
<td>MT_DOMINGUEZ_2014</td>
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<td>P_MADEJON_2004tes</td>
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<td>P_MADEJON_2006</td>
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<td>P_MADEJON_2009-11</td>
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<td>P_MADEJON_2009pas</td>
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<td>P_MADEJON_2013car</td>
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<td>TE_Mayo14</td>
<td>Digestion with &quot;aqua regia&quot; (concentration of ClH and HNO₃); determination by spectrometry (ICP-MS, inductive coupling plasma mass spectrometry)</td>
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<tr>
<td>MT_DOMINGUEZ_2005</td>
<td></td>
<td></td>
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</table>
Digestion with "aqua regia" (concentration of CIH and HNO₃); determination by spectrometry (atomic absorption spectroscopy, with hydride generator or graphite chamber where necessary)

Table 4. Summary of methods and units for determination of pseudototal trace elements in soils.

<table>
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<tr>
<th>ORIGIN_FILE</th>
<th>Método</th>
<th>Unidades</th>
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<td>P_MADEJON_2007a</td>
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<td>J_XIONG_2003-11</td>
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<tr>
<td>P_MADEJON_2009-11</td>
<td>Digestion with CaCl₂ solution (0.1M); determination by spectrometry (ICP-OES, optical emission spectrometry with inductive coupling plasma)</td>
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</tr>
<tr>
<td>MT_DOMINGUEZ_2014</td>
<td>Digestion with NH₄NO₃ solution (1M); determination by spectrometry (ICP-OES, optical emission spectrometry with inductive coupling plasma)</td>
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<tr>
<td>MT_DOMINGUEZ_2005</td>
<td>Digestion with NH₄NO₃ solution (1M); determination by spectrometry (ICP-MS, inductive coupling plasma mass spectrometry)</td>
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</tbody>
</table>

Table 5. Summary of methods and units for determination of soluble trace elements in soils.

Pearson analysis found a significant correlation between Cd content determined by extraction with 0.05 M EDTA and by applying Sequential ET extractions (Tessier 1979) (P < 0.0001 ρ: 0.9565). The best fitting in the regressions analyses was linear (P < 0.0001, R²: 0.9832) (y = 0.21122 x² + 1.21718 x +1.59574) (y = 2.359583 x - 0.002597).

3.3. Impact of sugar beet lime in different land use with other amendments

In figure 5 have been expressed the ln pseudototal concentration of trace elements (ppm). In every land use selected, the level of pseudototal concentration down in case of Cadmium. However, As didn’t have change significative of basin level. Non-irrigated arable land has 3 soil remediation measures with sugar beet lime where the soil treatment 30 (Compost+ 2 sugar beet lime doses) have lowest level of Cd. In Agro-forestries areas we founded 2 soil amendments and the soils with soil treatment 52 (Compost+Red clay+2 doses of sugar beet lime) showed the lowest concentration of cadmium. However, the level of pseudototal concentrations of cadmium in soils of Broad-leaved forests didn’t have significance difference between soil treatments. The Natural grasslands showed a total of 11 soil measures and the soil treatments 23, 28, 30, 40, 42 and 52 showed reduction of cadmium respect basin levels.
In terms of percentage of reduction of cadmium level, the table XX show the reduction respect to mean of basin levels and mean of level of cadmium resulted of soil amendments, as well as, the mean of basin levels and 2001 levels of pseudototal of trace elements. T52 and T30 showed in Agroforestrries areas the worst percentage of reduction. However, the basin level of Cadmium in this land use was low. If we showed the pseudototal of cadmium and related to percentage of reduction, the soil treatments most effective was T28 in land use 321 and T30 in land use 211 (Figure 6). The level up of As and other trace elements in soils is similar of results showed in other works (Cabrera et al., 2008; Domínguez et al., 2008; Madejón, P. et al., 2018) (Table 6, Annex II). The database showed level up of other trace elements such Cu, Pb and Zn also. This was attributed to the mixing and burying of the remains of the sludge layer by the heavy machinery used for sludge removal, liming, and manuring (Cabrera et al., 2005, 2008; Nagel et al., 2003; Simón et al., 2008a). The cost of sugar beet lime and compost applied in Guadiamar case study was 166 $/ha and 398$/ha respectively, but the cost most important is the transport of amendments. (T_SPA028es, WOCAT Database)
Conclusions

In this study we propose an integrative approach that comprises existing and new methodologies for evaluating and monitoring of soil treat measures in soils contaminated. In fact, the current trend at European and global level in relation to environmental information, and particularly in relation to sustainable management and protection of soil resources, is to develop common databases shared in an open, standardized and harmonized manner, compatible with other disciplines and data banks globally, able to be used to the formulation of comprehensive knowledge, according to the scientific and technical principles previously examined by the European Thematic Strategy for the Protection of Soils (SEC, 2006; Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - The implementation of the Sustainable Thematic Strategy and on-going activities, COM / 2012, and FAO (Harmonized World Data Base, 2008, Intergovernmental Technical Panel on Soils, 20171), which have in fact served as the basis for the objectives of subsequent international initiatives in terms of soil use and protection, such as the Global Soil Partnership, the European Soil Partnership or the Research Data Alliance, among others. The collection of data from diverse sources produced under disparate criteria implies an arduous and expensive work in time, although it is the only way to extract data that has been produced historically without objectives of unification or standardization. To carry out an adequate evaluation and monitoring of areas affected by pollution, it would be necessary to establish and apply a standardized and standardized data sampling and communication protocol at a European and international level, in accordance with the recommendations and present needs of the Strategy. European Thematic for the Protection of Soils of the European Commission, the Global Soil Partnership, the European Soil Partnership or FAO, among others. The protocol referred to in the previous paragraph should establish the nomenclature principles, the headers to be available in each database, the order of heads to follow, etc. In this way, the problems generated in understanding, communication problems and problems were
reduced when standardizing and harmonizing all the databases, with the corresponding saving of time and effort and with higher quality results.

Exploitation of the information contained in the created database by the application of advances in analytic and statistics techniques will allow for identifying key indicators of the soil condition, as well as modelling and evaluating the performance of the considered soil-plant-atmosphere system over time, under predicted scenarios of land use, management and climate change. What is more, it allows for models validation and the long-term monitoring of the area through the addition of new and updated information. On the top of that, this database development is allowing for establishing the resilience to pollution by trace elements of the different soils affected in the area, the guiding for further action programs, and the creation of expert knowledge to be extrapolated and applied in other areas.

Different soils measures have been studied at different scales, including monitoring and evaluation. We proposed a methodology for upscaling and replicate in other areas attending of land use and soils types. It is important select the most effective soil measures attending to reduction of cadmium in soils and cost of amendment and transport. The sugar beet lime is used in agriculture for level up of pH, however, frequently it is being used such as remediation of soil contamination so, it is necessary more research for estimate the efficiency depending of soils, climate, and trace elements goal.

The approach presented has the potentiality to provide environmental and socioeconomic benefits in the short medium and long-term, by implementing soil evaluation over the time, as well as to generate a broad and powerful tool for management according to given social and economic constraints, with relevant impact to political, administrative and technical objective from the local to the international scale.

Acknowledgements

This work has been funded by the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreements n° 603498 (RECARE), and the Spanish Ministry of Science and Innovation that granted both TORRES QUEVEDO and INDUSTRIAL DOCTORATE Projects to Evenor-Tech, with references PTQ-14-07267 and DI-15-07873, respectively, that are co-financed by the European Social Fund. We thank to Dr. Rafael Pino from Department of Statistics and Operational Research of University of Seville and MSc. Olaia Etxebarria Garmendia from Master of Climate Change, Carbon, and Water resources of University Pablo de Olavide for collaborate with us and provide their information.

References


Zing F (2014) Evaluate Long-Term Fate of Metal Contamination after Mine Spill; Assessing Contaminant Changes in Soil. The Guadiamar Case Study; Southern Spain. MSc Thesis. Wagchenen University. 57 pp
## ANNEX 1 Table 1. Description of soil treatments in Guadiamar Case Study

<table>
<thead>
<tr>
<th>TREAT</th>
<th>TREAT_Description</th>
<th>TREAT_T_CODE</th>
</tr>
</thead>
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<tr>
<td>COMPOST (20)</td>
<td>Application of compost (20 Tm / ha dose) in October-December 1999</td>
<td>1</td>
</tr>
<tr>
<td>MANURE (20)</td>
<td>Application of manure (20 Tm / ha dose) in October-December 1999</td>
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<td>SUGAR BEET LIME 1(15)</td>
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</tr>
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<td>Application of sugar beet lime (20 Tm / ha dose) in August 2000-April 2001</td>
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<tr>
<td>SUGAR BEET LIME 2(30)</td>
<td>Application of sugar beet lime (30 Tm / ha dose) in August 2000-April 2001</td>
<td>8</td>
</tr>
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<td>Application of sugar beet lime (50 Tm / ha dose) in August 2000-April 2001</td>
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<td>COMPOST (20)+RED CLAY(720)</td>
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<td>Application of Fe-rich red clayey materials (900 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (20 Tm / ha dose) in August 2000- April 2001</td>
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<td>Red Clay(900)+Sugar Beet Lime 1(40)+Sugar Beet Lime 2(30)</td>
<td>Application of Fe-rich red clayey materials (900 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001</td>
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<td>Red Clay(900)+Sugar Beet Lime 1(40)+Sugar Beet Lime 2(50)</td>
<td>Application of Fe-rich red clayey materials (900 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (50 Tm / ha dose) in August 2000- April 2001</td>
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<td>Red Clay(960)+Sugar Beet Lime 1(40)+Sugar Beet Lime 2(20)</td>
<td>Application of Fe-rich red clayey materials (960 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (20 Tm / ha dose) in August 2000- April 2001</td>
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<td>Red Clay(960)+Sugar Beet Lime 1(40)+Sugar Beet Lime 2(30)</td>
<td>Application of Fe-rich red clayey materials (960 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001</td>
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<td>Red Clay(960)+Sugar Beet Lime 1(40)+Sugar Beet Lime 2(50)</td>
<td>Application of Fe-rich red clayey materials (960 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (50 Tm / ha dose) in August 2000- April 2001</td>
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<td>Compost (20)+Red</td>
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CLAY (320) + SUGAR BEET LIME 1 (40) + SUGAR BEET LIME 2 (20)

1999 PLUS Fe-rich red clayey materials (320 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (20 Tm / ha dose) in August 2000- April 2001

COMPOST (20) + RED CLAY (320) + SUGAR BEET LIME 1 (40) + SUGAR BEET LIME 2 (30)

Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (320 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001

COMPOST (20) + RED CLAY (320) + SUGAR BEET LIME 1 (40) + SUGAR BEET LIME 2 (50)

Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (320 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (50 Tm / ha dose) in August 2000- April 2001

COMPOST (20) + RED CLAY (662) + SUGAR BEET LIME 1 (40) + SUGAR BEET LIME 2 (30)

Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (662 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001

COMPOST (20) + RED CLAY (662) + SUGAR BEET LIME 1 (40) + SUGAR BEET LIME 2 (50)

Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (662 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (50 Tm / ha dose) in August 2000- April 2001

COMPOST (20) + RED CLAY (745) + SUGAR BEET LIME 1 (40) + SUGAR BEET LIME 2 (20)

Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (745 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (20 Tm / ha dose) in August 2000- April 2001

COMPOST (20) + RED CLAY (745) + SUGAR BEET LIME 1 (40) + SUGAR BEET LIME 2 (30)

Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (745 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001

COMPOST (20) + RED CLAY (745) + SUGAR BEET LIME 1 (40) + SUGAR BEET LIME 2 (50)

Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (745 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (50 Tm / ha dose) in August 2000- April 2001

COMPOST (20) + RED CLAY (801) + SUGAR BEET LIME 1 (40) + SUGAR BEET LIME 2 (50)

Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (801 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (50 Tm / ha dose) in August 2000- April 2001
Annex II Table 3. Description of the compiled information packages included in the Guadiamar database.

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<td>Informe sobre los trabajos efectuados por la Consejería de agricultura y Pesca para caracterizar la afectación de los suelos agrarios por los vertidos de la balsa de la mina de Aznalcóllar (Sevilla). Secretaría general de Agricultura y ganadería, Consejería de Agricultura y Pesca, Junta de Andalucía, Marzo de 1999.</td>
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<td>Madejón P, Murillo JM, Marañón T, Cabrera F (2006) Bioaccumulation of trace elements in a wild grass three years after the Aznalcollar mine spill (South Spain). Environmental Monitoring and Assessment 114, 169-189.</td>
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Annex III. Table 6. Pseudototal concentration (mg/kg) of trace elements in soils of the Guadiamar area at different land uses and soil techniques.

