



UNIVERSITÀ POLITECNICA DELLE MARCHE
Repository ISTITUZIONALE

C-sequestration and resilience to climate change of globe artichoke cropping systems depend on crop residues management

This is the peer reviewed version of the following article:

Original

C-sequestration and resilience to climate change of globe artichoke cropping systems depend on crop residues management / Deligios, P.A., Farina, R., Tiloca, M.T., Francaviglia, R., Ledda, L.. - In: AGRONOMY FOR SUSTAINABLE DEVELOPMENT. - ISSN 1774-0746. - 41:2(2021). [10.1007/s13593-021-00680-5]

Availability:

This version is available at: 11566/290512 since: 2024-03-25T10:45:49Z

Publisher:

Published

DOI:10.1007/s13593-021-00680-5

Terms of use:

The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. The use of copyrighted works requires the consent of the rights' holder (author or publisher). Works made available under a Creative Commons license or a Publisher's custom-made license can be used according to the terms and conditions contained therein. See editor's website for further information and terms and conditions.

This item was downloaded from IRIS Università Politecnica delle Marche (<https://iris.univpm.it>). When citing, please refer to the published version.

Publisher copyright:

Springer (article) - Postprint/Author's accepted Manuscript

This version of the article has been accepted for publication, after peer review (when applicable) and is subject to Springer Nature's AM terms of use <https://www.springernature.com/gp/open-research/policies/accepted-manuscript-terms>, but is not the Version of Record and does not reflect post-acceptance improvements, or any corrections. The Version of Record is available online at: 10.1007/s13593-021-00680-5.

(Article begins on next page)

1 Research Article

2 C-sequestration and resilience to future climate change of globe artichoke cropping systems greatly
3 depends on crop residues management

4
5 Paola A. Deligios¹, Roberta Farina^{2*}, Maria Teresa Tiloca¹, Rosa Francaviglia², Luigi Ledda³

6
7 ¹ Department of Agricultural Sciences, University of Sassari, Viale Italia 39, 07100 Sassari, Italy

8 ² Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Centro di ricerca Agricoltura e
9 Ambiente (CREA-AA), Italy

10 ³ Department of Agricultural, Food and Environmental Sciences, Marche Polytechnic University, Via
11 Breccie Bianche 10, 60131 Ancona, Italy

12
13
14
15
16
17 Corresponding author roberta.farina@crea.gov.it (Roberta Farina); Consiglio per la ricerca in
18 agricoltura e l'analisi dell'economia agraria, Centro di ricerca Agricoltura e Ambiente (CREA-AA),
19 Via della Navicella 2-4, 00184 Roma (Italy). ORCID ID 0000-0003-4378-0484

20
21
22 **Abstract**

23 Globe artichoke is one of the most intensively cultivated horticultural species in Mediterranean regions.
24 In this context, sustainable agronomic management is a requisite to increase the soil carbon content,
25 making the artichoke cultivation system more resilient to climate change. A ten-year experiment was
26 considered to forecast the influence on soil C dynamic of three globe artichoke managements:
27 monoculture with dry crop residues incorporation (conventional monoculture); monoculture with the
28 inclusion of a cover crop (alternative monoculture); rotation with cauliflower plus cover crop (biannual
29 rotation). During the 2006-2016 period, total soil organic carbon content and plant C inputs to soil were
30 measured. RothC model was used to predict the effect on the soil C stock and C sequestration potential
31 in 20 years of the three managements tested in the field, plus a hypothetical conventional scenario with
32 no residues' incorporation (no-residues). Plant C inputs increased according to the number of crops in
33 rotation in each system, resulting 25% lower in conventional monoculture with respect to biannual
34 rotation, whereas the C stock change was significantly higher ($p < 0.01$) in conventional and alternative
35 monoculture (+ 7.57 and 7.14 t C ha⁻¹) compared to biannual rotation (-1.03 t C ha⁻¹). In the twenty
36 years predictions all the systems had a positive C balance. The soil organic carbon change (t C ha⁻¹) for
37 the future climate was + 7.2 for alternative monoculture, and + 0.6 for monoculture with residues

38 removals. For the first time, in this study, we clearly shown in the long-term and in a climate change
39 perspective that an improper crop residues management might lead to a loss of soil fertility in
40 intensively cultivated horticultural soils under Mediterranean climate. The adoption of biannual rotation
41 with cauliflower needs to be evaluated carefully because it proved to be less efficient in terms of C
42 sequestration potential.

