

1 **Evaluating the Tea Bag Index approach for different management practices in**
2 **agroecosystems using long-term field experiments in Austria and Sweden**

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25 **Abstract**

26 Litter decomposition is an important factor affecting local and global C cycles. It is known that
27 decomposition through soil microbial activity in ecosystems is mainly influenced by soil type and
28 climatic conditions. However, for agroecosystems, there remains a need for a better understanding
29 how management practices influence litter decomposition. This study examined the effect of
30 different management practices on decomposition at 29 sites with long-term (mean duration of 38
31 years) field experiments (LTEs) using the Tea Bag Index (TBI) protocol with standard litter
32 (Rooibos and Green tea) developed by Keuskamp et al. (2013). The objective was to determine if
33 the TBI decomposition rate (k) and stabilization factor (S) are sensitive enough to detect
34 differences in litter decomposition between management practices, and how they interact with
35 edaphic factors, crop type and local climatic conditions. Tea bags were buried and collected after
36 ~90 days in 16 Austrian and 13 Swedish sites. The treatments at Austrian LTEs focused on mineral
37 and organic fertilizer application, tillage systems and crop residues management, whereas those in
38 Sweden addressed cropping systems, mineral fertilizer application and tillage systems. The results
39 showed that in Austria, incorporation of crop residues and high N fertilizer application increased
40 k . Minimum tillage had significantly higher k compared to reduced and conventional tillage. In
41 Sweden, fertilized plots showed higher S than non-fertilized plots and high N fertilizer had the
42 highest k . Growing spring cereal lead to higher k than forage crops. Random Forest regressions for
43 Austria and Sweden jointly showed that k and S were mainly governed by climatic conditions,
44 which explained more than 70% of their variation. However, under similar climatic conditions,
45 management practices strongly influenced decomposition dynamics. Thus, the TBI approach may

46 be suitable to apply in a more large-scale network on LTEs for evaluating decomposition dynamics
47 in agroecosystems more precisely.

What I miss in the abstract are implications for the global C cycle (C sink function of the managed soils). At least, the outcome of this research should be linked to the reason for initiating it. In this case the local and global C cycles (most importantly, the C sink capacity as described in the introduction).

49 **Introduction**

50 Soil organic carbon (SOC) is one of the most used indicators for soil quality, since its dynamics is
51 involved in regulating ecosystem functionality through its influences on physical, biological and
52 chemical soil properties, which are critical for nutrient cycling and soil fertility (Davidson et al.
53 2006; Janzen 2015). Management practices, such as fertilizer application, use of catch- and cover
54 crops, organic amendments, length of bare fallow periods, permanent surface protection with
55 perennial crops, tillage practices and aboveground crop residue management, are impacting SOC
56 balances for agroecosystems (Kätterer and Bolinder, 2022; Sandén et al., 2018; Paustian et al.,
57 2016).

58 Agricultural soils play a crucial role in the global carbon (C) cycle due to their C sink capacity
59 (Paustian et al., 2016; Lal, 2004). In this context, improved management practices that maintain
60 or increase SOC stocks are considered essential in national greenhouse gas reporting systems
61 (IPCC, 2006), as well as in other international incentives such as the 4 per mille initiative (Minasny
62 et al., 2017). The SOC balance is dynamic and determined by the difference between annual C
63 inputs to soil, and the annual C outputs through the decay of existing soil organic matter and
64 resulting from microbial activity, which is the main contributor to stable SOC (Tiefenbacher et al.,
65 2021; Bolinder et al., 2007). Management practices have a great impact on these two factors by
66 affecting either the amount of C inputs or outputs through decomposition, or both factors
67 simultaneously.

68 Litter decomposition is a complex biogeochemical process controlled by several biotic and abiotic
69 factors, where the biological activity of decomposers varies with soil properties and is driven
70 largely by climatic conditions (Daebeler et al., 2022; Bradford et al., 2016; Cleveland et al., 2014;
71 Gholz et al., 2000). Decomposition and SOC stabilization are **long processes**, therefore long-term
72 field experiments (LTEs) are among the most useful resources for quantifying the impact of
73 management practices on litter decomposition, SOC changes, and soil functioning (Sandén et al.,
74 2018; Kätterer et al., 2012; Bergkvist and Öborn, 2011). **Experiments determining litter mass loss**
75 over time *in situ* are also important for understanding SOC dynamics, nutrient cycling and
76 colonization by soil biota under field conditions. The traditional method that has been used in
77 ecology for more than 50 years consists of litterbag studies, burying known quantities of various
78 organic materials into the soil, and retrieving them successively at different intervals (Kampichler
79 and Bruckner, 2009; Burgess et al., 2002; Bockock and Gilbert, 1957). These studies are not always
80 comparable because they are subject to variations in e.g., litter type, mesh-size, sample preparation
81 and analytical methods, and the placement of litterbags may alter the microclimate for
82 decomposers (Kampichler and Bruckner, 2009).

83 Keuskamp et al. (2013) developed therefore a **low-cost and time-efficient methodology** called Tea
84 Bag Index (TBI), characterizing the decomposition process with commercially available tea bags,
85 where green tea is representing labile organic material and rooibos tea as a surrogate for
86 recalcitrant litter. A decomposition rate (k) and a stabilization factor (S) are obtained accordingly
87 with their chemical composition and the respective weight lost at a single point in time after an
88 incubation period of ca 90-days in the soil. The TBI approach is particularly useful for assessing
89 geographical differences in decomposition dynamics because results are directly comparable

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90 across sites, varying only with local edaphic and seasonal environmental conditions (Keuskamp et
91 al., 2013).

92 In several studies, the TBI has been used as an indicator for biological (Sandén et al., 2021;
93 Costantini et al., 2018) and microbial activity (Daebeler et al., 2022; Treharne et al., 2019; Tóth et
94 al., 2017), ecosystem functioning, nutrient cycling (Zaller et al., 2016), and soil quality (Tresch et
95 al., 2018; Buchholz et al., 2017). Generally, this follows the concepts of soil quality as reviewed
96 by Bünemann et al. (2018), where TBI would primarily be a biological soil quality indicator,

97 although the data apparently were not normalized for the temperature effect. According to the TBI
98 community, data collected from networks of researchers and citizen scientists for constructing a
99 global TBI map (www.teatime4science.org) shows that most studies have been using the TBI
100 approach for different forest and grassland ecosystems or urban soils, agricultural fields represent
101 less than 15% of data. Indeed, there are only a few published studies (Daebeler et al., 2022;

102 Dossou-Yovo et al., 2022; Struijk et al., 2022; Fu et al., 2021; Sandén et al., 2020; Barel et al.,
103 2019; Poeplau et al., 2018; Sievers and Cook, 2018) that have been using the TBI approach for
104 evaluating agroecosystems, and it is not clear if this method is sensitive enough to detect
105 differences between management practices. to investigate

106 This study used the TBI approach for investigating the effect of management practices on the
107 decomposition rate (k) and stabilization factor (S) at several LTEs in Austria and Sweden, with
108 different soil characteristics, and climatic conditions, and subjected to various
109 management/treatments.

110 To the best of our knowledge, this is the first analysis using the TBI approach for such a large
111 number of LTEs and different treatments for agroecosystems. The treatments covered management
112 practices such as organic amendments, crop rotations, aboveground crop residue handling, mineral

reads very specific; is it necessary to state this here in the introduction ?

Do I understand correctly that only 15% of all TBI data collected has been published or used for constructing a global TBI map? Please rephrase this sentence.

113 fertilizer application, and tillage. Our objectives were: (i) to evaluate if the TBI k and S parameters
114 are **sensible** enough to distinguish between different management practices; (ii) to quantify the
115 effect of management practices on k and S ; and (iii) to identify the most important local climate
116 and/or soil properties affecting litter decomposition in Austria and Sweden.

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118 **Materials and Methods**

119

120 **Study sites**

121 *Austria*

122 We used sixteen Austrian (AT) sites, by selecting contrasting treatments from three different
123 categories of LTEs where the management practices had been in place for 11 to 63 years (see
124 details in Table 1). The TBI measurements were made in 2014, 2015 and 2016. Measurements
125 sometimes took place in more than one year at the same LTE (e.g., MUBIL), and the sites were
126 abbreviated as AT1 to AT16. Six experiment categories involved carbon balance practices (CB)
127 focusing on organic matter inputs such as compost and crop residues, eight sites were studying
128 soil fertility (SF) in terms of differences in mineral N and P fertilization, and two sites examined
129 tillage systems (TS). The sites are located in several agricultural areas across the country (Fig. 1),
130 with diverse soil textures (Table S1) and variable crop types (Table 1) and climatic characteristics
131 (Table 3) during the years of TBI measurements. More details for some of the sites are available
132 in specific publications: AT3 (Spiegel et al., 2018; Lehtinen et al., 2017; Tatzber et al., 2015;
133 Aichberger and Söllinger, 2009), AT4 to AT6 (Spiegel et al., 2018; Lehtinen et al., 2014), AT15
134 and AT16 (Tatzber et al., 2015; Spiegel et al., 2007). In addition, Sandén et al. (2018) puts the
135 Austrian LTEs in the context of other European LTEs.