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<td>sd</td>
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<td><strong>T52</strong> mean</td>
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<td>0.76</td>
<td>68.57</td>
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<tr>
<td>Soil physical properties</td>
<td>Coarse fragments (&lt;2 mm); Coarse sand; Fine sand; Clay; Silt; Bulk density; Water content.</td>
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<td>Soil chemical properties</td>
<td>pH (1:1) H2O; pH (1:1) CaCl2; Electrical conductivity; Total carbon content; Organic carbon; Calcium carbonate; N org., Nitrate, Ammonium, Total P; Available P org.; Available P inorg.; exchangeable K; exchangeable Na; exchangeable Ca; exchangeable Mg; Silica (SiO2); Alumina (Al2O3), Magnesium oxides (MgO).</td>
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<tr>
<td>Trace elements content in soil</td>
<td>As, Cd, Co, Cu, Fe, Hg, Mn, Ni, Pb, Sb, Ti, Zn (pseudototal); As, Cd, Cu, Fe, Mn, Ni, Pb, Zn (soluble); Others: Ag, Al, Ba, Be, Bi, Cr, Cs, Cu, La, Mn, Mo, Nb, Ni, Sb, Sc, Ti, V, W, Y (pseudototal); Al, Co, Sb, Ti (soluble).</td>
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<td>Trace elements content in sludges</td>
<td>As, Cd, Cu, Fe, Hg, Mn, Ni, Pb, Ti, Zn (pseudototal)</td>
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<td>Trace elements content in sediments</td>
<td>As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Ti, Zn (pseudototal)</td>
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<tr>
<td>Other contaminants in sediments</td>
<td>Total S</td>
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<tr>
<td>Trace elements content in water</td>
<td>As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Ti, Zn (pseudototal)</td>
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<tr>
<td>Trace elements content in vegetal biomass</td>
<td>As, Cd, Co, Cr, Cu, Fe, Mo, Mn, Ni, Pb, Sb, Ti, U, V, Zn; Others: Bi, Sn, Th.</td>
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<tr>
<td>Nutrients in vegetal biomass</td>
<td>N, P, K, S, Ca, Mg, Na</td>
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<tr>
<td>Trace elements content in animal biomass</td>
<td>As, Cd, Cu, Fe, Mn, Ni, Pb, V, Ti, Zn.</td>
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<tr>
<td>Other contaminants in soil</td>
<td>S (pseudototal; soluble); others: Soluble cyanides (CN-)</td>
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<tr>
<td>Soil biological activity</td>
<td>Basal respiration rate; Potential nitrogen mineralization rate; Potential nitrification rate; NO2 (gas) production; Denitrification; Urease activity (dry soil); Dehydrogenase activity (fresh soil, dry soil, 80% FC); Acid phosphatase activity (fresh soil, dry soil, 80% FC); Alkaline phosphatase activity (dry soil); Arylsulfatase activity (dry soil, dry soil, 80% FC); beta-Glucosidase activity (dry soil, 80% FC); Microbial chemical toxicity (CE50); Microbial mean chemical toxicity; Microbial resistance; Microbial mean resistance.</td>
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<tr>
<td>Soil biodiversity</td>
<td>Nematodes abundance (density) and abundance (45 taxa).</td>
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<tr>
<td>Management: amendments</td>
<td>Fe-rich cly materials, Sugar beet lime; Biosolid compost; Manure.</td>
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<tr>
<td>Climate</td>
<td>Monthly temperature (Current, Future); Monthly precipitation (Current, Future)</td>
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Soil land use


Table 2. Geodatabase processed for the Guadiamar Green Corridor assess during the last 20 years.

<table>
<thead>
<tr>
<th>ORIGIN_FILE</th>
<th>Method</th>
<th>Units</th>
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<tbody>
<tr>
<td>F_ZINGG_2014</td>
<td>Digestion with &quot;aqua regia&quot; (concentration of ClH and HNO3); determination by spectrometry (ICP-OES, optical emission spectrometry with inductive coupling plasma)</td>
<td></td>
</tr>
<tr>
<td>MT_DOMINGUEZ_2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P_MADEJON_2004tes</td>
<td>Digestion with &quot;aqua regia&quot; (concentration of ClH and HNO3); determination by spectrometry (ICP-OES, optical emission spectrometry with inductive coupling plasma)</td>
<td>mg/kg</td>
</tr>
<tr>
<td>P_MADEJON_2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P_MADEJON_2009-11</td>
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<td></td>
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<tr>
<td>P_MADEJON_2009pas</td>
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<tr>
<td>P_MADEJON_2013car</td>
<td></td>
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</tr>
<tr>
<td>TE_Mayo14</td>
<td>Digestion with &quot;aqua regia&quot; (concentration of ClH and HNO3); determination by spectrometry (ICP-MS, inductive coupling plasma mass spectrometry)</td>
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</tr>
<tr>
<td>MT_DOMINGUEZ_2005</td>
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<tr>
<td>C_AGRPES_98</td>
<td>Digestion with &quot;aqua regia&quot; (concentration of ClH and HNO3); determination by spectrometry (atomic absorption spectroscopy, with hydride generator or graphite chamber where necessary)</td>
<td></td>
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</tbody>
</table>

Table 4. Summary of methods and units for determination of pseudototal trace elements in soils.

<table>
<thead>
<tr>
<th>ORIGIN_FILE</th>
<th>Método</th>
<th>Unidades</th>
</tr>
</thead>
<tbody>
<tr>
<td>F_ZINGG_2014</td>
<td>Digestion with EDTA solution (0.05 M); determination by spectrometry (ICP-OES, optical emission spectrometry with inductive coupling plasma)</td>
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</tr>
<tr>
<td>P_MADEJON_2004tes</td>
<td></td>
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<tr>
<td>P_MADEJON_2007a</td>
<td>Digestion with EDTA solution (0.05M); determination by spectrometry (ICP-MS, inductive coupling plasma mass spectrometry)</td>
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</tr>
<tr>
<td>J_XIONG_2003-11</td>
<td>Digestion with CaCl2 solution (0.01M); determination by spectrometry (ICP-OES, optical emission spectrometry with inductive coupling plasma)</td>
<td>mg/kg</td>
</tr>
<tr>
<td>P_MADEJON_2009-11</td>
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<tr>
<td>MT_DOMINGUEZ_2014</td>
<td></td>
<td></td>
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<tr>
<td>MT_DOMINGUEZ_2005</td>
<td>Digestion with NH4NO3 solution (1M); determination by spectrometry (ICP-MS, inductive coupling plasma mass spectrometry)</td>
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</table>

Table 5. Summary of methods and units for determination of soluble trace elements in soils.
<table>
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<th>TREAT</th>
<th>TREAT_Description</th>
<th>TREAT_CODE</th>
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<tbody>
<tr>
<td>COMPOST (20)</td>
<td>Application of compost (20 Tm / ha dose) in October-December 1999</td>
<td>1</td>
</tr>
<tr>
<td>MANURE (20)</td>
<td>Application of manure (20 Tm / ha dose) in October-December 1999</td>
<td>2</td>
</tr>
<tr>
<td>RED CLAY(662)</td>
<td>Application of Fe-rich red clayey materials (662 Tm / ha dose) in November 2000-April-June 2001</td>
<td>3</td>
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<tr>
<td>SUGAR BEET LIME 1(15)</td>
<td>Application of sugar beet lime (15 Tm / ha dose) in February-October 1999</td>
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<tr>
<td>SUGAR BEET LIME 1(20)</td>
<td>Application of sugar beet lime (20 Tm / ha dose) in February-October 1999</td>
<td>5</td>
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<td>SUGAR BEET LIME 1(40)</td>
<td>Application of sugar beet lime (40 Tm / ha dose) in February-October 1999</td>
<td>6</td>
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<tr>
<td>SUGAR BEET LIME 2(20)</td>
<td>Application of sugar beet lime (20 Tm / ha dose) in August 2000- April 2001</td>
<td>7</td>
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<td>SUGAR BEET LIME 2(30)</td>
<td>Application of sugar beet lime (30 Tm / ha dose) in August 2000- April 2001</td>
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<td>SUGAR BEET LIME 2(50)</td>
<td>Application of sugar beet lime (50 Tm / ha dose) in August 2000- April 2001</td>
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<tr>
<td>COMPOST (20)+RED CLAY(720)</td>
<td>Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (720 Tm / ha dose) in December 1999 - May 2000</td>
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<tr>
<td>COMPOST (20)+SUGAR BEET LIME 1(20)</td>
<td>Application of compost (20 Tm / ha dose) in October-December 1999 PLUS sugar beet lime (20 Tm / ha dose) in February-October 1999</td>
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<td>COMPOST (20)+SUGAR BEET LIME 1(40)</td>
<td>Application of compost (20 Tm / ha dose) in October-December 1999 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999</td>
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<tr>
<td>MANURE (15)+SUGAR BEET LIME 1(20)</td>
<td>Application of manure (15 Tm / ha dose) in October-December 1999 PLUS sugar beet lime (20 Tm / ha dose) in February-October 1999</td>
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<tr>
<td>MANURE (20)+SUGAR BEET LIME 1(20)</td>
<td>Application of manure (20 Tm / ha dose) in October-December 1999 PLUS sugar beet lime (20 Tm / ha dose) in February-October 1999</td>
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<tr>
<td>RED CLAY(480)+SUGAR BEET LIME 1(20)</td>
<td>Application of Fe-rich red clayey materials (480 Tm / ha dose) in December 1999-May 2000 PLUS sugar beet lime (20 Tm / ha dose) in February-October 1999</td>
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<tr>
<td>RED CLAY(662)+SUGAR BEET LIME 1(40)</td>
<td>Application of Fe-rich red clayey materials (662 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999</td>
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<tr>
<td>Experiment</td>
<td>Description</td>
<td>Application Dates</td>
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<tr>
<td>RED CLAY(720)+SUGAR BEET LIME 1(20)</td>
<td>Application of Fe-rich red clayey materials (720 Tm / ha dose) in December 1999-May 2001 PLUS sugar beet lime (20 Tm / ha dose) in February-October 1999</td>
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<tr>
<td>RED CLAY(960)+SUGAR BEET LIME 1(20)</td>
<td>Application of Fe-rich red clayey materials (960 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (20 Tm / ha dose) in February-October 1999</td>
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<tr>
<td>RED CLAY(320)+SUGAR BEET LIME 2(30)</td>
<td>Application of Fe-rich red clayey materials (320 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (30 Tm / ha dose) in August 2000-April 2001</td>
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<tr>
<td>RED CLAY(801)+SUGAR BEET LIME 2(30)</td>
<td>Application of Fe-rich red clayey materials (801 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (30 Tm / ha dose) in August 2000-April 2001</td>
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<tr>
<td>RED CLAY(801)+SUGAR BEET LIME 2(50)</td>
<td>Application of Fe-rich red clayey materials (801 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (50 Tm / ha dose) in August 2000-April 2001</td>
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<tr>
<td>SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(20)</td>
<td>Application of sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (20 Tm / ha dose) in August 2000-April 2001</td>
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<td>SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(30)</td>
<td>Application of sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000-April 2001</td>
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<td>SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(50)</td>
<td>Application of sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (50 Tm / ha dose) in August 2000-April 2001</td>
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<tr>
<td>COMPOST (20)+RED CLAY(320)+SUGAR BEET LIME 1(40)</td>
<td>Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (320 Tm / ha dose) in November 2000-April-June 2001 PLUS Application of sugar beet lime (40 Tm / ha dose) in February-October 1999</td>
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<tr>
<td>COMPOST (20)+RED CLAY(720)+SUGAR BEET LIME 1(20)</td>
<td>Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (720 Tm / ha dose) in December 1999-May 2001 PLUS Application of sugar beet lime (20 Tm / ha dose) in February-October 1999</td>
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<tr>
<td>COMPOST (20)+RED CLAY(745)+SUGAR BEET LIME 2(20)</td>
<td>Application of compost (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (745 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (20 Tm / ha dose) in August 2000-April 2001</td>
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<tr>
<td>COMPOST (20)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME</td>
<td>Application of compost (20 Tm / ha dose) in October-December 1999 PLUS sugar beet lime (40 Tm / ha)</td>
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<tr>
<td>Index</td>
<td>Description</td>
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<td>2(20)</td>
<td>Application of compost (20 Tm / ha dose) in October-December 1999 PLUS sugar beet lime (20 Tm / ha dose) in August 2000- April 2001</td>
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<td>29</td>
<td>COMPOST (20)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(30) Application of compost (20 Tm / ha dose) in October-December 1999 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001</td>
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<td>30</td>
<td>COMPOST (20)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(50) Application of compost (20 Tm / ha dose) in October-December 1999 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (50 Tm / ha dose) in August 2000- April 2001</td>
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<tr>
<td>31</td>
<td>MANURE (20)+RED CLAY(480)+SUGAR BEET LIME 1(20) Application of manure (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (480 Tm / ha dose) in December 1999-May 2000 PLUS Application of sugar beet lime (20 Tm / ha dose) in February-October 1999</td>
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<td>32</td>
<td>MANURE (20)+RED CLAY(720)+SUGAR BEET LIME 1(20) Application of manure (20 Tm / ha dose) in October-December 1999 PLUS Fe-rich red clayey materials (720 Tm / ha dose) in December 1999-May 2001 PLUS Application of sugar beet lime (20 Tm / ha dose) in February-October 1999</td>
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<td>33</td>
<td>RED CLAY(320)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(30) Application of Fe-rich red clayey materials (320 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001</td>
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<td>34</td>
<td>RED CLAY(662)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(30) Application of Fe-rich red clayey materials (662 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001</td>
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<td>35</td>
<td>RED CLAY(662)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(50) Application of Fe-rich red clayey materials (662 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (50 Tm / ha dose) in August 2000- April 2001</td>
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<td>36</td>
<td>RED CLAY(745)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(30) Application of Fe-rich red clayey materials (745 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001</td>
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<td>37</td>
<td>RED CLAY(801)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(30) Application of Fe-rich red clayey materials (801 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001</td>
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</tr>
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<td>38</td>
<td>RED CLAY(801)+SUGAR BEET Application of Fe-rich red clayey materials (801 Tm / ha dose) in November 2000-April-June2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001</td>
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<tr>
<td>Application</td>
<td>Dose and Duration</td>
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<tr>
<td>LIME 1(40)+SUGAR BEET LIME 2(50)</td>
<td>ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (50 Tm / ha dose) in August 2000- April 2001</td>
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<td>RED CLAY(815)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(30)</td>
<td>Application of Fe-rich red clayey materials (815 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001</td>
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<td>RED CLAY(900)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(20)</td>
<td>Application of Fe-rich red clayey materials (900 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (20 Tm / ha dose) in August 2000- April 2001</td>
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<tr>
<td>RED CLAY(900)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(30)</td>
<td>Application of Fe-rich red clayey materials (900 Tm / ha dose) in November 2000-April-June 2001 PLUS sugar beet lime (40 Tm / ha dose) in February-October 1999 PLUS sugar beet lime (30 Tm / ha dose) in August 2000- April 2001</td>
<td></td>
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<tr>
<td>RED CLAY(900)+SUGAR BEET LIME 1(40)+SUGAR BEET LIME 2(50)</td>
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<td>Case Study</td>
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Table 1. Description of soil treatments in Guadiamar Case Study
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after the Aznalcollar mine spill (South Spain). Environmental Monitoring and Assessment 114, 169-189.