43

44 **Keywords:** *Cynara cardunculus* var. *scolymus*, crop modeling, soil carbon content, sustainable
45 horticulture

46

47 **1. Introduction**

48 In view of wellbeing, World Health Organization directions advocate an enhancement in vegetable
49 individual daily intake. Therefore, worldwide vegetable production is quickly increasing (FAO 2017).
50 Vegetable production is predominantly achieved through intensive horticultural systems. High rates of
51 chemical inputs (e.g. fertilizers, pesticides), repeated cultivation operations, and inadequate soil surface
52 cover are frequent issues threatening the preservation of soil quality (organic matter content and other
53 soil properties) in intensive horticultural systems (EIP-AGRI Focus Group 2015). Moreover, the high
54 application of chemicals also increases the probability that fertilizers and pesticides reach surface and
55 groundwater by runoff and leaching (Eurostat 2015). Soil health is somewhat impaired by intensive
56 agriculture, primarily for fertility depletion (e.g. soil organic matter). For some horticultural crops, only
57 a small amount of organic material is returned to the soil after harvest (Brennan and Acosta-Martinez
58 2017). Thus, horticultural cropping systems could have a serious negative effect on soil fertility and
59 ecosystem services delivery. Indeed, within the Mediterranean intensive horticultural systems, the
60 distribution of organic fertilizers based on humic and fulvic acid has become a common practice, in
61 relation to the need to improve cation exchange capacity of the soil and provide slowly available organic
62 nitrogen (Alvarenga et al. 2015; Urra et al. 2019). At present, agronomic studies have usually neglected
63 investigations on soil fertility in horticultural systems, and this may be regarded as an important research
64 shortcoming, which should be addressed with the aim to develop new knowledge to meet the demand
65 of sustainable food by a rising population (Norris et al. 2018). To improve soil fertility, different
66 alternative managements and agronomic techniques have been suggested, aiming also at reducing
67 external inputs and nutrients losses, e.g. stubble retention. Sustainably managed, agriculture can
68 minimize the impacts caused by intensification and foster the soil resilience in the long-term (Gomiero
69 et al. 2011). Over the past years, research has resulted in significant progress in developing
70 techniques/practices of crop production while reducing negative effects on soil quality and ecosystem
71 services delivery, i.e. adopting conservation agriculture with minimum tillage, and decreasing
72 exogenous fertilisers application by a sound use of crop rotations or pre-plant soil analysis (Knowler
73 and Bradshaw 2007). Nevertheless, these progresses were mainly addressed to open-field crops such as
74 cereals, mostly used for animal feeding (Cassidy et al. 2013) rather than to human consumption. To

75 enhance soil organic carbon (SOC) content and promote sustainability, an adjustment of management
76 is needed, including organic amendments both of animal and of plant origin, cover-crop or mulching,
77 and a lower number of cultural operations (EIP-AGRI Focus Group 2015). Globe artichoke (*Cynara*
78 *cardunculus* L. var. *scolymus* (L.) Fiori) is a horticultural species widely grown in Mediterranean
79 climate-type areas for its heads (Deligios et al. 2017). In Southern Italy, where the majority of the globe
80 artichoke cultivation is carried out, re-flowering genotypes (e.g. Spinoso sardo) are well adapted to
81 forcing technique (summer implantation by dormant offshoots, followed by frequent irrigations) and are
82 usually cultivated in monoculture (consecutively for seven or more years), with a large amount of
83 chemical fertilizers supply (e.g. 250 – 400 kg N ha⁻¹, Bianco and Calabrese 2009). The earliest head
84 productions of such genotypes (from October to February), because of their better quality and higher
85 commercial price, are destined for fresh consumption, while only the late ones (from late March to
86 April) are used for the food industry (Sgroi et al. 2015).

87 From this perspective, an environmentally sound management, including incorporation of crop residues,
88 use of cover-crop, and a proper crop-rotation can be regarded as practices able to ensure long-term
89 nutrient supply and soil fertility. Furthermore, these techniques may be considered as management
90 alternatives on which to plan innovative and resilient globe artichoke cropping systems.