136 The purpose of the Austrian C balance LTEs was threefold: i) to assess the sustainability of
137 stockless vs. livestock-keeping organic farming management on soil and crop traits (AT1, AT2),
138 ii) to investigate the effects of compost amendments on soil and crops (AT3), and iii) to compare
139 crop residue incorporation and removal (AT4-AT6). Compost amendment LTE and crop residue
140 incorporation LTEs also included mineral fertilizer application, whereas AT1 and AT2 only
141 focused on different organic fertilizer treatments.

142 The eight soil fertility LTEs (AT7-AT14) were all focusing on the effect of mineral fertilizer on
143 soil and crop properties. In most cases, treatments studied different amounts of mineral nitrogen
144 fertilizer, whereas AT9 and AT12 also investigated the effect of different amounts of K fertilizer
145 application. Nitrogen fertilizer was applied in four stages and potassium in three stages, according
146 to Austrian guidelines for fertilizer (BMLFUW, 2017).

147 For the tillage system experiments, conventional tillage (CT) was compared to reduced tillage (RT)
148 and minimum tillage (MT). Regular mouldboard ploughing to 25–30 cm soil depth was applied in
149 CT treatment, whereas cultivator in autumn to a depth of 15–20 cm was used in RT treatment and
150 a rotary driller that loosened the soil to a depth of 5–8 cm was used in MT treatment. The soil was
151 turned over only in the CT treatment, where inversion tillage was incorporating the crop residues.
152 Fertilizer application was crop specific according to the Austrian guidelines for fertilizing
153 (BMLFUW, 2017).

154

155 *Sweden*

156 We used thirteen Swedish (SE) sites by selecting contrasting treatments from three different
157 categories of LTEs, where the management practices had been in place for 11 to 59 years (see
158 details in Table 2). TBI measurements at these sites were made only in one year (2016), and were

159 abbreviated as SE1 to SE13. Six sites involving combined management practices (CMP), four
160 studying the effect of rotations (ROT), and three sites with tillage systems (TS). The sites are
161 located in several agricultural areas across the country (Fig. 1), with diverse soil textures and
162 variable crop types (Table 2) and climatic characteristics (Table 3) during the year of TBI
163 measurements. Bergkvist and Öborn (2011) give a general description of all these LTEs. Only a
164 brief description of treatments are provided below, more details on the sites with combined
165 management practices is given by Carlgren and Mattson (2001), and for tillage systems by
166 Arvidsson et al. (2014), while Poeplau et al. (2015) provide some more insight on the rotation
167 experiments.

168 The initial purpose of the six LTEs with combined management practices (SE1-SE6) was to
169 compare a change from the traditional mixed farm production system including crops and livestock
170 into a pure cash crop system, by studying their effects on the sustainability of crop production and
171 soil properties (entitled *soil fertility experiments*). The dairy production treatments contain
172 exclusively perennial grass-clover leys and receive one farmyard manure (FYM) application per
173 rotation. The cash crop treatments consist of annual crops (i.e., oilseed is replacing leys in the
174 rotation) without manure applications (0 FYM) only receiving mineral fertilizers application
175 (NPK). PK applications in all the treatments we selected were aimed at achieving rapid build-up
176 of the soil PK status, i.e., the amount applied was first replacing that exported in harvested products
177 (i.e., maintenance principle), to which an extra amount was added (corresponding to the max
178 treatment). The N-rates in all NPK treatments were also corresponding to max application rate,
179 and were adapted depending on crop type, where spring cereals, oilseeds, and leys received 125
180 kg, while sugar beet received 210 kg N ha⁻¹ yr⁻¹. We were also using the control plots receiving no
181 NPK (0 NPK). As a third factor, aboveground crop residue removal takes place in all FYM

182 treatments, simulating use of harvest residues for fodder or bedding material that are recycled as
183 manure. The southern sites have 4-year rotations and those in central Sweden have 6-year
184 rotations. The north site (SE5) is slightly different from the others, consisting of a 7-year rotation
185 and is studying only the livestock-based production system.

186 For rotation experiments purposes, we were comparing extreme treatments representing two
187 rotations from four LTEs (SE7-SE10) with the main objective to study changes in SOC (named
188 *humus balance experiments*), i.e., a continuous spring cereal (SC) system and a ley-dominated
189 rotations (L). The straw was removed from the plots every year in the SC treatments, and L
190 consisted of a grass-clover mixture re-established every fourth year. Both rotations were receiving
191 P and K accordingly with the maintenance principle, and SC and L were receiving 120 and 150 kg
192 N ha⁻¹ yr⁻¹, respectively.

193 In the three tillage experiments (SE11-SE13), the conventional tillage (CT) and direct seeding
194 (DS) treatments were the same for all sites, consisting of inversion plowing to a depth of 20-23 cm
195 and by using a disc seed drill, respectively. The shallow (5-7 cm) and deep (~12 cm) reduced
196 tillage treatments (SRT and DRT, respectively), consisted of primary tillage operations made in
197 the autumn and most commonly with a chisel plough. The main crops in all the tillage system
198 experiments were winter and spring cereals (occasionally oilseed), fertilized accordingly with local
199 recommendations and with the aboveground residues chopped and left in the field.

200

201 **TBI method and sampling design**

202 The TBI method was used according to the protocol established by Keuskamp et al. (2013) to
203 determine litter decomposition using two types of commercial tetrahedron-shaped tea bags by
204 Lipton Unilever (Green tea and Rooibos tea). The green tea (*Camellia sinensis*; EAN:

205 8722700055525) has high cellulose content, higher soluble fraction, and lower C:N ratio; while
206 rooibos tea (*Aspalathus linearis*; EAN: 8722700188438) has high lignin content, lower soluble
207 fraction, and higher C:N ratio, which is expected to slow down decomposition (Keuskamp et al.,
208 2013). The synthetic tea bag material has a mesh size opening of 0.25 mm allowing access to
209 microorganisms, very fine roots and root hairs.

210 The initial mass of the tea bag contents was determined on 20 randomly selected bags for each tea
211 type from different boxes, oven-dried at 70°C for 48 hours and weighed separately; the mean dry
212 mass for green tea was 1.717 ± 0.048 g and that for rooibos tea was 1.835 ± 0.027 g. For both
213 countries, close to seeding of annual crops, from end of April to mid-June depending on location,
214 each tea bag was properly identified and buried in the soil at 8 cm depth.

215 For Austria, four bags of each tea were used and placed side by side at a distance of 2 to 3 cm.
216 Each tea bag was properly identified and buried in the soil at 8 cm depth. The TBI incubation
217 period from placement to last retrieval averaged 80 ± 13 days (Table 3) due to logistic issues for
218 collection. After collecting, the tea bags were oven-dried at 70°C for 48 hours after removal of
219 adhered soil particles according to the standardized protocol by Keuskamp et al. (2013). After
220 drying, the tea bags were opened and the tea content was weighted. The ash content was not
221 determined.

222 The same TBI protocol was used for the Swedish sites. As in Austria, four bags of each tea were
223 used per experimental unit, placed side-by-side at a distance of 2 to 3 cm. Each tea bag was
224 properly identified and buried in the soil at 8 cm depth. The mean TBI incubation period from
225 placement to last retrieval date averaged 91 ± 1 day (Table 3). In addition to the removal of adhering
226 soil particles, the ash content was determined (i.e., both for green and rooibos tea on mixed samples
227 of the four replicates) in a muffle oven at 550°C for 16 hours. The rationale for measuring the ash

228 content was that three of the Swedish sites had a high clay content (Table S1), where the complete
229 removal of adhering soil particles may be more difficult. However, the ash content was on average
230 quite low, representing $15\pm 6\%$ and $10\pm 4\%$ for the Green and Rooibos tea bags, respectively (data
231 not shown).

232 After measuring the remaining dry matter, the decomposition rate (k) and stabilization factor (S)
233 for both countries were calculated according to the TBI presented by Keuskamp et al. (2013). This
234 standardized method that is using single measurements after an incubation period in the soil of 90-
235 days have received some criticism. For instance, Mori (2022) and Mori et al. (2023) showed that
236 this incubation period is not always long enough for the mass loss of green tea to reach a plateau,
237 and further suggested that time-series mass loss data of rooibos tea is also required to respect the
238 underlying assumptions of the TBI method. Time-series (15, 30, 60 and 90-days) of green and
239 rooibos tea were available for all the Swedish sites but only at one Austrian site (16, 26, 62 and
240 91-days at AT16). The incubation period was consistently always 90-days for the Swedish sites,
241 and only shorter than that (i.e., about 60-days incubation period) for a few of the Austrian sites
242 (Table 3). To have as uniform comparisons as possible between the two datasets, we only used the
243 last measurement for both countries for calculating k and S . The purpose of using the time-series
244 for testing the underlying TBI assumptions was beyond the scope of this paper.