Table 3. Description of the compiled information packages included in the Guadiamar database.

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Table 6. Pseudototal concentration (mg/kg) of trace elements in soils of the Guadiamar area at different land uses and soil techniques.
Figure 1: Location of the Guadiamar Green Corridor

Figure 2: Land use 1999 (left) and soil types (right) of the Guadiamar Green Corridor
Figure 3 Benchmark sites selected for soil samples

Figure 4. Distribution of remediation measures across the Guadiamar Green Corridor during the period 1998-2002
Comparison between pH in solution SOIL:H2O (1:1) versus dissolution Soil:CaCl2 (1:1)

Figure 5.
Figure 6. Comparison of TE pseudototal concentrations between soil amendment extracted by EDTA from soils of Guadiamar river basin in 2001. (Results expressed in Naperian logarithm)
Figure 7. Results obtained of pseudototal cadmium in soils related to soil treatments and land use.
Abstract: The aim of study was to assess the effectiveness of organic and inorganic amendments to immobilize cadmium (Cd), lead (Pb) and zinc (Zn) in soil and reduce their phytoavailability. An experimental field was set-up in Copșa Mica area and four amendments were applied: Na-bentonite, dolomite, natural zeolite and manure. Following the application of the amendments, a mix of perennial grasses and straw cereals were sown. The effectiveness of applied amendments was assessed using single extraction of metals from soil (using DTPA-CaCl2-TEA at pH 7.3 or NH4NO3) and the plant uptake. All treatments produced significant increases of pH values in soil. The mean soil pH of the control plots was 5.18. The best results were observed after applications of dolomite (pH 7.18) or Na-bentonite (pH 6.83). After two years from applications all amendments caused a reduction of heavy metal (Cd, Pb or Zn) mobility compared to the control but the magnitude of effects depends on metal and amendment. The addition of dolomite reduced statistically significant the NH4NO3-extractable Cd, Pb and Zn concentrations in soil from 8.0 mg/kg Cd, 21.6 mg/kg Pb and 274 mg/kg Zn (control) to 0.6 mg/kg Cd, 0.7 mg/kg Pb and 14 mg/kg Zn. As compared with control (untreated soil), the addition of dolomite led to a significant decrease of cadmium content in plant (from 11 mg/kg Cd to 5.4 mg/kg Cd). Also, the applications of dolomite and Na-bentonite reduced significantly the concentrations of Pb and Zn in grass but this reduction is not enough to produce healthy food or fodder. The application of manure led to a significant increasing of biomass yield comparing with control even if the extractability of metals in manure treated plots was moderate. The results demonstrate the high potential of Na-bentonite and dolomite to reduce the availability and possible toxicity of heavy metals in contaminated soils. More attention should be paid to the transitory liming effect and metal remobilizing over time.
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Abstract

The study was aimed at evaluating the effectiveness of zeolite and natural bentonite for immobilization of cadmium (Cd) and zinc (Zn) in soil after application of four amendments: N-acid, dolomite, natural zeolite, and natural bentonite. Following the amendment application, the Cd and Zn availability was assessed, as well as the extraction of metal from soil (using DTCaCl\(_2\)-TMAH system). All treatments significantly increased the metal availability compared to the control but the metal content of all amendments. Additionally, dolomite increased the metal availability compared with the control (untreated soil) and a significant decrease of 43\% was observed for Cd (from 8.0 mg kg\(^{-1}\) to 2.1 mg kg\(^{-1}\)) and Pb (from 21.6 mg kg\(^{-1}\) to 7.1 mg kg\(^{-1}\)) in the top 2 cm of soil. The addition of dolomite significantly increased the Cd and Zn concentrations in the soil compared with the control (untreated soil) and the results indicated that micrometeorological conditions and the existence of Cd and Zn availability in treated plots was significant. The treatments decreased Cd and Zn toxicity in contaminated soil by limiting their immobilization over time.

Keywords

Z. A. and M. M. for the mobilization of heavy metals in a mineral mixture within two months. N.O. 1*.
1. ���u c ��  

2. a v y  ��ls c ��� on is �� e a sin g l y  b e �� orta �� or �� qua �� t y  

3. ���e  a�� ��� C ui e � a l., 2011 �� c ���� y  a dve rse l y  

4. a c c �� ��ter  -  ��  –  ��  –  a nim a ��system ��c �� y  a nd �� c �� y  influ e ��  

5. ��a �� (Adr ��� 2001; Guo e a�� 200�� Ra �� 2018) . ��c ��� to �� �� �� �� c ��lle c ��, ��e e ��2011 ��, ��a ��S oil  �ta C e ��  � ��Eur ope a ��  

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7. The  main c �� ��r a � oil  a nd �� ��ct ��s, ��a �� c ��y  a nd �� ��a �� on a nd �� e �� tot a �� c onc e �� �� a nd ��x ��y ��ls ��rsist �� �� ��ri ��me ��fter �� input  �optsi k, �� Hoube �� e ��201. 

8. The  c ��nvironmen �� ��s ��o ��n only �� their  tot a ��c onc e �� ��ns ��a �� to �� ������ �� (Cui e � a l. 2016) . ��y (��) ��f�� t�� �� ��� t y  ��  

9. ��ls �� �� ��s ��� sl y  on ��  c h a r a c t e r ��t ��c a s �� p ��a ��tex �� �� t y  a nd ��a n ti t y  o � ��y  h yd rox ��a nd ��a c �� ��a b e,  phospha te a nd �� la y  

10. ��h a r e  the  ���� �� ��tuents ��ble  f ����p t�� �� �� ��a v y  ��ls ��a �� c ��n contaminat ��in ��ropla ��c a ��e  t �� dieta r y  e x ���  �� ���� -  plant - food  c h a in  r a  a � g ��  

11. ��  to t ��� �� e c ��ts �� human s  ��� e �� �� �� �� ��a v y  ��ls ��  

12. c ��ropla ��c a ��e  t �� dieta r y  e x ���  �� ���� - plant - food  c h a in  r a  a � g ��  

13. ��ri e � a �  ( ��) ��f e �� e d  that ��rie �� ��mes ��e ��gge �� t ��e ��c ��y  c ��y  e ��c ��i c a �� uns ��a ��  

14. The  tec hnic a l  

15. ��olut ions for  tre a �e nt ��c ��y  ��sit e ��a r e  ��y  c ��y  ec �� c i c a �� u n ��a ��  

16. ��
Because high carbon emissions are only possible in a context, on small areas. On large areas, where land is cultivated and contamination is critical, it is more difficult to find solutions that are less expensive and have ecological effects. I have observed heavy metals in the soil media of paddy rice (Freire et al., 2009).

Because high carbon emissions are only possible in a context, on small areas. On large areas, where land is cultivated and contamination is critical, it is more difficult to find solutions that are less expensive and have ecological effects. I have observed heavy metals in the soil media of paddy rice (Freire et al., 2009).

The area is estimated using environmental measurements and by heavy metal contamination. The method was developed in the traditional media of measuring the element's content and by heavy metal contamination (Derakhshani et al., 2010). The area has been used frequently as amendments for zas and yard waste materials with high carbon content and hydrides, such as Fe and zinc oxide (Peters et al., 2005; Peters et al., 2011; Rasekh et al.) and organic products such as manure compost, bio-ads and bio-ads composite, due to various content and soil tests (leaching, aging, etc.) as why is very important to assess the long-term effects of heavy metals. Also, in situ
z a strategies to account both inability and ecological magnetic extent (Menca et al. 2003 cited by Lee et al., Brow a nd Ch a y, 2016).

The main c o ntent was to test e ffectiveness differences to educate the phy levels into food chain. ecss treatment is su b follows a  y period following treatment, a sserver c hildren to very attached c ontracted grown on these a a

2 Material and methods

2.1. Study site description

The study site is located in Sibic City, around an a ortant factor for process ing non-r teous e – Cop sa –. The management is non – ss a ctivity of the heavy in tensive Z a – a

The amew k of the R – tamental filing up in 2015 in a y effects are used for non-media on many c onstructs, a nd was used a grassland. The main c racteristic was the ex experimenta ��ld a very a

The experiment wa cailed in a Randomized C ��e te B locks designation with 20 e xperiments organised in a r – a

The amendments are only e only in 2015 a nd t following 90 t – b entonite 50 t – dolomite 90 t – ozone olite and 45 t – manure

AMENDMENTS

- Bentonite 50 t
- Dolomite 90 t
- Ozone olite and 45 t
- Manure 1
2.2. Soil and plants

The F-anthrone was produced by S.C. Beralia Industrie S.A (grain size 0.16 mm, pH 7.073 mg kg\(^{-1}\) Cd, 20.2 mg kg\(^{-1}\) P and 15.1 mg kg\(^{-1}\) Mg). The dolomite is double carbonated and ground by S.C. Dolimite Production SA, Rupesi Braai (pH 7.14 mg kg\(^{-1}\) Cd, 8.7 kg kg\(^{-1}\) P and 6.0 mg kg\(^{-1}\) Mg). The study was done on S.C. Anthrone by small farm every year (pH 1.59 mg kg\(^{-1}\) Cd, 106 \(\mu\)g P and 118 \(\mu\)g Pb). The grass and cereal were only composed mainly for stonecrop. The manure was collected by a small farm every year (pH 1.86 mg kg\(^{-1}\) Cd, 106 \(\mu\)g P and 118 \(\mu\)g Pb) and 2 mm. One composition 9 subsamples were collected from 14 September 2016 and 15 July 2017. The composite sample was sieved, crushed, and passed through a 2-mm sieve for the analysis. Soil samples were sieved through a 0.2-mm sieve for the analysis.
P l a n t  e x p l a n a t i o n  c o l l e c t i o n  c a s e s  J u l y  2 0 1 6  a n d  J u l y  2 0 1 7 .  F r o m 1 4 3  e a c h  c o l l e c t e d  p l a n t s  e x p l a n a t i o n  p a r t)  c o s t a  x c e s s  p l a n t s  o n 1 4 4  a .

1 4 6  C h e m i c a l  a n a l y s i s

1 4 7  S o i l  p H  m e a s u r e m e n t  u s i n g  p o t e n t i o m e t r y  m e t h o d (1:2.5 w/v, 1 4 8  w a t e r  T 1 4 9  c o n t a c t  ( S t a n d a r d  1 5 0  s o i l  e x t r a c t  u s i n g  d i c h r o m a t e  1 5 1  f o l l o w e d  b y  a c t i v e  a n i o n t r o u s  s ul f a t e  ( W a l k e y  a 1 5 2  c o n t r o l).  A 1 5 3  a l a n a c h e m i c a l  p h a s p h o r u s  a n d  k a p h a t o n  e x t r a c t  w i t h a c t i v e  a n i o n  a c e t a t e  l a c t i c 1 5 4  c o n t a m p l a t e  p h 3.75 ( R a m p e r s o n  S t a n d a r d  S 7184/19 - 1 5 5  m e t h o d)  a n d  a 1 5 6  l y b y  f l a m e  s y n t h e s e ( f o r  k a p h a t o n  c o n t e n t)  a n d 1 5 7  i t r o m e t r y  f o r  p h o s p h u s  c o n t e n t .