91 To promote alternative management of artichoke cropping systems, is of paramount importance to
92 enhance awareness of farmers and policy makers on advantages of an environmental sound crop
93 management. The adoption of more resilient cropping systems, aims to positively affect the soil C stock,
94 contributing significantly to adaptation and mitigation of climate change. However, providing advices
95 on best practices to reach the objective of increasing soil C content in soils is challenging, due to the
96 slow change of soil C in response to management (Mondini et al. 2012), often difficult to measure in
97 short-term field experiments. The combination of long-term experiments (> 6 years) and process-based
98 models has proved to be an effective approach to predict the soil carbon dynamics over long periods,
99 thus allowing for a long-term estimation of farming practices effects on SOC. Among the most used
100 models, RothC (Coleman and Jenkinson 1999) has proved to be well suited to simulate accurately the
101 soil C dynamics in several pedoclimatic situation and in Mediterranean cropping systems (Mondini et
102 al. 2012; Pardo et al. 2017; Farina et al. 2018). With specific regards to horticultural systems in the
103 Mediterranean region, a successful example of combining data from long-term experiments and
104 process-based model, is represented by the use of RothC with a dataset obtained from an Italian long-
105 term horticulture experiment under organic management (Farina et al. 2018). We used a long-term field
106 experiment (Deligios et al. 2017) as a case-study representative of horticultural systems in the
107 Mediterranean area to predict the long term effect on soil C dynamic of alternative artichoke cropping
108 system management, namely: conventional monoculture with residue retainment in the field and
109 improved management of fertilization, alternative monoculture with bean as cover crop and biannual
110 rotation with cauliflower and pea as cover crop. Soil C content during the years and plant C inputs to
111 soil were measured. For the first time, RothC model was used to forecast the long term effect of the

112 different management combinations plus a hypothetical monoculture with residues removal scenario on
113 the soil C stock in 20 years, used as a reference systems, but also realistic because it takes into account
114 the still used practice of burning biomass or the possible alternative use of residues as a feedstock for
115 biorefinery (D'Avino et al. 2020). The resilience of each system, in terms of C sequestration potential,
116 to climate change was assessed.

117

118 **Here Figure 1 The two phases of the biannual rotation system. The picture on the left shows the**
119 **cauliflower phase, and the picture on the right the globe artichoke phase. In the biannual rotation**
120 **management globe artichoke is grown in sequence to cauliflower. By contrast, in the traditional**
121 **globe artichoke cultivation practice globe artichoke is grown in monoculture for many**
122 **consecutive years.**

123

124 **2. Material and Methods**

125 *2.1 Site and treatments description*

126 The long-term field experiment is ongoing since 2006 at the experimental farm 'Mauro Deidda' few
127 kilometers apart from Sassari, in Sardinia (Southern Italy: 40°46'N, 8°29'E). Following the Köppen-
128 Geiger climate classification (Beck et al. 2018), the experimental site has a hot- summer Mediterranean
129 climate, with warm winters, hot and dry summers, and with the highest precipitation in autumn and
130 winter. During the studied period (2006–2016), the mean annual temperature, precipitation and
131 potential evapotranspiration were 16.6 °C, 529 and 776 mm respectively. The soil is Lithic Xerochrept
132 (USDA 1999) developed on a limestone bedrock with 49.0% sand, 24.3% silt and 19.6% clay (sandy
133 clay loam). In 2006, at the start of the experiment the topsoil (0–20 cm) soil organic C content ranged
134 from 49.8 t ha⁻¹ to 58.2 t ha⁻¹, and pH was 7.9. A full description of long-term experiment is detailed in
135 Deligios et al. (2017). Globe artichoke, 'Spinoso sardo' varietal type, was grown according to three
136 different crop managements: a conventional monoculture, and two sustainable systems (alternative
137 monoculture and biannual rotation). The experimental field (in total 4080 m²) was organized according
138 to a randomized block design with three treatments and three replications. Blocks and plots were
139 separated by approximately 3 m.

140 To mimic the traditional forcing technique (Ledda et al. 2013), every year since 2006, after plowing at
141 25 cm depth and harrowing at 10 cm, at beginning of July, the 10-cm-long semi-dormant offshoots of
142 Spinoso sardo artichoke were planted. The distance between plants within a row was 70 cm, achieving
143 a density of around 9500 plants ha⁻¹. Drip irrigation of approximately 300 mm was applied to the entire
144 experimental field (when accumulated daily evaporation reached 35 mm, 100% of maximum
145 evapotranspiration) from the date of planting to the first rainfalls (on average from the end of July to
146 the end of October).