245 The daily climate data for Austria were retrieved from the Central Institution for Meteorology and
246 Geodynamics (ZAMG). For Sweden, the daily climate data were gathered through official data
247 from the most nearby LantMet climate stations, and from the Swedish Meteorological and
248 Hydrological Institute (SMHI). The climate variables used in this study were air temperature,
249 precipitation, solar radiation, wind speed and air humidity (Table 3).

250 For Austrian soils, pH was measured electrochemically (pH/mV Pocket Meter pH 340i, WTW,
251 Weilheim, Germany) in 0.01 M CaCl₂ at a soil-to-solution ratio of 1:5 (ÖNORM L1083). Total
252 soil organic C (TOC) concentrations were analyzed by dry combustion in a LECO RC-612 TruMac
253 CN (LECO Corp., St. Joseph, MI, United States) at 650°C (ÖNORM L1080). Total N (N_{tot}) was
254 determined according to ÖNORM L1095 with elemental analysis using a CNS (carbon, nitrogen,
255 sulfur) 2000 SGA-410–06 at 1250°C. Texture was determined according to ÖNORM L1061-1 and
256 L1062-2. For Sweden the data were gathered from recent archived analysis protocols (pH was
257 measured in water). Clay content, C content, C:N ratio, and pH measured from each site in both
258 countries are shown in Table S1 (Supplementary material).

259

260 **Data analysis**

261 Analysis of variance (ANOVA) for each experiment category (i.e., CB, SF, TS, CMP and ROT)
262 was performed to analyze the effects of the treatments and the differences between sites on k and
263 S separately for both countries. When the treatments were identical within the same experiment
264 category, sites were used as a random effect with a mixed ANOVA to test the average treatment
265 effect, mean values were used as replicates to test the differences between sites. The Tukey's test
266 ($p < 0.05$) was used for comparing the same treatments and the same sites using R software version
267 4.2.2. We have treated the data from different years at the same sites in Austria as independent
268 observations, in the sense they are not a time series of measurement. Interactions between site and
269 treatment were considered.

270 We calculated a climate-dependent soil biological activity parameter (Re_{clim}), by using mean daily
271 air temperature, total precipitation, and potential evapotranspiration (PET) data in pedotransfer,
272 soil water balance and biological activity functions. Compared to raw climatic data alone, this
273 parameter is integrating the effect of climate, soil and crop properties. It is calculated as the product

274 of a soil temperature (Re_{temp}) and relative water content (Re_{wat}) factor with a daily time step (i.e.,
275 $Re_{clim} = Re_{temp} \times Re_{wat}$), which is thereafter averaged to give an estimate of soil biological activity
276 for a given time period. These two factors are derived from soil temperature and soil moisture
277 response functions expressing the activity of decomposers and their relative effect on the decay
278 rates of organic materials in the arable layer of agricultural soils. Briefly, the Re_{temp} is calculated
279 from air temperature and leaf area index using an empirical model (Kätterer and Andrén, 2009),
280 while Re_{wat} is calculated using pedotransfer functions for simulating the soil water balance and a
281 function for estimating PET. In addition to air temperature and leaf area index, calculations of
282 Re_{wat} also involve the use of daily climatic data for precipitation, wind speed, air humidity, and
283 solar radiation, as well crop types and yields, soil texture and SOC content. For details see Bolinder
284 et al., 2008, and Fortin et al., 2011) and information in the following R package used for the
285 calculations: <https://github.com/ilmenichetti/reclim> (Please refer to the package documentation).
286 The Re_{clim} concept can be used for quantifying regional differences in soil biological activity alone
287 (Bolinder et al., 2013; Andrén et al. 2007) or integrated as a parameter in the ICBM SOC model.
288 In the latter case, it is adjusting the decomposition rates of both C inputs to soil from crop residues
289 (e.g., straw) and that of the more stable SOC (Andrén and Kätterer, 1997; Andrén et al., 2004). In
290 this study, we used the concept of Re_{clim} and the Re_{temp} and Re_{wat} factors to test if the product of
291 soil-temperature and relative water content better explained the variation in k and S than the two
292 latter alone, and to determine if they also better explained this variation compared to using only
293 raw climatic data.

294 We calculated simple correlation between variables mean annual temperature (MAT), mean
295 temperature during the incubation period (MAT_{TBI}), total annual precipitation (TAP), total
296 precipitation during incubation period (TP_{TBI}), potential evapotranspiration (PET), potential

297 evapotranspiration during incubation period (PET_{TBI}), aridity index (AI), aridity index during
298 incubation period (AI_{TBI}), temperature and precipitation factor (TxP), Re_{clim} , Re_{wat} , Re_{temp} , pH,
299 SOC, clay and C:N ratio, using Pearson correlation. For more accurate results, we applied random
300 forest (RF) regression in order to rank the importance of variables for k and S , using the random
301 forest R package (Liaw and Wiener, 2002). The RF is a machine learning technique based on
302 decision trees that predicts a certain variable from a set of other variables through a series of binary
303 splits of the data, where the variables are either continuous or categorical. For example, in the case
304 of a continuous variable it consists of all the data points above or below a certain threshold, for a
305 categorical variable it consists of all the data points belonging or not to a specific class. All these
306 subsequent splits constitute a decision tree. A random forest is a set of decision trees and it is
307 therefore an ensemble technique. This allowed us to utilize treatment and crop variables (including
308 N fertilizer) without having to convert them into a ranking. Another useful asset of an RF
309 regression is that it evaluates the importance of each variable in defining the predicted variable.
310 There are various possible measurements to do that, but they are all based on measuring the
311 effectiveness of each subsequent split in each node of a decision tree in sorting out the information.
312 In our study, we used a measurement called node purity based on the Gini index, which expresses
313 the probability of one split of the data (i.e., one node of the tree) defining the predicted variable.
314 The total node purity of a certain variable in a tree is the sum of all the node purity measurements
315 for each node considering that particular variable, and the higher it is the more that variable is
316 important.

317 We used the following models to predict the two TBI parameters k and S :

318
319 $k_n f(TN, SOC, CN, cl, cr, tr, pH, N, PET, PET_{TBI}, TAP, TP_{TBI}, MAT, MAT_{TBI}, AI, AI_{TBI}, Re_{clim}, Re_{wat}, Re_{temp})$

320 $S_n f(TN, SOC, CN, cl, cr, tr, pH, N, PET, PET_{TBI}, TAP, TP_{TBI}, MAT, MAT_{TBI}, AI, AI_{TBI}, Re_{clim}, Re_{wat}, Re_{temp})$

321

322 where soil variables (continuous) were TN (total N g kg⁻¹), SOC (g kg⁻¹), CN (C:N ratio), cl (clay
323 content g 100 g⁻¹) and pH . Categorical variables were N (N fertilizer application factor with 4
324 levels), cr (crop factor, e.g., barley, ley (establishment), ley (production), oat, spring oilseeds,
325 sugar beet, maize and winter wheat) and tr (a treatment factor with 30 levels). The climatic
326 variables (PET_{TBI} , PET , TP_{TBI} , TAP , MAT_{TBI} , MAT , AI_{TBI} and AI) are as defined in Table 3. The
327 climate response variables Re_{clim} , Re_{wat} , Re_{temp} are as described above.

328 Since many of variables in our model are likely to be correlated and carry similar information, we
329 applied the recursive feature elimination algorithm implemented in the caret R package by Kuhn
330 et al. (2016), which assess in subsequent iterations the optimal set of predicting variables (features)
331 to be utilized by the RF model. The procedure starts by fitting a RF model with all variables,
332 ranking them by importance, and discarding the least important. The algorithm then iterates. The
333 optimal number and set of features are then defined by a fitness metric (in our case the model R²),
334 selecting the set with the best model fitness. The selected models were used to compute the
335 variables' relative importance.

336 In order to better understand the similarities between the sites, we run a principal component
337 analysis (PCA) in the space composed by the variables pH, SOC, TN, C:N, clay, TAP, MAT, PET,
338 AI and TxP. The analysis was run with the R command prcomp (Venables and Ripley, 2002), from
339 the base R installation (“Stats” package). Variables were all standardized by rescaling them to zero
340 mean and unit variance.

341

342 **Results**

343 *Effect of management practices*

344 *Austria*

345 Both the TBI parameters k and S varied between treatments and sites in Austria, and even between
346 years at the same site within the C balance category (Fig. 2 and Table S2). In general, all treatments

347 in AT1 with a lucerne crop under wetter conditions (2014) **presented** higher k and lower S than in
348 AT2 with a wheat crop under dryer conditions (2015), and the treatment with municipal compost
349 and green manure (FW) had the highest S in 2015. The AT3 site did not **present** significant
350 differences between the treatments. Crop residue incorporation treatment (CRI) had higher k than
351 the crop residue removal (CRR) at the AT4 and AT6 sites, and AT6 **presented** a higher k than at
352 AT4. Comparing years for the same experiment site and type with different crops, AT5 (2015;
353 with wheat) had higher S than AT6 (2016; with maize).