1 5 8  T h e  p s e u d o - t o t a l  c o n c e n t r a t i o n C d, P a n Z 1 5 9  m e t e r  i n  t h e  e x t r a c t  b y  a t o m i c  a b s o r p t i o m e t r y , a f t e r 1 6 0  e x t r a c t i o n  b y  a n i o n  - r e g i a - c r e w a v e  d i s s o l v e r 1 6 1  m e t h o d  a c c o r d i n g  S R  a 1 6 2  c e n s u r e  a c c u r a c y  t h e 1 6 3  a n a l y s e  f o r  a n i o n - r e g i a 1 6 4  e x t r a c t a b l e  m e t a ls  e x t r a c t  o n  (10  g  w i t h 2 1 6 0  e x t r a c t i o n  s o l u t i o n (0.00 1 6 3  c a C l 2 1 6 4  a n d 1 6 5  t e t r a e t h y l a m m o n i u m  a d j u s t e d  t o p H 7.3),

1 6 6  W a t e r  C l e a n t  i o n s  a n i o n - e x t r a c t e d  o n  (10  g w i t h 2 1 6 6  e x t r a c t i o n  s o l u t i o n (0.00 1 6 7  c a C l 2 1 6 8  a n d 1 6 9  t e t r a e t h y l a m m o n i u m  a d j u s t e d  t o p H 7.3),

1 7 0  A n a l y z e  f o r  a n i o n - e x t r a c t e d  m e t a ls  w a v e  e x t r a c t  b y  a n i o n - r e g i a - c r e w a v e  d i s s o l v e r 1 7 1  m e t h o d  a c c o r d i n g  S R  I S 1 4 8  70:2002. E x t r a c t s  a c c e n t u a t e  g e  a 1 7 2  f o r  AA 1 7 3  c o n t e n t  a n d 1 7 4  i t r o m e t r y  f o r  p h o s p h u s  c o n t e n t .
4. Extract examples to analyze for a variety of solutions.

The examples are shed to water first and with aze for in order to remove possible substances. After drying (60°C, 7 hours) and then digestion with nitric acid in a crow digest system, the metal content is measured using atomic absorption (F G B C A Z).

3. Statistical tests on the results of the field experiments are done using TREATMENT (C C C T STATISTICS C S T SYSTEM by S . One-way ANOVA were performed to assess whether there was a significant difference among the treatments. The Tukey's HSD was used to determine a significant difference among the means.

3.1. Effects of soil pH

As shown in Fig. 2 time mean pH is compared to the same treatment with Na bentonite and dolomite significantly decreased (p. 0.05) and the strongest action Na-bentonite compared to control (pH 5.18) and treated with manure (pH 5.92) and azote (pH 6.02) Two years after the highest values of pH were measured in the treatment with dolomite (pH 7.18) and Na-bentonite (6.83). There were no statistically different effects of these treatments.

3.2. Effects of metal salts upon metal uptake

191  e x tra c table C d, P b and Z n
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193  I both y e a �� a �� i on 5 -1
dolome educ e s ��� c a c y  signi fic a nt �� e x tra c table C c c e ntr a �� om �� m��
194  -1  to 8.5 k g C (2016 )
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e nha ��g the Z ��mobo a on in s oil compare ��a �� l e olite. Com ���
196  e nha ��g the Z ��mobo a on in s oil wit ���
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198  202  e x c �nge a �� met a ls a c ��� om ��  a nd thi �� is ��a ���y  the  c onc e ntr a ��
199  ��ls in soi ls a ���than c onc e �� �� - e x tra c table ��ls.
200  As ���in F 4 in th e x �rimen �� y e a rs,  N H 4  a nd Z ��r e  c c a s e ��
201  a nd the y  followe �
202  ��r ( �g h e �� ��� ol z e o � te  manur e ���l z e o�te dolome h)
203  The  ��� �obtain e in 2017 c a �� that �� d ��� e  a �� c a � on led  to ��� c ontent �
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205  Z ��sim c e a ��c ��
206  The  v alues e x c �n g e a �� P b c ontent in dolome tre a ���� wa �� � ����r tha n v alues of � x c ��e a ������ �� s .
207  e x tra c table ��in �� c r e a �d ��� c a � y  sig nific a ntl y  (p. 0.05)  �� o ��� mg k g
208  C 2017)
209  2017)
210  211  212  213  214  215  216
to mg kg⁻¹, om 21.6 mg kg⁻¹ (treated vs control) to mg kg⁻¹.

217 By giving zeolite treatment for 219 case significantly compared with control. (Fig 5).

220 Plants showed a decrease of zinc content above-ground biomass observed after dolomite application (Fig 5).

221 Compare to control, the analysis of Pb and Zn content in samples were significantly 0.05) to 20 mg kg⁻¹ Pb and 25 mg kg⁻¹ Zn plants grown in treated with dolomites. 5).

222 Application turf zeolite...
4 Discussion

4 Effects of oil pH on the oil yield, e.g., in situ and onavy oils using lees extraction and soluble. The goal was to remove the oil from the oil, to reduce the acidity by using some chemical parameters (pH, etc.).

Soil pH is an important factor that affects the oil content and affects the acidity and toxicity to plants (Rahni 2018). Processing is essentially immediate, and major changes are expected to occur less significantly in alkaline conditions of the previous (Frisel et al., 2010).

The pH values for a treatment are significantly lower in the (p. 325) experiment compared to the current years from the sample. The processing of the pH in the control is going to be expected to be under the conditions for and the remaining period. Otherwise, they are not as done for a long time in the control, by processing under the conditions (Lal. 2003) and can be expected to be under the conditions for the period.
including $\text{CaCl}_2$ etc., a to a ess

authors that is suitable for car care, an and for $\text{CaCO}_3$ and lea included als.

ding with Lay and Norvell 1978 noted by Lay and Zhou (2009 DTPA extractant can (1) a high concentration of $\text{CaCl}_2$ may change y with extractons, es $\text{Ca}$ and $\text{P}$ in the case acidic (2) a high chloride concentration these extractnts, an (3) triethanolamine (EA) isotonate $\text{pH}$ a could change $\text{H}^+$ in the case extricate soil treatment.

Our result, $\text{pH}$ increase after ac addition of dolom e and antonite (as ion) en nol on $\text{pH}$ by long-term ion layers (Shah e e al. 2015).

ter 2 y ears om a action dolom e and a sit every extract which improve (with $\text{CaCl}_2$) $\text{CaCl}_2$ in the case that creation of $\text{pH}$fic w after dolom e ac action.

t a contaminate $\text{CaCl}_2$ a reduce $\text{Ca}$ aility aols in $\text{Ca}$ g sing extract with $\text{CaCl}_2$ the results (less ec in $\text{Ca}$ aility the results; $\text{CaCO}_3$ less ec $\text{Ca}$ aility. The $\text{Ca}$ is in a gement with $\text{Ca}$ at. a that c rea o $\text{Ca}$ aility fic wantly as dolomite troduction. 

T ae ole to contaminate $\text{CaCl}_2$ reduce $\text{Ca}$ aility $\text{Ca}$ in both y ears t esti c. Comparing with ac action Na-$\text{CaCO}_3$ the results; $\text{CaCO}_3$ less ec $\text{Ca}$ aility the results; $\text{CaCO}_3$ less ec $\text{Ca}$ aility. The $\text{Ca}$ is in a gement with $\text{Ca}$ at. a that c rea o $\text{Ca}$ aility fic wantly as dolomite troduction.
Effects of extra dry building and on the vital saplings support.

Sim a small y regarding effects of arable then in the experiments 2005. 293

Moving a small metals a process in and lead to a significant amount in. Casing with these amends could be in other and perhaps eaten to recommended (Ma jon et al. 2012). 294

The case is that intensive age treatment covered is important in

The anti pollution as well as a run off and movement of the biodiversity.

There are few toxic effects of elevated a small metals in only ions some authors say manure with toxic effects on some grown. 295

Properly assessed for testing amends to change in the amount by annual processes and arable cereals sown in experiments field. 296

Antonite dolomite should play a small role some authors say. 297

Extensive pH values a small to hazardous essential to.

(Pusche et al. 2013)
The effects on pH are flected on the roots assessed by NH$_4^+$ extractions. The effects are amendable by Antonite and dolomite. Comparing with previous years, the effects of dolomite are confirmed with significantly higher. While the effects are clearly shown in the plants, it shows that the extraction gives sufficient amounts of available plant. While dolomite is used as an agent for C and P accumulation in the plant, while the dolomites are used as a reduced by 50% C and P concentration after ten years (F 5).

The main finding is that the comparison of the effects by washing non-elevating and washing NH$_4$Cl-TEA after setting the following metals (i) inorganic anions are significantly increasing the availability by extraction with Na-CaCl$_2$-TEA, achieving the...
(ii) Organic extraction for manure increase significantly availability, due to binding of metals to organic matter as metal-organic complexes. This reduces significantly the availability to plants, thus reducing uptake of cadmium in grass-stages to amount of kg$^{-1}$. As a result, soil fertility and treatments are maintained to ensure a permanent effect, even if they change biomass yields.

(v) Mention should be made to the ecodynamics and species involved. Our evidence that application could be essential for Acknowledgement.

The considerable funding from European Seventh Framework Programme (FP7-2013) grant agreement 603498...
Brown, S. L., C. S., R., Use a mendeme to store e c system function to metal

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Role of inorganic compounds in leaching and cropland contamination with Cd, Cu, and Zn in cultivated trees with cropping and identification of metal using topic techniques. Environmental Science and Technology 37, 98–108.


Applying manure and compost to contaminated ecosystems by Solanum nigra inoculated with arbuscular mycorrhizal fungi. Environmental Pollution 608–616.

McB��, ������ r �e sses of �e a v y meta � a nd ox y a��� �pti ��y  �� � �� � �nts,

P a��rs of �� I  C �g �ss � I �� �� ona l S oil �c � �e ��iet y�� - �u g �t, 1986,

H a��g , vol. 6, 559 - 99.

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sorption � c a dmi um a�� sur �c e  c h a � � �� s, Eur ope ��J ourna � o � S oil  S c �� e , 45,  

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��duc e  h e a v y  ���ls ��: 276 —��  
��,  Y.,  F e n g � D.,  Wu, J., R �� Z ., S �g ,  L., Wa �� J., ��� �� �� ��a bil � y ,  
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U.P.B . S c �� ull , S e rie � B , vol. 68 (3) �� - 78.

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471 | 472 | 473 | 474 | 475 | 476 | 477 | 478 | 479 | 480 | 481 | 482 | 483 | 484 | 485 | 486 | 487 | 488 | 489 | 490 | 491 | 492 | 493 | 494 | 495 | 496 | 497 | 498 | 499 | 500 | 501 | 502 | 503
Figure 1
Values followed by "***" letter *** significantly at 5% level according to Tukey's Significant Difference test.
Values followed by the same letter significantly at the 5% level according to the Tukey's Significant Difference test.
Values followed by the same letter are not significantly different at the 5% level according to Tukey's Significant Difference test.

Figure 4
Values followed by "sam" letter significantly at 5% level according to Tukey's Significant Difference test.

- Bm (M. ham.)
- Cd plan (mg kg M.)
- Zn plan (mg kg M.)
- Pb plan (mg kg M.)

Figure 5
Title: Experimental acidification of pasture: effects of long-term pH adjustment on soil biodiversity, fertility and function in comparison to heathland and acidic grassland

Article Type: VSI: Testing soil conservation

Keywords: Soil acidification; soil biodiversity; soil chemistry, acid grassland; heathland, sulfur, litter bags, fungal/bacterial ratios, arbuscular mycorrhiza, ericoid mycorrhiza

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Abstract: We investigated how large scale experimental acidification with sulphur affected soil biodiversity and function over a period of 17 years. A field experiment was conducted in the Isle-of-Purbeck, England using ferrous sulphate and elemental sulphur as acidifying agents. We tested the contribution made by differing components of the soil biota using a biotic-size-partitioning litterbag experiment and examined changes in soil biology at a range of scales including key components of the macro and micro-biota and their respective activities. Other variables that may be affected by changes in soil biodiversity and function were also assessed, including the effect on soil nutrient availability, mycorrhizas and plant community composition. We found that elemental sulphur had a considerable and persistent effect on soil pH, lowering it to levels found in the surrounding reference acid grassland and heathland sites. A newly adapted heath restoration index based on soil chemistry, found that elemental sulphur was by far the most successful treatment leading to soil conditions similar to the heathlands. Overall, acidification caused a loss of basic cations and an increase in toxic Al3+. Consequently the more mesotrophic components of soil biology were reduced by acidification during the course of the experiment. This transformed the soil biological system into one typical of acid grasslands and heathlands. Concomitant litter decomposition was similarly inhibited by acidification, with the microbiota more strongly hindered in acidified soil than the macroscopic fauna. The vegetation community was also strongly modified by the elemental sulphur treatments and, where grazing was restricted, soil acidification allowed a restored heathland community to persist. Arbuscular mycorrhizal colonisation of grasses were reduced where heather plants were established, while ericoid mycorrhizas had developed sufficient populations in the acidified pastures to match the colonisation rate in the native heathlands.
Hereby submit our 'Experiment to diffuse pure: effects of timing soil diversity, fertility, and ion in comparison heated and acidic gravel to the RE CARE specific sieve. Our study concerns demise, long-term soil acidification or helped andolian gravel at a site. We exhibit the effects of the acidification treatments on litter position, soil fauna and flora in importance by herthy,
Abstract

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Experimental acidification of pasture: effects of long-term pH adjustment on soil biodiversity, fertility and function in comparison to heathland and acidic grassland

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Abstract

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Key words: Soil acidification; soil biodiversity; soil chemistry, acid grassland; heathland, sulfur, litter bags, fungal/bacterial ratios, arbuscular mycorrhiza, ericoid mycorrhiza, soil microbiology
1.0 Introduction

Soil is a habitat for a huge variety of living organisms contributing enormously to global biodiversity (Orgiazzi 2016) yet is subject to several threats due to human interventions. A decline in soil biodiversity is the reduction of forms of life inhabiting soil (both in terms of quantity and variety), and this can cause a subsequent deterioration or loss of one or more soil functions. Soil biodiversity does not, however, decline independent of other factors and is usually related to other deterioration in soil quality, resulting in a reduction in the condition and/or number of biological habitats in the soil that support soil biodiversity.