147 The conventional monoculture was carried out according to the ordinary practice of local farmers,
148 incorporating into the soil the senescent artichoke residues, at the end of the growing cycle in June, by

149 chopping, plowing and harrowing up to a 10-cm depth. Fertilizer application, based on crop uptake
150 which reflects the synchronization of crop nutrient requirements and soil macronutrient supply (Piras,
151 2013) was 150, 125, and 140 kg ha⁻¹ of total N, P, and K, respectively in four split doses, namely at
152 planting, mid-September, late-November, and late-February. Pest and disease controls followed the
153 Best Management Practices recommended at Regional level.

154 In the alternative monoculture, the artichoke crop cycle was ended when the harvest of heads was no
155 longer profitable (around the first half of April) and the artichoke whole fresh residues were
156 incorporated into the soil by chopping and harrowing at 20-cm depth. Thereafter, a bean cover crop
157 (*Phaseolus vulgaris* L. cv. Bronco) (Monsanto Agricoltura Italia SpA, Italy) was sown, and its growing
158 cycle was interrupted soon after the first pod harvesting to incorporate fresh residues of the cover crop
159 before preparing the seed-bed (by plowing at 25-cm depth and harrowing at 10 cm) for the following
160 artichoke growing cycle.

161 In the biannual rotation system, a two-year rotation artichoke-cauliflower (*Brassica oleracea* L. var.
162 *botrytis*; cv Nautilus) (Clause Italia SpA, Italy) was set-up on alternate plots; thus, all phases of the crop
163 sequence were present in the field every year. Moreover, each year in February, in inter-row spaces, a
164 pea cover crop (*Pisum sativum* L.; cv Attika) (Limagrain Verneuil Holding, France) was systematically
165 sown after an interrow rotary harrowing pass (10-cm depth). At the end of the harvest period, both for
166 cauliflower and globe artichoke, all fresh residues, including those of the cover-crop, were chopped and
167 incorporated into the soil by rotary-harrowing at 20-cm depth. Two months after incorporation, the beds
168 in all plots were plowed at 25-cm depth and harrowed at 10 cm for the next cauliflower or artichoke
169 production cycle. In the two sustainable systems, plant nutrients demand was satisfied by the plant fresh
170 residues incorporated to soil, since the aim was to design a cropping system without external chemical
171 fertilisers input. Moreover, the alternative monoculture and biannual rotation systems were conducted
172 without synthetic pesticide use.

173

174 **2.2 Samplings and analysis**

175 Soil samples at 0-20 cm depth were randomly collected in July 2006 in the whole experimental field,
176 in order to assess the total organic carbon at the start of the experiment. In the years 2009, 2013, 2016
177 four soil samples per plot were collected before the starting of each new growing season, in order to
178 quantify the effect of plant residues soil incorporation (namely globe artichoke, weeds, cauliflower and
179 cover crops). Soil samples after air-drying to constant weight, were analyzed for total organic carbon
180 using the LECO analyzer (628 Series; LECO Corp., St. Joseph, MI, USA).

181 Every year, before the end of the growing season, samples of total fresh biomass were taken for each
182 plot as follows: three plants of artichoke (for all the cropping systems); six plants of cauliflower
183 (biannual rotation) and bean (alternative monoculture); 0.5-m² of central area in the inter-row spaces
184 for the determination of pea (biannual rotation) and weeds biomass (for all the cropping systems). The
185 average total biomass per plant was multiplied by crop density for absolute biomass (kg ha⁻¹) estimation.

186 Plant samples were fractionated into two parts. One part was dried at 55 °C to constant weight and
187 stored for nutrient analysis; another part was dried at 80°C for 24 hours (up to weight stabilization) for
188 the determination of the dry matter content. All the organic biomass utilized as C input was analyzed
189 for C content using a LECO analyzer by a dry combustion method. Total carbon content per hectare of
190 biomass was calculated by multiplying the content by the whole biomass value (dry-weight basis). Root
191 biomass was estimated as 30% of the aboveground biomass for all the crops.

192

193 **2.3 Modeling**

194 The RothC model (Coleman and Jenkinson 1999) simulates SOC dynamics and has been tested in a
195 large range of pedoclimatic conditions and cropping system management. The model requires relatively
196 easily available inputs and produces reliable and accurate simulations (Francaviglia et al. 2012; Farina
197 et al. 2018; Robertson and Nash 2013). Soil C is split into five pools: four active compartments,
198 decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO) and
199 humified organic matter (HUM), each decomposing by a first order kinetics and specific decomposition
200 rate (years⁻¹), and one inert organic matter pool (IOM). All C inputs, from plants or external organic
201 fertilizers, are split between DPM and RPM, with a variable ratio depending on the type of material.
202 Both DPM and RPM decompose to form CO₂ (lost from the system), BIO and HUM, depending from
203 soil clay (Coleman and Jenkinson 1999).