354 For the soil fertility experiment category (Table 1), AT12 had the highest k and AT13 had the
355 highest S . Sites receiving NPK fertilizer application (AT7, AT8 and AT9) had higher k and S even
356 at different N doses than at the AT12, AT13 and AT14 sites receiving only N (i.e., without P and
357 K). Stabilization was significantly higher in AT9 than in AT7. For potassium trials, AT11
358 presented significantly higher k and S than AT10. Regarding sites receiving only N addition
359 (AT12, AT13, and AT14), maximum doses (180 kg N) presented the highest k (0.0095), and no N
360 addition had the lowest k (0.0066) (Fig. 2 and Table S2).

361 Regarding the tillage system experiment category (AT15 and AT16 - Table 1), k was significantly
362 higher in shallow reduced tillage (SRT) and S was higher in deep reduced tillage (DRT) in 2015
363 (AT15), but no significant differences between treatments were found in 2016 (AT16). Site AT16
364 had significantly higher S than AT15 (Fig. 2. and Table S2).

presented
seems a
strange
word to
indicate that
differences
between k
and S .
Alternative
is "show".
However,
not being a
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myself I am
not
absolutely
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Please
reconsider
using "
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365

366 *Sweden*

367 At the Swedish sites (Table 2), the TBI measurements for the combined management practices
368 experiment category showed that both k and S were significantly higher for the FYM/NPK
369 treatments maximum amount of farmyard manure and maximum doses of NPK (FYM/NPK) (Fig.
370 3, Table S3) compared with the control treatments (0 FYM/0 NPK). Comparing sites, SE5 and
371 SE6 had the highest k and SE4 had the lowest k , while SE3 presented the highest S followed by
372 SE6, SE5 and SE4, the lowest S was for SE1 and SE2 (Table S3).

373 Regarding the rotation experiments, the continuous spring cereal rotation presented higher k than
374 for ley, but there was no significant difference in S . Comparing sites, SE9 presented higher k than
375 SE7, SE8 and SE10, whereas SE7 and SE8 had the highest S .

376 For the tillage system experiment category, conventional tillage (CT) had the lowest k and S , while
377 deep reduced tillage (DRT) had the highest k and S . The highest S was observed for the SE12
378 followed by SE11 and SE13. Sites did not show significant differences for k .

379 Comparing tillage system experiments in Austria and Sweden (2016) for sites (AT16, SE11, SE12
380 and SE13) for the treatments that were the same in both countries (CT, SRT and DRT), deep
381 reduced tillage had the highest k and shallow reduced tillage had the highest S . The Austrian site
382 presented the lowest k and the highest S compared to the Swedish sites, which did not present
383 significant differences among them (Table S3).

384 The field application of the TBI found a clear discrimination of both k and S values between the
385 two countries. The both mean k and S values were higher in Sweden (Table 4, Fig. 4). In general,
386 the variation in k and S values were lower in Austria. Indeed, mean k by site in Austria varied
387 between 0.0058 and 0.0128 and mean S varied between 0.113 and 0.442 (Table S2). Whereas mean

388 k by site in Sweden was between 0.0084 and 0.0301, and mean S was between 0.118 and 0.361
389 (Table S3). All values for k and S were within the range of the previous global TBI investigation
390 (0.005-0.04 for k ; and 0.05-0.55 for S) by Sandén et al. (2020).

391

392 *Influence of climate and soil properties*

393 Using the combined dataset for Austria and Sweden, resulted in significant negative correlation
394 between k and MAT, TAP, PET, TxP factor, Re_{clim} and Re_{temp} , and significant positive correlation
395 with the C:N ratio (Table S4). Stabilization factors in Austria and Sweden combined correlated
396 negatively with MAT_{TBI} period, Re_{clim} and Re_{temp} .

397 The variable selection procedure with the random forest models (Fig. 5) identified fewer variables
398 explaining k and S values for the combined dataset. The variables explaining k is low, but the
399 overall predicting power of the model decreased substantially.

400 According to the optimized random forest model, most of the variance in k was accounted for by
401 climatic variables (Fig. 5), with Re_{temp} ranking the highest, followed by AI and MAT. It was also
402 showing that treatment, C:N ratio and SOC were important factors as well. The S was also
403 influenced by climate-related variables, with Re_{temp} leading the ranking, and it was followed by pH
404 and more agronomic variables such as treatment, crop and N fertilizer application.

405 The principal component analysis (Fig. 6) revealed that the data are well divided in two groups,
406 representing the two countries, which allow us to say that indeed edapho-climatic characteristics
407 are different between Austria and Sweden. PC1 showed that points in Austria are positively related
408 to climatic characteristics, such as MAT, TAP and PET. On the other hand, points in Sweden are
409 positively influenced by high clay content and high C:N ratio. High C:N enhancement is related
410 to low TAP and TxP. High clay contents are related to low MAT and PET, which can be due to an

411 historical influence on soil weathering. PC2 is dominated by SOC and TN contents, mainly at two
412 points in Austria (AT7 and AT9: two sites testing soil fertility with NPK and relatively low TAP
413 and TP_{TBI} compared to other sites). Austria presented more divergent data, having more
414 heterogeneous sites than in Sweden.

415

416

417 **Discussion**

418 *Influence of climate and soil properties*

419 In previous studies using the TBI approach, it was shown that climate played a significant role on
420 decomposition in a temperate biome (Djukic et al., 2018), but when comparing several different
421 biomes, climatic conditions were of relatively low importance (Fanin et al., 2020). In Boreal soils,
422 Althuizen et al. (2018) found that increased temperatures enhanced k , whereas increased
423 precipitation decreased k across years. Many studies **have showed** a positive correlation between **have shown**
424 precipitation and decomposition rates (Pimentel et al., 2019; García Palacios et al., 2016), however
425 precipitation did not show correlation with k according to the random forest analysis. On the other
426 hand, Re_{wat} showed great importance (Fig. 5). It is because this variable includes nonlinearities due
427 to its shape according to which decomposition increases with soil moisture and then decreases at
428 high soil water content due to oxygen limitation of microorganisms (Moyano et al., 2013).

429 In general, higher k values were observed when the aridity index was lower, and it was identified
430 by the random forest regression model being an important variable affecting the rate of
431 decomposition (Fig. 5). This may be related to the observations that in more arid and warmer sites,
432 the biological processes driving SOC dynamics are impaired which may result in decreasing soil
433 C and N stocks (Kerr and Ochsner, 2020; Ontl and Schulte, 2012; Jiao et al., 2016; Reynolds et
434 al., 2007).

435 For practical reasons the teabags in our study were buried in the soil during the growing season,
436 corresponding to a period when the soil biological activity is highest (Bolinder et al., 2013). When
437 burying the teabags during the growing season, the difference in climatic variables between sites
438 are attenuated, in particular with respect to air temperature. For example, the MAT at the Swedish
439 most northerly (SE5 and SE9) and southerly (SE2) sites are 4.1 and 9.0 °C, respectively, whereas

440 the corresponding mean air temperatures during the incubation period (MAT_{TBI}) were 14.3 and
441 16.2 °C, respectively.

442 The TBI S parameter was also dependent on climate. Indeed, the random forest model identified
443 climatic parameters as the main factors affecting S in both Austria and Sweden during all evaluated
444 periods. In particular, Re_{clim} and Re_{temp} often showed significant negative correlations, which
445 implies a negative impact of air temperature on S . However, raw climatic variables, such as
446 precipitation and temperature were only weakly correlated with S . This is probably due to
447 nonlinear processes, which are considered in the ICBM climate-dependent soil biological activity
448 calculations such as Re_{wat} (as discussed above). Furthermore, since litter decomposition dynamics
449 is influenced by multiple factors that interact and change over time (Bradford et al., 2016), the
450 relationships are not always linear. Random forest models that we fitted to the data are more
451 efficient capturing such combinations and interactions of factors, and can detect relationships that
452 would not be detectable by linear approaches.

453

454 *Effect of management practices*

455 Our results revealed that a large number of different management practices significantly affected
456 both the decomposition rate k and stabilization factor S according to the TBI approach used in
457 several LTEs in Austria and Sweden (Fig. 2, 3 and 5). This is in contrast to the studies by Djukic
458 et al. (2018) as well as Saint-Laurent and Arsenault-Boucher (2020), who did not find any
459 significant effect of land use and management practices on early-stage litter decomposition in a
460 temperate biome.