In general and geographical terms, the state of soil biodiversity has been well described in the atlases of soil biodiversity (Jeffery et al., 2010; Orgiazzi 2016). The Atlas tries to address a fundamental problem with assessing soil biodiversity: if we do not know what is out there, how do we know if it is in decline? Even with these resources it is challenging to gauge soil biodiversity at national, European and global scales. At local levels it is clear that biodiversity is in decline. For example, soil sealing causes the death of soil biota by cutting off water and carbon and nutrient inputs (Turbé et al., 2010). In this extreme case, most biodiversity is lost. In other cases, soil biodiversity decline can be linked to erosion, organic matter depletion, salinization, contamination and compaction (Gardi et al., 2013; Montanarella, 2015).

Wherever soil biodiversity decline occurs, it can significantly affect the soils’ ability to function normally and respond to perturbations. The soil biota has a capacity to resist events that cause disturbance or change and a certain capacity to recover from these perturbations. A loss of biodiversity is thought to lead to a soil with lower resistance to
perturbation and reduced capacity to recover subsequently (Allison and Martiny 2008; Downing et al., 2012).

Soil biodiversity and its functions are influenced by complex interactions of abiotic and biotic factors, of which land-use change and degradation may have a negative effect. Along with other physical and chemical variables, changes in soil pH can have a strong influence on soil communities. Griffiths et al., (2011) analysed more than 1000 soil cores across the UK using molecular techniques, providing large-scale confirmation that bacterial diversity and communities were strongly affected by soil pH. Using molecular community profiling, they found a positive correlation of increasing pH with α-diversity, while β-diversity increased at lower pH and was dominated by a few taxa. On a larger scale, both in terms of organism and geography, soil pH was the main parameter influencing collembolan richness and communities analysed on a transect across Europe, including a range of land-uses as part of the EcoFINDEERS project (da Silva et al., 2016), and drove the structure of microbial communities in post-glacial and arable soils (Tripathi et al., 2018; Rousk at al., 2010). Such interesting observations on the effect of soil pH on soil biodiversity are surprisingly rare and few papers deal with this topic directly. In a search in the Core Collection of Web of Science in February 2018 only one paper on record was returned on a search of soil* & biodiversity & pH in the title field, this was Oldén, et al (2016). Only 52 studies were returned for "soil biodiversity" & pH in the topic field. While pH is often related to the populations of soil organisms, evidence of its direct effect on soil biodiversity through contrived experimentation is less prevalent and hence the effect of direct acidification as a threat to soil biodiversity is not well documented despite pH being such a vital controlling (master) variable.
An increasing common use of soil acidification in Europe has been in cases of heathland and acidic grassland restoration (Dunsford, 1998; Owen et al, 1999; Owen & Marrs 2000; Lawson et al, 2004; Tibbett & Diaz 2005; Diaz et al, 2008; van der Bij et al 2018). These habitats develop only on acid soils and have specialised soil biota and above-ground communities. The extent of European lowland heath and acid grasslands has seen a dramatic decline since the 1750’s due to the abandonment of traditional agricultural practice, driven by shifting economic circumstance and, more recently, the development of heathland for housing, roads, golf courses and the like. The reversion of improved agricultural land to an acidic grassland and heathland mix has become a conservation priority since the 1980’s to protect the rare plants and animals it supports, and to allow more traditional land uses to flourish. Moreover, the management required to maintain the heathland plagioclimax is often neglected in small fragments, resulting in the continued loss of heathland and biodiversity in the landscapes that remain (Diaz et al., 2013). The remaining fragments of heathland and acid grassland can exhibit an extinction debt for some of the species still present as population sizes are already too small (Piessens and Hermy, 2006; Gibson et al 2013).

The restoration of modern agricultural land to heathland is a far more challenging task than the management of existing fragments. Twentieth century agricultural improvement of podzolic soils often required aggressive physical and chemical interventions; transforming a heterogeneous, nutrient poor acidic system into a uniform nutrient enriched circum-neutral soilscape. To restore such land back into nutrient poor acid systems, countermanding and equally aggressive measures are required such as top soil removal or acidification by elemental sulphur (Diaz et al., 2008). Top soil removal can be effective (Allison & Ausden, 2004), but disposal of the removed soil can be costly and archaeological remains can be damaged during removal. Acidification can effectively remove competitive mesotrophic
grasses but may be slow to modify fertility and has unknown consequence for soil biodiversity and function.

Given the paucity of knowledge on the direct effects of soil acidification on soil biodiversity we investigated how experimental acidification using two different measures, of high and low acidification potential, has affected soil biodiversity over a period of up to 17 years. The experimental measures were imposed on improved agricultural pasture land on the Isle of Purbeck in England, with a view to provide treatment options for agricultural reversion to traditional acid grassland and heathland systems. We report here on measurements made and experiments conducted between 2008 and 2017. Changes to the chemical environment for soil organisms and the abundance of key groups of biota were assessed as part of the RECARE project (http://www.recare-project.eu/). We tested the contribution made by differing components of the soil biota using biotic-size-partitioning litterbag experiments and examined changes in soil biology at a range of scales including key components of the macro and micro-biota and their respective activities. Other variables that may be affected by changes in soil biodiversity and function were also assessed including the effect on soil nutrient availability, mycorrhizas and plant community composition.

2.0 Materials and methods

2.1 Case Study area and monitoring sites

The study site is located on the Isle of Purbeck, not a true island but a peninsula of ~200 km² on the south coast of England. It lies in the County of Dorset where it forms part of the Dorset Area of Outstanding Natural Beauty. It has a mild temperate Atlantic climate with mean annual rainfall of around 777 mm.y⁻¹ and an average temperature of around 11°C.
Purbeck is a complex multifunctional, multi-land-use landscape with a range of competing pressures from arable farming, high and low intensity livestock grazing, touristic land use with quarrying and military areas all sharing the lands' ecosystem services.

The geology of the Isle of Purbeck comprise complex geological deposits, including Tertiary sand, Jurassic limestone and clay. Glacial drift over Mesozoic and Tertiary clay and loam constitute almost 60% of the study area. The study site is located near Wareham, Dorset, UK (2 040 W, 50 390 N) and directly abuts the neighbouring Hartland Moor National Nature Reserve and Middlebere Heath and includes two similar soil series. The predominant soil type is a Tertiary deep sand (Sollon Series, Association 641b; FAO Endogleyic Albic Carbic Podzols) which are generally stone free and naturally acidic. These are humose sandy soils with a bleached subsurface horizon typically affected by groundwater and comprise more than a quarter of the Purbeck Peninsula by land area (NSRI 2001). The other less common soil type present is similar (Isleham Series, Association 861a: FAO Arenic Mollic Gleysols) which are typically seasonally wet, deep sandy soils with a humose or peaty surface horizon. They have complex soil patterns with hummock and hollow micro-relief and can be at risk of winter flooding and wind erosion (NSRI, 2001) See supplemental material for further details.

2.2 Experimental design and treatments

Experimental plots were established in 1999 on National Trust land on the Isle of Purbeck to test the effects of pH management on soil and plant variables (Figure 1). The study area was established on agricultural pasture on to two adjoining farms (Newlines and Hartland Farms) owned by the National Trust. The farms were created during the 1950s and 1960s by the gradual improvement of the podzolic heathland soil through the addition of rock phosphate, manure and chalk marl. This increased the pH and nutrient levels of the soil sufficiently to allow the growth of mesotrophic grassland for cattle grazing (Tibbett and Diaz
Across this contiguous farmland, representative plots (50 m²) were selected to be amended with ferrous sulphate (FS) as Wet Copperas 50™ (19% Fe and 13% S) or elemental sulphur (ES) as Brimestone 90 (90% S), alongside a control plot (C) with no amendment added. Treatments were applied at a rate of 2,000 kg ha⁻¹ in May 2000 with an additional 1,600 kg ha⁻¹ applied the following year. In addition, two adjacent natural heathlands (Middlebere and Scotland) were used as reference sites for heathland (H) and acid grassland (AG). For a detailed site description, see Green et al., 2007 or Diaz et al., 2008.

2.3 Study overview

A number of studies took place at the field site between 2008 and 2017 that are reported on here. Chronologically, these are studies on decomposition in 2008-2009, soil microbiology in 2009, vegetation and soil chemistry in 2014, earthworm populations in 2016, and other soil fauna and mycorrhizal colonisation in 2017.

2.4 Soil sampling and chemical analysis (2014)

Soil samples were collected using a gouge auger in November 2014 from 0-5, 5-10 and 10-15 cm depths. Twenty-five soil samples were collected in a ‘W’ pattern and mixed into one composite sample per plot.

Composite soil samples were sieved to 2 mm, a subsample was stored at 4°C for microbial analysis and the remainder of the sample was air-dried for chemical analysis. Soil pH was measured by 2.5:1 water-soil slurry after shaking for 15 min at 120 rpm (Rowell 1994). Exchangeable Al³⁺, Ca²⁺, Mg²⁺, K⁺ and Mn²⁺ and extractable Fe were determined by 1M ammonium nitrate (NH₄NO₃) (Stuanes et al, 1984), in a 10:1 extractant to soil ratio. The final centrifuged supernatant was filtered and run with Agilent Technologies 5100 inductively
coupled plasma optical emission spectrometry (ICP-OES). Soil available P was extracted by a 0.1M H$_2$SO$_4$ solution (Sorensen & Bulow-Olsen 1994). The sample was centrifuged and the supernatant was analysed by flow injection analysis (FIA).

2.5 Vegetation assessment (2014)

In September 2014, Hartland and Newline Farms’ sward composition was assessed with a 1 x 1 m quadrat. In each 50m x 50m experimental plot 12 quadrats were recorded in sets of three randomly selected locations in each quarter in order to assess a representative sample population. Plants species were visually assessed and classified as the mean percentage cover of five functional groups: grasses, forbs, legumes, shrubs and heather.

2.6 Litter decomposition study (2008)

This experimental decomposition study was installed during August 2008 and assessed during August 2009. The aim of this study was to determine whether soil biological function, in terms of litter decomposition, had shifted from the unamended control plots towards the native heathland and acid grassland systems. In particular, we were interested to understand how different functional groups of soil organisms (based on biotic size) have been changed under acidification for nine years. Consequently, a subset of plots were selected from the full trial to represent four acidified heather-dominated elemental sulphur plots, four control plots and four native heathland and acid grassland plots. The criteria for selecting the elemental sulphur plots was having lowest soil pH and best heather establishment consistent with native heathland communities. The control, heathland and acid grassland plots were randomly selected.

Nylon litterbags of 9 cm × 8.5 cm with mesh sizes of 100 µm, 2 mm and 4.7 mm were obtained from a commercial supplier (Northern Mesh and Technical Fabrics, Oldham, UK).
The smallest mesh (100 µm) allowed only the soil micro-fauna and flora to access the litter, the medium mesh (2 mm) included the meso-fauna, and the largest mesh size (4.7 mm) also permitted the macro-fauna to access the litter (Bradford et al. 2002). Thus, this method provides an insight into the contribution made by differing components of the soil biota. Each litter bag was filled with 0.9-1.1 g of barley straw and sealed. Six replicates of each mesh size were inserted into the soil of each plot at a depth of 3-5 cm in 2008. Litter bags were retrieved one year later. The litter remaining in each bag was carefully washed to removed adhered soils and roots, dried at 30°C and then re-weighed to determine percent mass loss.

2.7 Soil microbiology and activity (2009)

Sampling from the same plots used for the litter bag study, plots were sampled for microbiological and chemical analysis in June 2009. Twenty-five soil samples (0-15 cm) were taken in a ‘W’ pattern over each plot before being bulked. Samples were briefly stored at 4°C prior to microbial analysis. Remaining soil samples were then air-dried for chemical analysis.