204

205 **2.3.1 Running RothC**

206 Running RothC requires the following:

207 (a) Climatic data: Monthly rainfall (mm), potential evaporation (mm) and mean air temperature
208 (°C);

209 (b) Soil data: Clay content (%), initial SOC (t C ha⁻¹), bulk density (g cm⁻³), depth of the soil layer
210 considered (cm);

211 (c) Land use and land management data: Soil cover (1/0), C input from plants, residues, and organic
212 fertilisers (t C ha⁻¹).

213 For RothC running, the potential evapotranspiration (ET) was calculated from measured weather data
214 using the Thornthwaite equation. The irrigation amount was calculated by the difference between
215 rainfall and ET and slightly corrected in order to keep available water at 80% during the irrigation period
216 (from July to November) (350 mm as average). The bulk density, used to transform mg of C per kg of
217 soil in t C ha⁻¹, was the average of the measurements in all plots at the beginning of the experiment.
218 RothC was initialized using the SOC content measured at the beginning of the experiment using the
219 default partitioning among the SOC pools. The model was run iteratively to equilibrium (10.000 years)
220 in order to generate the input required to match the initial stock of SOC, and then calibrated with the
221 conventional treatment. The aboveground C inputs of the artichoke and weeds were measured, whilst
222 belowground were estimated according to Raccuia and Melilli (2010) for artichoke and Farina et al.

223 (2018) for cover crops, cauliflower and weeds considering a root:shoot ratio of 0.3. The total C input
224 was divided into monthly fractions according to the crop phenological stage following Raccuia and
225 Melilli (2010), ranging from a fraction of 0.05 at crop establishment to a 0.35 one at maximum biomass
226 development.

227 The model was calibrated using the conventional monoculture treatment and included the modification
228 of artichoke residues partitioning coefficient of the pools DPM and RPM, by adjusting the relative rate
229 to fit the measured C changes in the soil (Heitkamp et al. 2012). All the other treatments were used to
230 validate the model, with 18 pair of data (measured and modeled), not considering the data used for
231 initialization and calibration, according to the different land management.

232

233 2.3.2 Predictions of C sequestration potential in the medium term (20 years) for the different systems

234 We run the model for the different cropping systems to assess the medium-term potential to accumulate
235 soil C, using averaged field data for C inputs, irrigation and soil cover and climate projection (baseline
236 and future climate scenarios). Twenty years of simulated weather data were obtained by AGRI4Cast
237 Resource Portal (<https://agri4cast.jrc.ec.europa.eu/DataPortal/>), consisting in daily weather data for
238 Europe (on a 25 × 25 km grid) by three General Circulation Models: (1) METO-HC (METO); (2) DMI-
239 HIRHAM5-ECHAM5 (ECHAM); and (3) ETHZ-CLM-HadCM3Q0 (ETHZ) of the MARS-
240 AGRI4CAST as *Daily weather data for crop modelling over Europe derived from climate change*
241 *scenarios* (available at <https://agri4cast.jrc.ec.europa.eu/DataPortal/>, last accessed the 28th December
242 2020). The model was run with the baseline (1990-2010) and future (2011-2030) climate projections,
243 obtained by each of the three General Circulation Models. Projected baseline weather data were
244 comparable with those measured in the long-term. The temperature and rainfall changes in future
245 climate scenarios compared with current situation were as follow: METO no change of temperature and
246 + 13% of rainfall; ECHAM +0.35°C and +7% rainfall; ETHZ +0.6°C and +13% rainfall.

247 In addition to the simulations of the cropping systems tested in the field, we run also a hypothetical
248 reference system of conventional artichoke with residues removed from the field (monoculture with-
249 residues removals), representing a realistic situation where artichoke residues are burnt or removed as
250 biomass for biorefinery utilization. The C inputs used to run this scenario were the same of the
251 conventional monoculture for weeds and artichoke roots, whereas we assumed that 75% of the
252 artichoke aboveground biomass is removed, whatever the use, based on data reported by D'Avino et al.
253 (2020) in a similar system. Inputs for the biannual rotation are reported as average of the two fields.
254 Irrigation was not modified under future climate, to simulate a condition very common in Italy where
255 farmers have normally a fixed amount of water (350 mm in our case) distributed by the Water Use
256 Associations (ConSORZI di bonifica). The resilience to future climate change of each cropping system is
257 expressed as change in C sequestration potential i.e. % difference between SOC change in 20 years
258 between baseline and future climates.