461 In the C balance trials in Austria, soils receiving green manure + municipal compost had higher S
462 than soil receiving biogas slurry at the second year (Table S2). This is in agreement with studies

463 indicating that compost can improve SOC stabilization over time (Mekki et al., 2019; Eshetu et
464 al., 2013; Ceccanti et al., 2007). The higher k in the crop residues incorporated treatments (AT4
465 and AT6; Table S2) can be attributed to the fact that incorporation of crop residues into the soil
466 can increase the decomposition rate by stimulating microbial activity. During the early stages of
467 decomposition, soluble C is rapidly utilized by soil biota (Werth and Kuzyakov, 2010). The higher
468 k and lower S at AT6 compared to AT4 were likely due to the loamy texture, lower potential
469 evapotranspiration resulting in a lower aridity index at the AT4 site (Table 3 and Table S1),
470 corroborated by the PCA analysis (Fig. 6).

471 There were no significant differences in k and S found among treatments in the soil fertility trials
472 in Austria with NPK addition. However, there was a trend towards a higher S at AT9 compared to
473 AT7, likely related to the higher SOC content in AT9, since the climatic conditions and soil texture
474 were quite similar for both areas, which suggests that higher SOC content may have increased S .
475 Site AT11 had higher k and S than AT10. Possible explanations for this trend are that AT10 had
476 lower clay content, lower precipitation resulting in higher PET (corroborated by the PCA analysis)
477 and AI, contributing to a lower soil moisture content and thereby lower decomposition and
478 stabilization.

479 Nitrogen supply may favor microbial activity and thereby litter decomposition (Raiesi, 2004). This
480 was reflected in the treatments where only N was added, where the high dose of 180 kg N ha^{-1}
481 (AT12, AT13 and AT14) induced a significantly higher k (Table S2), compared to the treatments
482 with no N addition, which also had the lowest k . Furthermore, the significant difference between
483 sites, in which AT12 had the highest k could at least partly be explained by a higher SOC and
484 higher pH at this site (corroborated by the PCA analysis).

485 In the tillage system experiment at Fuchsenbigl in Austria in 2015 (AT15, with maize) and 2016
486 (AT16; with wheat), the shallow reduced tillage showed significantly higher k than deep reduced
487 tillage and conventional tillage, only in 2015, indicating that shallow soil tillage stimulated
488 decomposition that particular year. This was likely due to climatic conditions, since 2015 was
489 slightly drier and warmer, furthermore maize straw has lower C:N ratio than wheat straw and tends
490 to decompose faster. Some studies showed faster decomposition under conventional tillage than
491 under reduced tillage practices (e.g., Lupwayi et al., 2004). However, Kainiemi et al. (2015) found
492 a decrease in soil respiration in conventional tillage compared to shallow tillage in temperate
493 regions, which directly implies a lower decomposition (and lower k). These differences between
494 tillage treatments are attributable to indirect effects on soil moisture and temperature profiles. We
495 attribute the significantly higher S in 2016 to the fact that this year was moister and less warm,
496 compared to 2015, resulting in a lower aridity index during the TBI incubation period (AI_{TBI}).

497 In the Swedish combined management practices trials, treatments receiving organic and mineral
498 fertilizer application had higher k and S (FYM/NPK; Table S3), likely due to the increase in
499 microbial diversity and activity favored by nutrient and C supply (Stark et al., 2007). Sites SE5
500 and SE6 presented the highest k : SE5 had low evapotranspiration and aridity index, resulting in
501 more moisture; SE6 had also high S , due to high clay content and low PET (corroborated by the
502 PCA analysis). Site SE3 had high S , which could be related to a higher C:N ratio, as suggested in
503 another TBI experiment by Althuizen et al. (2018), a study showing that C:N ratio is positively
504 correlated to S . The SE1 and SE2 sites had lower S than SE3 despite similar climatic conditions,
505 which probably was related to the type of crops growing in these treatments (i.e., sugar beet in the
506 SE1 and SE2 and grass/clover ley in SE3), since these two crop types have different effects on soil
507 temperature and moisture.

508 In the Swedish rotation system trials, spring cereal (SC) had higher k than ley (Table S3). Site SE9
509 had higher k and lower S , in which the low stabilization may be caused by low clay content, low
510 pH, and high solar radiation, leading to low SOC (corroborated the PCA analysis). The highest S
511 were found in sites SE7 and SE8, in which the former presented high clay and SOC content, and
512 SE8 had high precipitation and low PET.

513 For the tillage system treatments in Sweden, similar to the Austrian sites, **the** conventional tillage
514 **presented** the lowest k , and also lowest S . Even when comparing tillage systems in Sweden and
515 Austria jointly (Table S3) we **could notice** that conventional tillage also presented the lowest k ,
516 while deep reduced tillage the highest.

517 The decomposition rate k was mostly affected by climatic conditions, which was already expected,
518 as temperature and aridity or moisture, however agronomic and edaphic factors proved to be of
519 great relevance for k , as soil management choice (treatment), soil C:N ratio, SOC, crop type, pH,
520 clay content, soil nitrogen and others. The stabilization factor S expresses the degree by which the
521 labile fraction of the plant material is decomposed. We observed that the influence of pH was the
522 most important edaphic factor, **and the agronomic factors as the soil management treatment**, crop
523 type, and N fertilizer application were also identified as good predictors. A study conducted by Fu
524 et al. (2021) suggested that pH, nutrient availability and soil compaction were the main reasons
525 contributing to the differences in litter decomposition. The net effect of pH is not clear since it
526 modifies both SOC decay kinetics and productivity simultaneously (Paradelo et al., 2015), with a
527 maximum effect at around neutral pH (Liao et al., 2016). Nevertheless, the impact of pH on litter
528 decomposition using the TBI approach seems clear in our study.

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type, ...

Here I also miss implications for global C cycling/soils as a C sink. This research is about how management practices may influence decomposition processes, and the reason for its importance is that agricultural soils play a crucial role in the global C cycle. Then I expect some words about what this research means for C cycling.

531 **Conclusion**

532 Our results show that both the TBI k and S parameters were sensitive to management practices in
533 agroecosystems in Austria and Sweden. We **were observing** significant differences for some of the we
534 treatments in all categories of LTEs. Notably, for the effect of crop residue incorporation, organic observed
535 amendments and N fertilizer application, crop types and tillage systems. In the Austrian LTEs,
536 application of green manure + municipal compost showed a higher S compared to the application
537 of other organic amendments. Incorporation of crop residues and high N fertilizer application also
538 increased k . In the Swedish LTEs, it was shown that combined management practices with both
539 farmyard manure and mineral NPK resulted in higher k and S compared to no manure and no NPK
540 applications, whereas growing spring cereals instead of leys increased k but did not change S . For
541 both countries, tillage systems with deep reduced tillage practices presented higher k , and shallow
542 reduced tillage presented higher S . However, these effects were also site or year dependent within
543 a given country. Climatic conditions had the most important impact on the decomposition rate k
544 and the stabilization factor S , but also pH, treatment, crop types, SOC, C:N ratio and clay content
545 were good predictors of the TBI parameters. Generally, the correlations with raw climatic variables
546 such as precipitation and temperature were quite poor. Better relationships were found when
547 nonlinearities due to interactions between climatic and edaphic conditions were accounted for. Our
548 results highlights how a wide range of soil management practices affect TBI parameters jointly to
549 soil and climatic conditions.

550

551 **Data availability**

552 Data can be provided by the authors upon request.

553

554 **Author contribution**

555 MRG, MB and TS wrote and prepared the manuscript draft; MB, TK and TS supervised and led
556 the research; MB, OA, HS, JKF, AS, AS and TS developed the methodology; MRG and LM
557 analyzed the data. All authors reviewed and edited the manuscript.

558

559 **Competing interests**

560 The contact author has declared that none of the authors has any competing interests.

561

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567

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798 **Tables**

799

800 Table 1. Experimental sites in Austria. Site acronym, location name, year of TBI measurements,
 801 category and type of LTE including its duration, main crop cultivated during the TBI
 802 measurements and management treatments

803

Site	Location	Year	Category*	Experiment [†]	Age	Crop	Treatments [§]
AT1	MUBIL	2014	CB	OA	11	Luzerne	GM, FW, FYM, BS
AT2	MUBIL	2015	CB	OA	12	Wheat	GM, FW, FYM, BS
AT3	Ritzlhof	2015	CB	IF-N & OA+N	24	Maize	0, 40, 90, 120 N CFW, CGM, CS, CSS+80N
AT4	Rottenhaus	2016	CB	CR with NPK	31	Maize	CRR, CRI
AT5	Rutzendorf	2015	CB	CR with NPK	34	Wheat	CRR, CRI
AT6	Rutzendorf	2016	CB	CR with NPK	35	Maize	CRR, CRI
AT7	Breitstetten	2015	SF	IF-N with PK	40	Wheat	60, 90, 120, 145 N
AT8	Breitstetten	2016	SF	IF-N with PK	41	Wheat	60, 90, 120, 145 N
AT9	Haringsee	2015	SF	IF-N with PK	40	Wheat	60, 90, 120, 145 N
AT10	Fuchsenbigl	2016	SF	IF-K with NP	61	Maize	0, 150, 300 K
AT11	Rottenhaus	2016	SF	IF-K with NP	63	Maize	0, 150, 300 K
AT12	Haringsee	2016	SF	IF-N without PK	41	Maize	0, 60, 120, 180 N
AT13	Zinsenhof	2016	SF	IF-N without PK	41	Maize	0, 60, 120, 180 N
AT14	Zissersdorf	2016	SF	IF-N without PK	41	Maize	0, 60, 120, 180 N
AT15	Fuchsenbigl	2015	TS	TS	27	Maize	CT, SRT, DRT
AT16	Fuchsenbigl	2016	TS	TS	28	Wheat	CT, SRT, DRT

804 * CB: carbon balance practices; SF: soil fertility; TS: tillage systems.