The number of colony forming units (CFUs) of bacteria, Actinomycete and fungi were determined by a selective viable count procedure. Microorganisms were extracted from 0.2 g of fresh soil by shaking in 20 ml of sterile H₂O for 10 minutes. Extracts were serially diluted and plated onto selective media. Selective media for bacterial and Actinomycete cultures were prepared according to Yang & Yang (2001). Fungi were cultured on rose Bengal chloramphenicol agar (Oxoid Ltd, Basingstoke, UK). Microorganisms were cultured at 25 °C for 6 days before the number of colonies were counted. Determinations were repeated four times for each plot and results expressed as CFU g⁻¹ air dried soil.
Soil microbial activity was determined through the hydrolysis of fluorescein diacetate (FDA) to fluorescein using the method described by Adam & Duncan (2001). Briefly, 2 g of fresh soil was added to a flask containing 15 ml of 60 mM potassium phosphate buffer (pH 7.6) and 0.2 ml of 1000 µg ml⁻¹ FDA was added. Flasks were incubated at 30 °C in a shaker/incubator for 20 min. Following incubation, hydrolysis of FDA was stopped by the addition of 15 ml chloroform/methanol (2:1 V/V). Samples were then centrifuged and filtered to remove soil particles prior to fluorescein release being quantified by measuring absorbance at 490 nm (Varian Cary 50 spectrophotometer). Two blanks were analysed for each soil sample as previously described, but with the omission of FDA solution. Absorbance of the blanks was removed from the samples to control for humic substances remaining after centrifugation/filtering. Results were then calculated as µg fluorescein released g⁻¹ soil h⁻¹.

Cognate soil chemical properties were measured including pH (1:2.5 soil:water), soil water, total C and N (Thermo Fisher Flash EA 1112) and organic matter (loss on ignition at 450°C). Available Al, Ca, Mg and P were determined by ICP-OES (Varain Vista Pro) after extraction by 0.01 M CaCl2 (Houba et al., 1996).

2.8 Earthworm sampling (2016)

Samples were collected in November 2016. For each plot, a cube of soil was removed from a 20 cm³ area using a flat shovel and placed in trays in the field for hand sorting. Worms were carefully removed, counted and placed in a subsample of soil to be transported back to the lab for characterisation. Specimens were rinsed, blotted dry and weighed individually and recorded as juvenile or adult.

2.9 Mycorrhiza sampling (2017)
279 A r ��ar myco r ��z ��i �� ion �� grass ��t ��s:
280 279 R ��t ��w ��sampl �� f �� ro m H ��l ��ati �� i ��l ��r i ��n�t ��ots.  R ��t 281 sampl ��s w ��w ash t h ��g ��y,  f �� ro m �� ��  l ��g t h w e ��r ��ml y su b - 282 sampl ��.  S ��-sampl ��s w ��r i ��K OH sol �� ��( ��w / v )  at ��t �� 283 ��si ��5 ��( v / v )  back i n ��g ar sol ��ti �� f ��u r ��f o r ��b �� w ash �� d 284 tr ��s f ��r ��sol �� o f  l ��g l y cerol �� Wa l k ��,  ��) .  C ��i ��i ��w as 285 scored �� t �� li �� i ��cept ��meth ��t t �� ���� o f  e ��t ��r ��,  �����or ves i 286 cul ��w as 287 288 c ��r ��c ��nce  o f  my ���z �� col ��i ��i ��w as 289 289 290 2.10 Nematode, Rotifer and Tardigrade Sampling (2017) 294 295 296 297 298 299 300 301 302 303 304 305 2.11 Statistical analysis
Statistical analyses were performed with the STATISTICA data analysis software system StatSoft, Inc., version 12, unless otherwise stated. Variables were preliminary checked in order to clarify if variables fulfilled the ANOVA assumptions of independency, normality and homogeneity of variance. The sample size in the control, ferrous sulphate and elemental sulphur plots was N=10 while in acid grassland and heathland plots it was N=4. Variables were checked for normality with the normal probability plot of the residuals and the Shapiro-Wilk W test for normality. Homogeneity of variance was analysed, in order to check if the variances in the different groups were equal, with the Levene and Barlett tests.

When independence, normality and homogeneity of variance were found a parametric one-way ANOVA was performed. For variables where there was no independence due to unequal sample size a parametric unbalanced one-way ANOVA mixed-model was performed. When the principle of normality and/or homogeneity of variance were not met, a Box-Cox transformation was performed to achieve normality and homogeneity of variances, followed by a parametric one-way ANOVA. For variables where the assumptions for normality and/or homogeneity of variance were not met after the Box-Cox transformation, a non-parametric Kruskal-Wallis ANOVA by ranks test was performed.

2.11.1a Plant data

Acidification treatment effects were analysed in vegetation data for grasses, legumes and forbs variables with the parametric balanced one-way ANOVA mixed model (P < 0.05), where Farm was selected as the random effect and Treatment was selected as the fixed effect, and sample size was balanced, N=10. F and P values were registered and a Fisher’s LSD post-hoc test (P < 0.05) was performed afterwards when significant differences were found among treatments. Heather and shrubs variables were analysed with the non-
parametric Kruskal-Wallis ANOVA by ranks test ($P < 0.05$). $H$ and $P$ values were registered and a Bonferroni post-hoc test ($P < 0.05$) was performed afterwards when significant differences were found among treatments. Univariate analysis was performed for vegetation with Microsoft® Office Excel 2010.

2.11.1b Soil data

Treatment effect was analysed for the soil chemical properties, where Farm was selected as the random effect and Treatment was selected as the fixed effect, and the sample size was unbalanced, N=4 and N=10. $F$ and $P$ values were registered and a Fisher´s LSD post-hoc test ($P < 0.05$) was performed after when significant differences were found among treatments.

Depth effect was analysed for the soil chemical properties for the control, ferrous sulphate and elemental sulphur plots with the unbalanced one-way ANOVA mixed model ($P < 0.05$), where Farm was selected as the random effect and Depth was selected as the fixed effect, and the sample size was balanced, N=10. Data obtained from acid grassland and heathland plots was analysed with a parametric one-way ANOVA, with no Farm effect and equal sample size, N=4. $F$ and $P$ values were registered and a Fisher´s LSD post-hoc test ($P < 0.05$) was performed afterwards when significant differences were found among depths.

Principal component analysis (PCA) was performed on both vegetation and soil chemical data with STATISTICA data analysis software system StatSoft, Inc., version 12. The soil chemical PCA was, in turn, used in the creation of a Heathland Restoration Index (see below).

2.11.1c Heathland Restoration Index (HRI)
A Heathland Restoration Index (HRI) was generated for each treatment using a similar technique to the Soil Quality Index (SQI) outlined by Andrews et al. (2002) and Romaniuk et al. (2011). Briefly this involves the use of PCA to generate a minimum data set of indicators (MDS) for the HRI, these MDS indicators are then used in a linear scoring model to generate an HRI. Each variable was initially subjected to Kruskal-Wallis one-way ANOVA on ranks. Only variables that showed statistically significant differences between treatments at \( p < 0.05 \) were then further analysed by PCA. Principal components (PCs) with eigen values >1 were included in the generation of the MDS. Within each of these PCs the highly weighted factors were retained for the MDS. These are defined as the variable with the highest absolute eigen vector, and any other within 10\% of the highest factor loading. When there were two or more variables retained from a single PC, a correlation coefficient was conducted, to ensure one does not influence the other. If they were found to be correlated \( (r^2 > 0.70) \), only the variable with the highest eigen vector was retained for the MDS, if they were not correlated both of them were retained for the MDS. Each indicator selected for the MDS was then transformed using a linear scoring method. For “less is better” indicators (native heathland soils were lower than the control plots) the lowest observed value, that was not an outlier, was divided by each observation (e.g. the lowest observed value received a score of 1) and for “more is better” indicators (native heathland soils were higher than control plots), each observation was divided by the highest observed value, that was not an outlier (e.g. the highest observed value received a score of 1).

Once scored, the indicators were weighted by the PCA Table as follows:

\[
Weighted\; factor = \frac{\%\; of\; the\; variation\; with\; respect\; to\; the\; total\; data\; set\; of\; PC\; variable\; selected\;}{cumulative\; \%\; of\; the\; variation\; of\; all\; PCs\; with\; eigen\; vectors\; > 1}
\]

Finally, the scored indicators were used to calculate the HRI as follows:

\[
HRI = \sum_{i=1}^{n} W_i S_i
\]
Where $S$ is the score of the indicator variable, and $W$ the weighted factor derived from the PCA. Higher index scores were assumed to give the soil conditions closest to native heathland.

2.11.2 Mycorrhizal and faunal analysis

Data sets were analysed for compliance with the assumptions of homogeneity of error variance using Levene’s test. When assumptions were not met, one-way ANOVA was conducted using Welch’s F ratio. The significance of differences between the means of each treatment were assessed using Tukey’s HSD post hoc test. Correlations between variables were evaluated using Pearson’s product moment correlation.

3.0 Results

3.1 Soil chemistry (2014)

Of the two measures tested, only elemental sulphur was successful in decreasing the pH below the control plots in all three depths. This acidification in the elemental sulphur plots was sufficient to result in a statistically similar pH to native acid grassland at all depths, and native heathland at 5-10 and 10-15 cm.

PCA for the HRI revealed that the chemical characteristics with the highest factor loadings, aside from pH, included available Al, P and Fe (see supplementary material) so assessment here will largely focus on these three elements. These characteristics, in turn, were used as the MDS during the calculation of the HRI (see below).

3.1.1 Available Al
Showing similar trends to pH, the same significant difference was found for $\text{Al}^{3+}$ concentrations between elemental sulphur and control plots, where the elemental sulphur application elevated $\text{Al}^{3+}$ concentrations to reach concentrations similar to heathland plots at the two lower depths (Table 1).

3.1.2 Available $P$

Surface $P$ concentrations, although elevated in the control plots, were not statistically different when compared to the acid grassland and heathland sites. Application of the two sulphur treatments, however, resulted in a significant increase in available $P$ at all three depths, when compared to the native heathland site (Table 1).

3.1.3 Available $Fe$

Surface (0-5 cm) $Fe$ concentrations were significantly lower in the control plots, compared to both measures, at all depths. Although this difference was not observed in the ferrous sulphate at lower depths. In addition while elemental sulphur plots were not significantly different to heathland plots. However, at the two lower depths control and native heathland plots were not significantly different. The elemental sulphur treatment, at all depths, resulted in $Fe$ concentrations statistically similar to those observed in the acid grassland and heathland sites (Table 1).

3.1.4 Basic cations

Concentrations of $Ca$ in the elemental sulphur treated plots were sufficiently reduced from the controls to match concentrations seen in native heathland and acid grassland (Table 1). Application of the ferrous sulphate, however, was unable to achieve this. Elemental sulphur treated plots did not present a reduction of $Ca$ with depth in contrast to the native heathland sites.
Concentrations of Mg were elevated in the native heathland, when compared to all other treatments. Application of the two sulphurous amendments was not able to increase concentrations of Mg from the controls to match those seen in the native heathland. In fact, application of elemental sulphur showed a reduction in Mg when compared to application of ferrous sulphate.

Surface K concentrations also did not vary significantly between the control, elemental sulphur and ferrous sulphate plots all being significantly reduced when compared to native heathland.

3.1.5 C and N

Total C, and the resultant C:N ratio, was elevated in the native heathland when compared to all other plots. Application of either elemental sulphur or ferrous sulphate did not influence the concentration of C or N when compared to control plots.

3.1.6 Heathland Restoration Index (HRI)

Only one of the measures (elemental sulphur application) resulted in an HRI elevated above the control plots (Figure 2). The elemental sulphur treatment was elevated to such a level to be comparable with the native heathland sites in terms of HRI based on soil chemistry.

3.2 Vegetation (2014 assessment)

Grasses were dominant in all treatments with around 60% of coverage, while heather and shrubs species were only registered in elemental sulphur plots, with 8% and 2% coverage respectively (see Figure 3). However, these generic analysis conceal a wide range of vegetation responses with some plots having successfully reverted to heather domination (Plate 1).
Mean percentage coverage of grasses ($P=0.551, F=0.61$), heather ($P=0.167, H=3.58$) and shrubs ($P=0.003, H=12.01$ but post-hoc test $P=0.054$ between elemental sulphur and ferrous sulphate plots) were not quite significantly different among treatments at the $P<0.05$ level.

A significant difference among treatments was only found in legumes ($P=0.017, F=4.89$) and forbs ($P=0.016, F=4.93$) communities. Control and ferrous sulphate plots, with 25% coverage by legumes, were found to be significantly different to elemental sulphur plots, where legumes covered only 7% of the surface. In comparison, forbs communities were significantly different between control and elemental sulphur plots, in this case, with the highest 23% of forbs coverage registered in the elemental sulphur plots.

Two important clusters were differentiated in the PCA ordination representing different vegetation communities (Figure 4). The first group was formed by control and ferrous sulphate plots, both plots characterised by high percentages of grasses and legumes species coverage. The second cluster was formed by the elemental sulphur plots, where forbs, heather and shrub species were more dominant.

### 3.3 Soil microbiology, activity and litter decomposition (2009)

Nine years after application, elemental sulphur application still depressed soil pH compared to the control plots and pH levels in the plots restored using elemental sulphur showed a soil pH indistinguishable from that of the native heathland plots. However, whilst soil organic matter, total C, total N and the C:N ratio were significantly different amongst the sites, values for the elemental sulphur plots remained very close to those of the controls. Indeed, moisture and total N levels in elemental sulphur treated plots were ~50% lower than native heathland, whilst organic matter levels and total carbon were ~ 70% lower (see supplementary material Table 1).
Microbial parameters for the soils showed significant differences amongst the sites (Figure 5). The numbers of bacterial CFUs were significantly higher in the control plots \( (F(3,12) = 35, P < 0.001) \), whilst CFUs for the sulphur treated plots were indistinguishable from the heathland sites. The number of fungal CFUs also differed significantly \( (F(3,12) = 5.1, P = 0.017) \), but in this instance, fungal CFUs were higher in the soils from native heathland.