805 [†] OA: organic amendments; IF-N & OA+N: N inorganic fertilization and organic amendments plus mineral N; CR &
 806 IF-P with NK: crop residues and P inorganic fertilization with 90 and 40 kg ha⁻¹ of N and K, respectively; IF-N with
 807 PK: N inorganic fertilization with 55 and 180 kg ha⁻¹ of P and K, respectively; IF-N without PK: N inorganic
 808 fertilization; IF-K with NP: K inorganic fertilization with 40 and 120 kg ha⁻¹ of P and K; TS: tillage system.

809 [§] GM: green manure; FW: municipal compost and green manure; FYM: farmyard manure; BS: biogas slurry; CFW:
 810 compost food waste with 175 kg N ha⁻¹; CGM: compost green manure with 175 kg N ha⁻¹; CS: compost slurry with
 811 175 kg N ha⁻¹; CSS: compost sewage sludge with 175 kg N ha⁻¹; CRR: crop residues removed; CRI: crop residues
 812 incorporated; CT: conventional tillage; SRT: shallow reduced tillage; DRT: deep reduced tillage.

813

814

815 Table 2. Experimental sites in Sweden. Site acronym, location name, year of TBI measurements
816 conducted in 2016, type of LTE including its duration, main crop cultivated during the TBI
817 measurements and management treatments
818

Site	Name	Experiment*	Age	Crop	Treatments†
SE1	Börgeby	CMP	59	Sugar beet	FYM/NPK
				Sugar beet	0 FYM/0 NPK
SE2	Ekebo	CMP	59	Sugar beet	FYM/NPK
				Sugar beet	0 FYM/0 NPK
SE3	Högåsa	CMP	50	Ley production year	FYM/NPK
				Ley production year	FYM/0 NPK
				Spring oilseed	0 FYM/NPK
				Spring oilseed	0 FYM/0 NPK
SE4	Kungsängen	CMP	53	Oat	FYM/NPK
				Oat	0 FYM/0 NPK
SE5	Röbacksdalen	CMP	47	Barley	FYM/NPK
				Barley	FYM/0 NPK
SE6	Vreta Kloster	CMP	50	Ley production year	FYM/NPK
				Ley production year	FYM/0 NPK
				Spring oilseed	0 FYM/NPK
				Spring oilseed	0 FYM/0 NPK
SE7	Lanna	ROT	35	Oat	SC
				Ley production year	L
SE8	Lönnstorp	ROT	36	Barley	SC
				Ley establish. year	L
SE9	Röbacksdalen	ROT	36	Barley	SC
				Ley establish. year	L
SE10	Säby	ROT	46	Wheat	SC
				Ley establish. year	L
SE11	Lanna	TS	34	Winter wheat	CT, DS
SE12	Säby	TS	11	Barley	CT, SRT, DRT, DS
SE13	Ultuna	TS	19	Barley	CT, DRT

819
820 * CMP: combined management practices; ROT: rotation systems; TS: tillage systems.
821 † FYM/NPK: maximum amount of farmyard manure and maximum doses of NPK; 0 FYM/0 NPK: no manure and no
822 NPK application; FYM/0 NPK: maximum amount of farmyard manure and no NPK application; 0 FYM/NPK: no
823 manure and maximum doses of NPK; SC: spring cereal; L: ley; CT: conventional tillage; DS: direct seeding; SRT:
824 shallow reduced tillage; DRT: deep reduced tillage.
825

826

827 Table 3. Annual climatic characteristics for the Austrian and Swedish sites during the entire year
828 of measurements and only during the TBI period (days) corresponding to the period between the
829 date of placement and the last retrieval date of the tea bags.
830

Site	TBI period	TAP	TP _{TBI}	MAT	MAT _{TBI}	PET	PET _{TBI}	AI	AI _{TBI}
	days	mm		°C		mm			
<i>Austria</i>									
AT1	99	756	294	12.5	20.3	811.4	414.0	1.07	1.4
AT2	61	516	65	12.6	18.8	605.1	141.3	1.17	2.2
AT3	80	622	161	12.2	20.0	682.9	295.1	1.09	1.8
AT4 & 11	84	939	384	11.2	20.5	763.4	306.1	0.81	0.8
AT5	63	516	82	12.6	19.4	605.1	148.6	1.17	1.8
AT6	96	735	226	12.0	21.6	854.2	394.0	1.16	1.7
AT7	59	516	81	12.6	19.3	605.1	137.4	1.17	1.7
AT8	84	735	240	12.0	17.1	854.2	334.2	1.16	1.4
AT9	60	516	81	12.6	19.2	605.1	139.6	1.17	1.7
AT10 & 16	92	735	205	12.0	21.4	851.2	378.9	1.15	1.8
AT12	87	735	203	12.0	21.8	854.2	367.4	1.16	1.8
AT13	84	939	327	11.2	20.5	763.4	304.3	0.81	0.9
AT14	82	735	154	12.0	21.3	854.2	319.6	1.16	2.1
AT15	81	516	103	12.6	22.5	605.1	212.9	1.17	2.1
<i>Sweden</i>									
SE1	92	436	141	9.2	16.7	444.6	235.1	1.02	1.7
SE2	91	681	270	9.0	16.5	578.5	297.8	0.85	1.1
SE3	91	458	142	7.9	13.3	618.0	306.4	1.35	2.1
SE4	93	429	126	7.1	15.3	640.0	367.0	1.48	2.9
SE5 & 9	92	526	164	4.1	14.3	396.2	218.2	0.75	1.3
SE6	91	433	158	7.9	13.3	617.5	301.8	1.16	1.9
SE7 & 11	91	412	115	7.4	12.7	514.2	276.4	1.3	2.4
SE8	90	610	224	9.4	14.4	500.2	265.7	0.82	1.2
SE10 & 12	91	429	126	7.1	15.3	358.5	155.7	0.84	1.2
SE13	92	429	126	7.1	15.3	639.1	377.8	1.5	3.0

831
832 TAP: total annual precipitation; TP_{TBI}: total precipitation during TBI period; MAT: mean annual temperature;
833 MAT_{TBI}: mean temperature during TBI period; PET: total annual potential evapotranspiration; PET_{TBI}: potential
834 evapotranspiration during TBI period; AI: annual aridity index (PET divided by TAP); AI_{TBI}: aridity index during TBI
835 period.
836

837

838 Table 4 – Mean values of decomposition rate (k) and stabilization factor (S) for the TBI approach
839 after the incubation period.

840

	Mean TBI parameters	
	k	S
<i>Sweden</i>	0.0160 ± 0.01	0.247 ± 0.14
<i>Austria</i>	0.0115 ± 0.004	0.228 ± 0.11

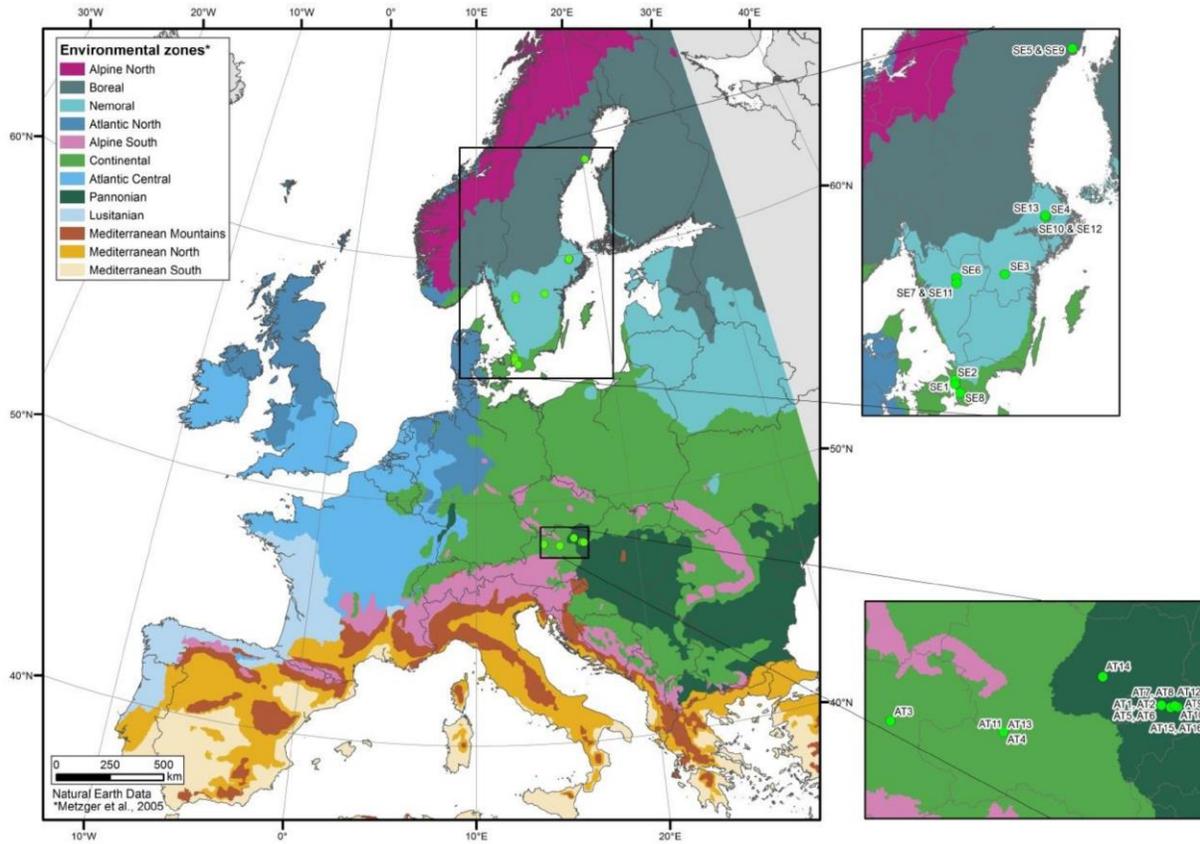
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843 **Figures**