Again, levels of fungal CFUs were indistinguishable between elemental sulphur treated and native heathland plots. The low count of Actinomycete CFUs showed a similar pattern to those of fungi, but differences were not significant \( (F(3,12) = 1.74, P = 0.21) \). The level of microbial activity in the soil as measured by the amount of fluorescein released from FDA, was significantly higher in the control plots \( (F(3,12) = 8.9, P = 0.002) \). Once again, the elemental sulphur and heathland plots did not differ significantly from each other in this parameter.

Microbial activity in the soil was very strongly and negatively correlated with fungal abundance and to a lesser extent, Actinomycete abundance. A very strong positive correlation was found between microbial activity and bacterial abundance. The relationship between fungal and bacterial abundance showed a very strong negative correlation with each other. Bacterial abundance in the soil was also very strongly correlated with soil pH (Table 2) and exhibited negative correlations with the C:N ration and total C content of the soil. Actinomycete abundance showed no significant correlations with the soil parameters measured, reflecting a lack of significant difference in abundance across the sites. Fungal abundance showed a strong negative correlation with soil pH, but was uncorrelated with other soil parameters.

The extent of litter mass loss resulting from only microbial decomposition (i.e. in the small mesh size litterbags) was significantly different amongst the sites \( (F(3,12) = 9.4, P = 0.002) \). The highest level of decomposition occurred in the soil of the control pasture.
plots, whilst decomposition in the restored (elemental sulphur) and native heaths sites was significantly lower and did not differ significantly amongst them. The addition of meso-fauna to the decompositional process (medium sized mesh) had little overall effect on overall mass loss from the litter, but resulted in a noticeable change in the pattern of litter mass loss amongst the sites. Significant differences remained overall \( F_{(3,12)} = 3.54, P = 0.048 \), but a clear difference was only found between the control (pasture) and Middlebere heath. The sulphur treated plots and Scotland heath did not show a significance difference from either the control plots or the Middlebere heath. When the macro-fauna had access to the litter (large mesh size) differences in mass loss amongst the sites were not significant, indicating equal decomposition of litter \( F_{(3,12)} = 1.45, P = 0.28 \).

Mass loss from the litter bags with a small mesh size was strongly correlated with the microbiology of the soil (Table 3). Mass loss was most strongly correlated with bacterial abundance. The microbial activity in the soil as measured by the release of fluorescein from FDA also showed a strong positive correlation. By contrast, fungal abundance exhibited a strong negative correlation with litter mass loss. Mass loss from the litter in bags with the medium mesh indicated that the abundance of the soil microbial community made a weaker contribution to litter decomposition. Mass loss was still strongly correlated with bacterial abundance, but the strength of the relationship was reduced. Fungal abundance continued to have strong negative relationship to mass loss, although this was marginally weaker. Microbial activity (fluorescein released) showed some correlation with mass loss, but this was not significant. Increasing the mesh size further decreased the importance of the abundance of the microbial community to litter decomposition, with mass loss from large mesh size bags showing no significant correlations with the microbial properties of the soil.

### 3.4 Earthworm sampling (2016)
Earthworm abundance was lowest in the heathland and elemental sulphur plots (Figure 7). There were no adult earthworms present in the 20cm x 20cm x 20cm soil cubes that were surveyed in any of the four heathland plots. In the elemental sulphur plots the adult earthworm accounted for more biomass than the juveniles, whereas in the control, ferrous sulphate treatment and acid grassland the juvenile biomass accounted for a larger proportion.

3.5 Ericoid and arbuscular mycorrhizal colonisation

Mean ericoid mycorrhizal colonisation was not significantly different in the heathland (66.81%; n = 7), acid grassland (77.33%; n = 8), or the elemental sulphur (69.74%; n = 3) plots. There was no significant difference in arbuscular mycorrhizal colonisation of *H. lanatus* roots between in any treatments (data not shown) and mean colonisation was relatively high (ca.70%) throughout. A closer examination of the data showed that in the pasture plots where heather plants (*C. vulgaris* or *Erica* spp.) were established, due to successful restoration, the level of AM colonisation was significantly lower than in plots where heath plants were absent (Figure 8).

3.6 Nematode, Rotifer and Tardigrade Sampling (2017)

The abundance of nematodes was significantly higher in the control plots than the elemental sulphur and acid grassland plots (Figure 9). The application of elemental sulphur resulted in significantly lower number of nematodes than the control plots, with the treatment effect persisting for 17 years post-application. The number of nematodes in the ferrous sulphate plots were not significantly different from any of the other plots. The mean number of rotifers present in 100 g of soil was less than 9 individuals, with no significant effect of
treatments compared to the control. Tardigrades were absent in the vast majority of samples.

4.0 Discussion

4.1 Long-term changes in soil chemistry

Soil pH in our experimental plots have previously been shown to respond to sulphur treatment, particularly for elemental sulphur treatment six years after application (Diaz et al. 2008). The elemental sulphur treatment remained effective 9, 14, 16 and 17 years after application. This demonstrates the longer-term effectiveness of sulphur treatment that may be sustained if heather plants establish and provide acidic litterfall into the soil-plant system.

Previous analysis of soils from our field sites have considered only superficial (0-4 cm) effects soon after application (Tibbett & Diaz 2005) or 15 cm depths in 2006 (Diaz et al. 2008). Here (2014 sampling) we have considered the soil increments in our experimental plots and the adjacent acid grassland and heathland in 5 cm increments to 15 cm. The acid grassland plots have a pH ca.5 regardless of depth while the heathland plots are far more acidic with a distinct and significant change with depth, pH 3.9 at the surficial increment and pH 4.7 at the deeper increment, in contrast to previous studies where little difference with depth was reported (Pywell and Webb, 1994). For heathlands, this strongly supports the tenet that acidic litterfall from *Calluna* and *Erica* species supply acidifying litter into the soil. After 14 years the elemental sulphur treated plots were not significantly different to the acid grassland or heathland except for the upper layer of the heathland soil which remains significantly lower.

The removal of basic cations from the original pasture soils is a significant step towards the recreation of acidic systems and $Ca^{2+}$ in the elemental sulphur plots is particular closely
matched to the acid grassland and heathland soils in addition to being significantly different from the ferrous sulphate and control plots. In contrast the available P in the soil increased under sulphur treatments. This may be due to acidification causing a release of P from historical rock phosphate amendments (see Tibbett and Diaz 2005). Notably, however, ferrous sulphate application has increased available phosphate not only soon after application (Tibbett & Diaz 2005) but also after 14 year in this experiment. The mechanism behind this response is unknown.

The significant difference in available aluminium, likely present as Al$^{3+}$, is a key driver in plant community change in heathland (De Graff et al 1997) and most likely to affect soil biodiversity. The parity of Al concentrations in elemental sulphur plots compared with our reference heathland sites and the significant differences to control and ferrous sulphate plots after 14 years indicates a clear toxicity driver caused by soil pH change after sulphur application.

While some available elements concentrations described above can change due to acidification, the total N and C levels remain the same. There was no effect of treatment after 14 years but there was a large and important difference in % of total C in heathland soils, which were over 10% C compared with a little over 4% in all other soils, including the acid grassland. This difference represents centuries of OM accumulation in the system where acid litters produce a recalcitrant organic layer (mor) not likely to be replicated for many decades under restoration programmes. This may be all the more problematic where soil striping and soil inversion has been employed.

Overall, application of elemental sulphur has influenced soil pH and chemistry to such a degree that soil conditions, as described by the Heathland Restoration Index, is comparable to those in the native heathland and acid grassland sites. The application of ferrous sulphate was unable to achieve these conditions. The index shows notable parity in soil conditions for
HRI and therefore it is likely that application of elemental sulphur will have a greater influence of vegetation assemblage and soil biodiversity indictors on the experimental plots, when compared to the ferrous sulphate and control plots.

### 4.2 Long-term changes to vegetation community

The shifts in plant community assembly in 2006 reported previously (Diaz et al. 2008) are essentially retained in our survey in 2014, 14 years after treatment applications ceased. The elemental sulphur treatment had a had long-term impact on the plant community structure with forbs and heather species separating the community from the control and ferrous sulphate treatments. There was a mixed retention of heathland vegetation communities that were well established in 2006, which were anecdotally related to grazing management and access of cattle to the plots.

Control and ferrous sulphate plots had no records of heather species despite the application of *C. vulgaris* clippings from the adjacent Middlebere Heath that were sown in 2001 and 2003 across all plots. The lack of regeneration of *C. vulgaris* in these plots is probably due to the retention of nutrient-rich competitive species (Lawson et al. 2004) due to the high fertility levels still found in these soils (Helsper et al 1983).

### 4.3 Changes in soil microbiology and litter decomposition

Different components of the soil microbial community are known to be strongly related to pH. Soil bacteria populations are favoured at higher soil pH where fungi are generally more dominant in acidic conditions (Rousk et al 2010). In this part of the work we were interested to test the microbiology of the best four restored elemental sulphur amended plots against their target heathland soils, and the control soils. The number of CFUs for bacteria and fungi
respectively almost directly mirrored each other. There were significantly more than double the CFUs for bacteria in the control plots with the higher pH profiles than the elemental sulphur and heathland plots. For fungal CFUs these were the reverse, with significantly fewer than half the CFUs in the control plots than the more acidic elemental sulphur and heathland plots. Indeed bacterial CFUs were strongly positively correlated with pH and fungal CFUs were negatively correlated with pH. For the control (improved pasture) plots versus the heathlands these results are quite characteristic of the systems and it is an important part of the reversion of the whole plant-soil systems that the microbiology of the elemental sulphur plots is in close parity with the target heathland systems. Whether the plant community change led to the change in the microbiota or the soil microbiology facilitated this change is an outstanding question for restoration ecologists (Harris 2009) although van der Bij et al (2018) have recently provided evidence that the latter may apply.

The function of the soil microbial community also appeared to have been largely restored, at least in terms of litter breakdown and microbial activity. Microbial activity was positively correlated with bacterial abundance and negatively correlated with fungal abundance. Mass loss in the litter bags with small mesh size (allowing only microbes access to the litter) showed significant correlation to the bacterial abundance in the soil and microbial activity. Thus, soil acidification mediated by elemental sulphur application suppressed bacterial abundance, microbial activity and reduced microbial decomposition of litter. These were all characteristics of the soil of the native heath.

The reduction in litter decomposition rate could potentially increase soil OM over a longer period, a parameter that was significantly different in restored heath compared to native heath. This could be facilitated by increased fungal numbers and low bacterial abundance, contributing to typical O horizon of mor humus podzolic soil that develops from litter decomposition dominated by fungi. The successful re-establishment of ericaceoaus dwarf shrubs on the heath should support this process and the N poor, acidic and polyphenolic
The litter of these plants is also a requirement of mor humus formation. However, the present
study demonstrated that barley straw decomposition was not significantly different amongst
the site when the soil meso and macro fauna had access to the litter. *Calluna* litter will
behave differently to barley straw and there was significantly greater SOM in the soil from
heaths, despite the same level of decomposition as the controls. Moreover, litter loss from
bags with larger mesh sizes does not equal organic matter loss from the soil, i.e.
meso/macrofauna feeding activity may shred the litter leading to loss from the bag and
eaten litter may be exported from the litterbag in the animals, but not necessarily from soil.
Observational evidence suggests that *Calluna* litter is building up on the soil surface, but it
remains to be seen if this will reduce available N levels. Overall, the reduced microbial
decomposition shows the importance of microbes in the functioning of the soil’s ecology
which is most sensitive under acidification.

**4.4 Changes in Mycorrhizal colonisation**

Arbuscular mycorrhizal (AM) colonisation can be strongly affected by soil pH. Acidic
conditions can not only suppress the beneficial effect of AM but also suppress the uptake of P
even when freely available (Graw 1979). In our field site P availability in soil was enhanced
under acidification almost certainly due to dissolution of antecedent rock phosphate
application (Tibbett & Diaz 2005). The reduced colonisation of AM in *H. lanatus* roots where
heather is present is therefore not surprising, although mean colonisation levels remain high
in almost all samples, regardless of treatment of heather presence. It should be noted that
aspects of the ecology of mycorrhizas at this site such as their community composition and
spatial structuring remain to be elucidated (Prober et al 2014).

The potential importance of ericoid mycorrhizas (ERM) in heathland restoration is commonly
acknowledged but rarely investigated (e.g. van der Bij et al 2018). In our previous work we
showed that juvenile heather plants (2-4 years after establishment) in the elemental sulphur treated plots were mainly uncolonised by ERM, and when they were colonised the rates were ca.10-20% of the root length. In contrast we found that heather plants in the native heaths and acid grassland were nearly all colonised at levels exceeding 70% (statistically different). Here we report very different findings 13-15 years after heather sowing. All plants examined in the elemental sulphur treated plots were colonised with a mean of 70% of root length which was no longer significantly different to that found in the heathland and acid grassland plants. This demonstrates clearly that given sufficient time, perhaps a decade or more, a natural population of ERM can support a heather-based plant community. This is an important step toward ecosystem restoration in terms of plant-soil interaction that has not previously been reported.

4.5 Changes in soil fauna

Monitoring changes to groups of soil organisms can provide an important indication of the effects of soil acidification. In this study, the artificial acidification caused by sulphurous amendments resulted in a reduction in nematode abundance and earthworm biomass. Although a significant reduction was only seen in the elemental sulphur treatment for the abundance of nematodes, the trend was similar for the rotifers and earthworms. Acidification of the soil can increase H⁺, Al³⁺ and NH₄⁺ ions, resulting in toxic effects on plants and soil organisms (Kuperman and Edwards 1997). In a two year study on soil acidification, Chen et al. (2013) reported a larger effect on the nematode and microbial communities than the above-ground plant communities. However, monitoring changes over a longer time frame may result in the changes to soil biodiversity and soil chemistry having a feedback on the plant communities. In our long-term study comparing artificial acidification to semi-natural heathland and acid grassland, it is interesting to note the
elemental sulphur plots had lower abundances of the measured soil fauna than the acid grassland, despite having similar pH values. The disturbance caused by the application of elemental sulphur on other soil chemical properties and plant communities may have been a driving factor in the inability of the system to recover even after 17 years. Lavelle et al. (1995) reported that soil fauna have a limited capability to adjust to soil pH, resulting in soil acidification having a negative effect on soil biodiversity. At a soil pH of <4, earthworms and Coleoptera were reduced compared to pH 4-5, while termites actually showed an increase in the number of individual at pH <4-5 but above pH 5 there was a large reduction (Lavelle et al. 1995). Although the abundance and biomass of organisms does not give detailed information on the functions or diversity of the system, it does support other studies that have found a reduction in soil fauna abundance and diversity under land-use intensification (Tsiafouli et al. 2015).

5.0 Conclusions

Elemental sulphur treatment has proven to be an effective method of acidifying the soil in improved pasture systems. The soil chemistry and its HRI show a shift of sites subject to sulphur treatment strongly in the direction of the heathland soils. The ecology and biodiversity of the acidified sites has changed considerably with different ecologies developed above and belowground. The shift in soil biological communities such as the microbiology, nematodes, earthworms and mycorrhizas, along with functional changes in litter decomposition, demonstrate the profound effects the acidification has had on biological form and function. Elemental sulphur is clearly a useful restoration tool for acid grasslands and heathlands, although further work is need on application rates and timing as well as integration with grazing management.
Acknowledgements

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References


Griffith, R. I., Thomson, B. C., P., B., Bl, T., Bl, M. & Wete, A. S. 10.6 log g of B r i t i e n l Environ Mi e My, 1-1654.

Harris, J. 2009. Soil microbial communities and restoration ecology: facilitators or followers? *Science.* 325. 573-574


Table 1 The effects of sulphurous amendments on soil chemical properties Mean (SE). Means with different lowercase letters (a, b, c, d) represent a significant difference between treatments (within the same depth). Means with different uppercase letters (A, B, C) represent a significant difference among depths (within the same treatment). Omission of uppercase letters meaning no significant difference between depths.

<table>
<thead>
<tr>
<th>Soil properties</th>
<th>Depth (cm)</th>
<th>Treatment</th>
<th>Control</th>
<th>Ferrous Sulphate</th>
<th>Elemental Sulphur</th>
<th>Acid Grassland</th>
<th>Heathland</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>0-5</td>
<td>5.6 (0.1)a</td>
<td>5.5 (0.1)ab</td>
<td>5.1 (0.2)c</td>
<td>5.1 (0.1)bc</td>
<td>3.9 (0.1)dA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5-10</td>
<td>5.5 (0.1)a</td>
<td>5.4 (0.1)a</td>
<td>4.7 (0.2)b</td>
<td>5.0 (0.2)ab</td>
<td>4.3 (0.2)bAB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-15</td>
<td>5.5 (0.1)a</td>
<td>5.5 (0.1)a</td>
<td>4.8 (0.2)b</td>
<td>5.1 (&lt;0.1)ab</td>
<td>4.7 (0.1)bB</td>
<td></td>
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<tr>
<td>Al&lt;sup&gt;3+&lt;/sup&gt;(mmol (+) kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>0-5</td>
<td>0.4 (0.1)a</td>
<td>0.4 (0.1)a</td>
<td>1.9 (1.0)b</td>
<td>1.0 (0.3)abc</td>
<td>5.6 (0.8)c</td>
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<tr>
<td></td>
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<td>0.4 (0.1)a</td>
<td>3.0 (1.0)b</td>
<td>1.0 (0.4)ab</td>
<td>3.8 (0.9)b</td>
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<td>1.1 (0.7)a</td>
<td>0.3 (0.1)a</td>
<td>3.6 (0.9)b</td>
<td>1.2 (0.5)ab</td>
<td>3.7 (0.8)b</td>
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<td>P (mg kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
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<td>8.9 (2.0)ab</td>
<td>30.7 (8.5)c</td>
<td>14.0 (2.8)ac</td>
<td>6.6 (1.6)abc</td>
<td>3.3 (0.8)bA</td>
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<td>23.4 (6.5)c</td>
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<td>19.6 (6.2)a</td>
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<td>2.0 (0.2)abB</td>
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<tr>
<td>Ca&lt;sup&gt;2+&lt;/sup&gt;(mmol (+) kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
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<td>63.3 (4.9)a</td>
<td>65.6 (9.7)a</td>
<td>32.5 (6.3)b</td>
<td>31.1 (7.8)ab</td>
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<td>63.9 (6.8)A</td>
<td>31.1 (6.1)b</td>
<td>30.1 (5.8)ab</td>
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<td>56.0 (4.4)A</td>
<td>62.0 (3.6)A</td>
<td>34.8 (6.4)B</td>
<td>25.0 (3.5)ab</td>
<td>9.5 (2.9)B</td>
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<td>8.2 (0.6)A</td>
<td>6.0 (0.6)B</td>
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<td>15.4 (2.7)cB</td>
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<td>5.8 (0.4)A</td>
<td>4.7 (0.5)a</td>
<td>7.9 (0.5)abB</td>
<td>10.6 (1.6)B</td>
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<td>1.2 (&lt;0.1)b</td>
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<td>1.1 (0.1)A</td>
<td>0.9 (0.1)A</td>
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<td>2.7 (0.3)B</td>
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<td>0.3 (0.1)A</td>
<td>0.4 (0.1)A</td>
<td>0.5 (0.1)A</td>
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<td>0.1 (&lt;0.1)A</td>
<td>0.3 (0.1)A</td>
<td>0.2 (0.1)A</td>
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<td>4.1 (1.0)b</td>
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<td>Mn&lt;sup&gt;2+&lt;/sup&gt;(mmol (+) kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
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<td>0.13 (0.02)A</td>
<td>0.10 (0.01)A</td>
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<td>0.05 (&lt;0.01)A</td>
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<tr>
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<td>0.06 (0.01)B</td>
<td>0.04 (0.01)A</td>
<td>0.02 (&lt;0.01)B</td>
<td>0.01 (&lt;0.01)A</td>
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<td>0.05 (0.01)B</td>
<td>0.05 (0.01)A</td>
<td>0.01 (&lt;0.01)B</td>
<td>0.01 (&lt;0.01)B</td>
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<tr>
<td>Total C (%)</td>
<td>0-5</td>
<td>4.1 (0.3)a</td>
<td>4.4 (0.4)a</td>
<td>4.0 (0.3)a</td>
<td>4.2 (0.5)a</td>
<td>10.1 (2.0)b</td>
<td></td>
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<tr>
<td>Total N (%)</td>
<td>0-5</td>
<td>0.3 (&lt;0.1)a</td>
<td>0.3 (&lt;0.1)a</td>
<td>0.2 (&lt;0.1)a</td>
<td>0.2 (&lt;0.1)a</td>
<td>0.3 (0.1)a</td>
<td></td>
</tr>
<tr>
<td>C:N</td>
<td>0-5</td>
<td>16.1 (0.7)ab</td>
<td>15.8 (1.6)ab</td>
<td>19.0 (1.9)B</td>
<td>18.3 (0.7)ab</td>
<td>30.3 (1.1)c</td>
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</tbody>
</table>
**Table 2** Correlations coefficients between the number of CFU (g⁻¹ soil) of soil microbes and selected parameters of the soil (n=16).

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>Moisture (%)</th>
<th>OM (%)</th>
<th>Al (mg kg⁻¹)</th>
<th>Total C (g kg⁻¹)</th>
<th>Total N (g kg⁻¹)</th>
<th>C:N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacterial CFUs</td>
<td>0.78***</td>
<td>-0.26</td>
<td>-0.46</td>
<td>-0.47</td>
<td>-0.54*</td>
<td>-0.44</td>
<td>-0.62*</td>
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<tr>
<td>Actinomycete CFUs</td>
<td>-0.23</td>
<td>0.25</td>
<td>0.33</td>
<td>0.08</td>
<td>0.32</td>
<td>0.25</td>
<td>0.33</td>
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<tr>
<td>Fungal CFUs</td>
<td>-0.57*</td>
<td>0.12</td>
<td>0.35</td>
<td>0.09</td>
<td>0.33</td>
<td>0.28</td>
<td>0.32</td>
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</tbody>
</table>
Table 3 Correlations coefficients between mass lost from litter bags with three different mesh sizes and the abundance of microbial groups (CFUs g\(^{-1}\) soil) and microbial activity (µg fluorescein released g\(^{-1}\) soil h\(^{-1}\); n=16).

<table>
<thead>
<tr>
<th></th>
<th>Bacterial CFUs</th>
<th>Actinomycete CFUs</th>
<th>Fungal CFUs</th>
<th>Microbial activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small mesh</td>
<td>0.73**</td>
<td>-0.48</td>
<td>-0.64**</td>
<td>0.61*</td>
</tr>
<tr>
<td>Medium mesh</td>
<td>0.63**</td>
<td>-0.30</td>
<td>-0.61*</td>
<td>0.48</td>
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<tr>
<td>Large mesh</td>
<td>0.27</td>
<td>-0.50</td>
<td>-0.29</td>
<td>0.24</td>
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<tr>
<td>Bacterial CFUs</td>
<td>-</td>
<td>-0.41</td>
<td>-0.65**</td>
<td>0.68**</td>
</tr>
<tr>
<td>Actinomycete CFUs</td>
<td>-0.41</td>
<td>-</td>
<td>0.63**</td>
<td>-0.66**</td>
</tr>
<tr>
<td>Fungal CFUs</td>
<td>-0.65**</td>
<td>0.63**</td>
<td>-</td>
<td>-0.82***</td>
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**Figure captions**

**Figure 1** Schematic diagram of the plot layout across two adjacent farms on the Isle of Purbeck, UK.

**Figure 2** The effect of sulphurous amendments on Heathland Restoration Index (HRI). Error bars represent the SE of the means. Means with different letters (a,b,c) represent a significant difference between treatments ($p<0.05$).

**Figure 3** The effects of sulphurous amendments on vegetation coverage classified by functional groups. Error bars represent the SE of the means. Means with different letters (a, b) represent a significant difference between treatments.

**Figure 4** PCA biplot on vegetation coverage classified by functional groups in the plots sampled: C=Control, FS=Ferrous sulphate, ES=Elemental sulphur. Labels in italic represent the variables calculated, the five different vegetation groups. Blue vectors represent their direction and magnitude.

**Figure 5** The effects of sulphurous amendments on soil microbiology i) bacterial colony forming units (CFUs) ii) fungal CFUs iii) actinomycete CFUs iv) soil microbial activity determined through the hydrolysis of fluorescein diacetate (FDA). Error bars represent the SE of the means. Means with different letters (a, b) represent a significant difference between treatments.

**Figure 6** The effects of sulphurous amendments on decomposition. Mass loss from i) small (100 μm) ii) medium (2 mm) and iii) large (4.7 mm) mesh size litter bags. Error bars represent the SE of the means. Means with different letters (a, b) represent a significant difference between treatments.
**Figure 7** The effects of sulphurous amendments on earthworm abundance. Error bars represent the SE of the means.

**Figure 8** Box and whisker plots, with arithmetic mean, of mycorrhizal colonisation of *Holcus lanatus* in plots where heather species were present or absent.

**Figure 9** The effects of sulphurous amendments on a) rotifer and b) nematode abundance. Error bars represent the SE of the means. Means with different letters (a, b) represent a significant difference between treatments.

**Plate 1** Heather community successfully established 14 years after elemental sulphur application on a 50 X 50 m plot.
<table>
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<tr>
<th>Species</th>
<th>Grass</th>
<th>Leaf</th>
<th>Fbsh</th>
<th>Shrubs</th>
<th>Fieldwork</th>
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<td>Anthoxanthum odoratum</td>
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<td>Cirsium arvense</td>
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<td>Cirsium discolor</td>
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<td>Cirsium vulgaris</td>
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<td>Dactylis glomerata</td>
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<td>Dactylis heliophila</td>
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<td>Epilobium adenocaulatum</td>
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<td>Erica cinerea</td>
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<td>Erica cinerea subsp. inana</td>
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<td>Juncus articulatus</td>
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<td>Lolium perenne</td>
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<td>Lolium avenaceum</td>
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<td>Molinia caerulea</td>
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<td>Plantago lanceolata</td>
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Background dataset
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