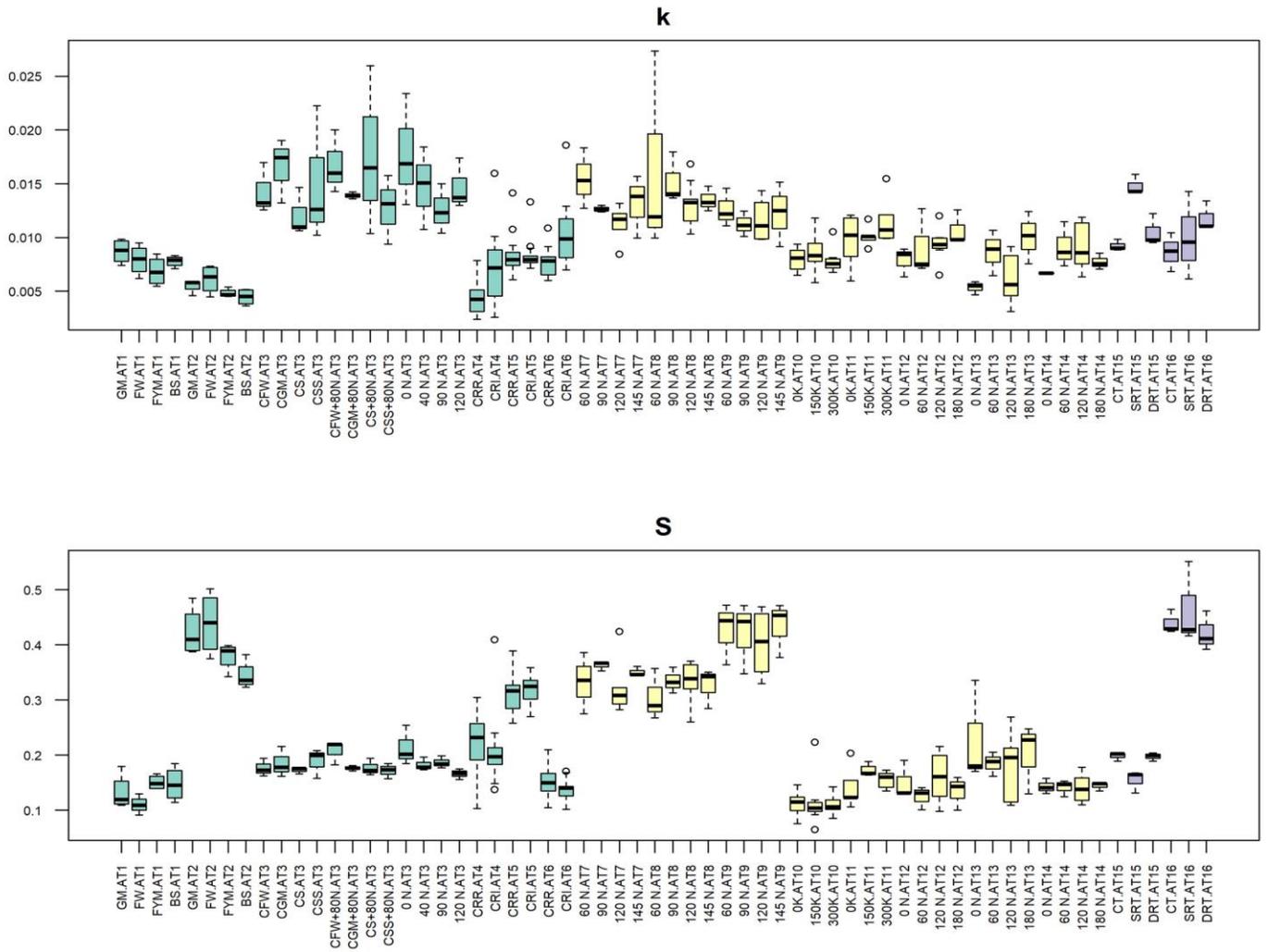
844

845 **FIGURE 1**

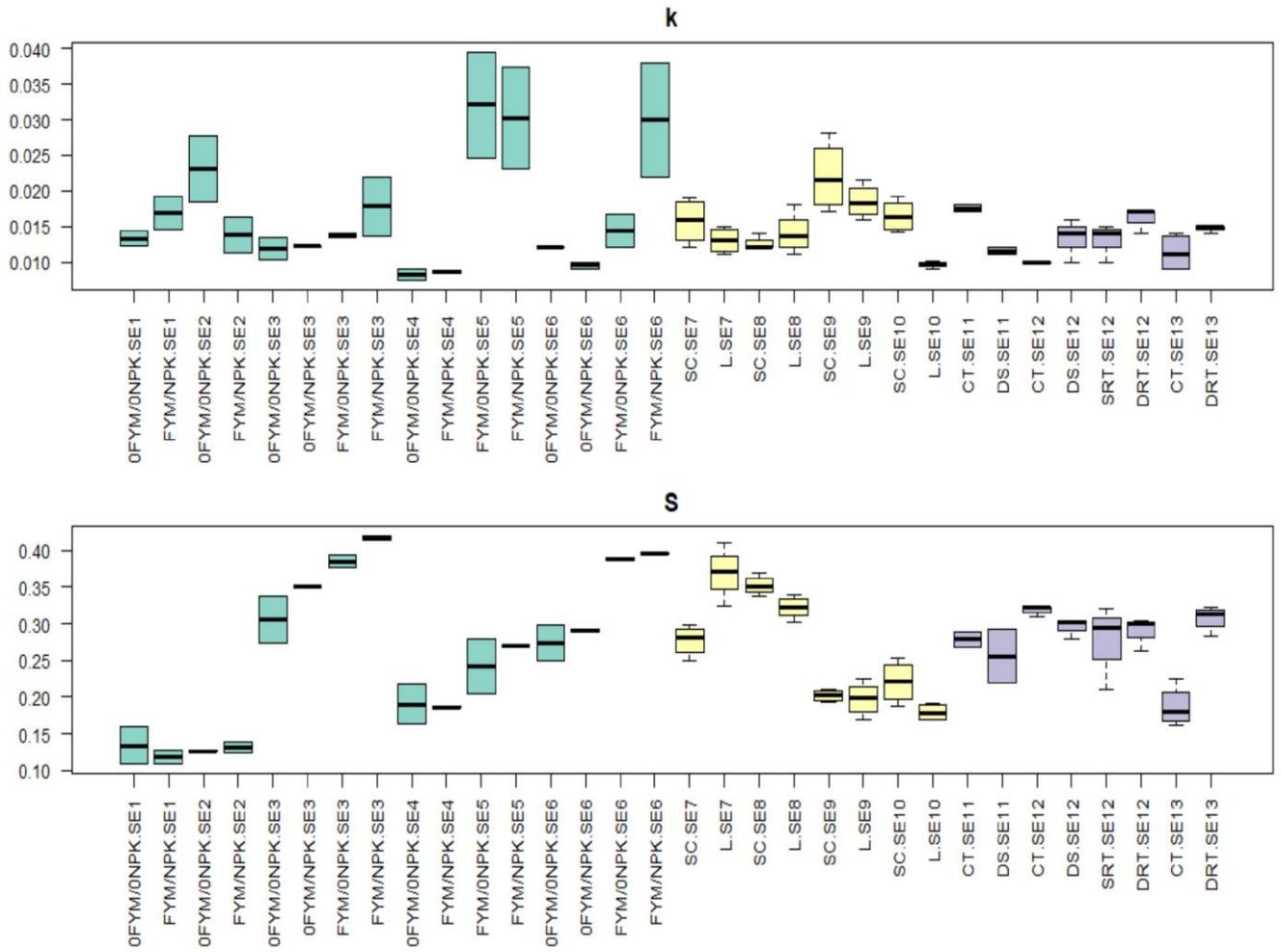


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847 **FIGURE 2**

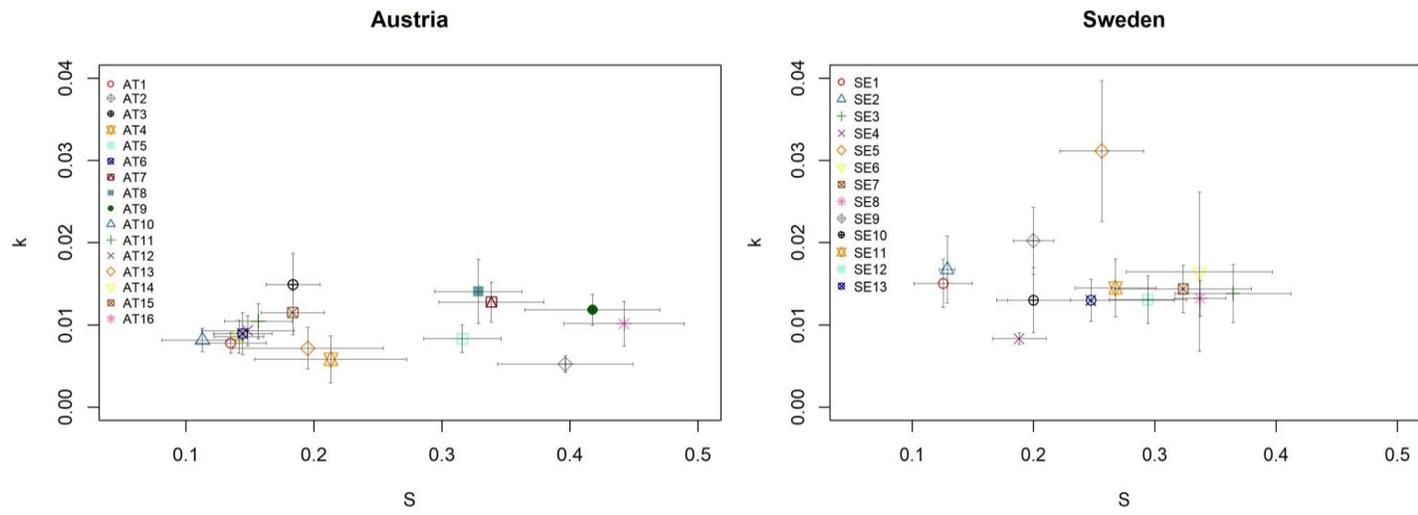


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852 **FIGURE 4**

853

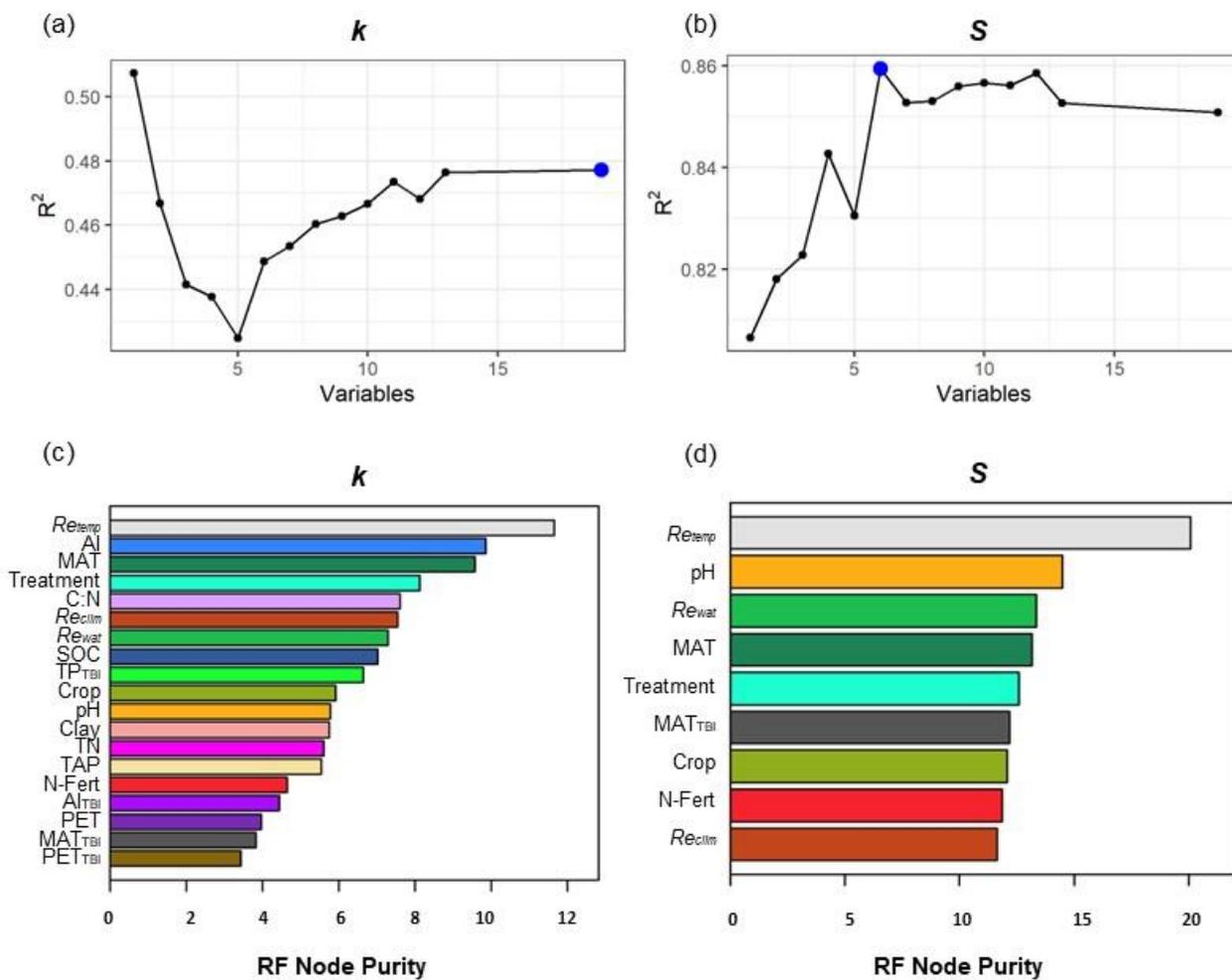


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855 **FIGURE 5**

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874

875 Figure 3 - Average decomposition rate (k) and stabilization factor (S) for each site and treatment
876 in Sweden. The extents of the box indicate 25th and 75th percentiles, and the lines represent the 50th
877 percentile. Whiskers represent the 10th and 90th percentiles. Green boxes: combined management
878 practices (CMP) experiment; yellow boxes: rotation (ROT) experiment; purple boxes: tillage
879 systems (TS) experiment.

880

881 Figure 4 - Distribution of the mean decomposition rate constant (k) and the stabilization factor (S)
882 for each site in Austria and Sweden. Errors bars represent standard deviation.

883

884 Figure 5 - a and b) Variables selection procedure to identify the optimal number of variables to
885 explain the variance of k and S with a Random Forest model. The blue point represents the optimal
886 model. c and d) Relative importance of the variables used by each optimized Random Forest model
887 to predict the variance in the k and S parameters in Austria and Sweden jointly. The higher the
888 Node purity, the higher the importance of such variable.

889

890 Figure 6 - Principal component analysis showing how the sites in Austria and Sweden differ based
891 on the variables. PC1 and PC2 are the first two components, explaining most variance. The
892 loadings (black arrows) are the weight of each variable in defining each principal component. The
893 size of the arrows can tell how much they contribute defining this space, while the direction is their
894 contribution on each axis. Tap: total annual precipitation; TxP: temperature x precipitation factor;
895 pet: potential evapotranspiration; mat: mean annual temperature; tn: total soil nitrogen; soc: total
896 soil organic carbon; cn: soil C:N ratio; ai: aridity index.