259

260 2.4 Analysis of data

261 In order to detect significant differences among systems in terms of C input to the soil and changes in
262 soil organic C stock, data were first tested for homogeneity of variances (Bartlett's test) and for normal
263 distribution (Shapiro–Wilk test). Data that violated the assumptions for analysis of variance or t-test
264 were subjected the non-parametric Kruskal–Wallis test (instead of analysis of variance) or Mann–
265 Whitney U-test (instead of the t-test). All statistical tests were performed using SAS software (SAS v
266 9.2 1999).

267 C sequestration potential of the different systems in the field and after 20 years of simulation were
268 indicated as C stock change and obtained as:

$$269 \text{C stock change} = C_{\text{final}} - C_{\text{initial}}$$

270 Where C_{final} and C_{initial} are the SOC measured/simulated after 20 years and at beginning of
271 experiment or simulation respectively.

272 To assess the model performance and to compare measured and simulated values, we used the following
273 indicators:

274 i) RMSE (root mean square error),

$$275 \text{RMSE} = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}}$$

276 ranging to 0 to positive infinity, that indicates the accuracy of simulations. A value of 0 would
277 indicate a perfect fit of the modeled data to measured. RMSE is expressed in the same unit of the
278 measured data;

279 ii) coefficient of determination (R^2) of the linear regression estimates versus measurements
280 (association), ranging from 0 (absence of fit of the regression line) to 1 (perfect fit of the regression
281 line): the closer the values are to 1 the better the model performance;

$$282 R^2 = \frac{\sum_{i=1}^n (P_i - O_i) \cdot (O_i - \bar{O})}{\sqrt{\sum_{i=1}^n (P_i - \bar{P})^2 \cdot \sum_{i=1}^n (O_i - \bar{O})^2}}$$

283 iii) the EF (model efficiency) with a range from negative infinity to 1 (optimum), the closer the values
284 are to 1 the more efficient the model with respect to the observed mean

$$285 \text{EF} = 1 - \frac{\sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2}$$

286
287 where, P_i and O_i are the i^{th} simulated and observed values respectively, \bar{P} and \bar{O} the average simulated
288 and observed values respectively, and n the total number of observations.

289

290 3. Results and discussion

291 3.1 Crop residues, C inputs and soil C stock change in the field experiment

292 Cumulative C inputs for the three crop management systems tested in the field are shown in Table 1.

293

294 **Here Table 1 Mean cumulative carbon inputs from crop residues over the 2006–2016 period and**
295 **changes in soil organic C stock**

296

297 The difference in the amount of the soil incorporated residues between the monoculture system and the
298 rotation ones was mainly due to the amount of weeds aboveground residues that in the case of
299 conventional monoculture accounted for about 50% of the total amount of residues (Figure 2).
300 Estimated belowground residues (roots) followed the same trend, since they were calculated as a
301 percentage of the aboveground biomass. Results indicate that in alternative monoculture system, 49.4%
302 of residues was due to globe artichoke below and aboveground biomass, 39.5% to weeds, while 11.1%
303 was due to the cover crop (bean). In the biannual rotation cauliflower residues account only for the 6.4%
304 of the total amount of residues returned to soil at the end of the 10-year period.

305

306 **Here Figure 2 The percent contribution of each system component in terms of residues (above**
307 **and belowground) in conventional and alternative monoculture and biannual rotation cropping**
308 **systems at the end of the 10-year period (2006-2016). Error bars indicate standard error of the**
309 **means, n=10.**

310

311 The cumulative C inputs in the ten years considered, increased with increasing of cropping system
312 complexity, i.e. number of crops in the rotation, being 15% and 25% lower in conventional monoculture
313 compared to alternative monoculture and biannual rotation respectively (Table 1). Focusing on the
314 artichoke residues from above and belowground, the highest inputs were those of alternative
315 monoculture, by about 33 and 55% higher than conventional monoculture and biannual rotation
316 respectively. The inputs from weeds were high in all the treatments, even though, and as expected,
317 slightly higher (numerically, but not statistically) in the conventional monoculture, for the long period
318 in which the soil cover is left undisturbed, and lower in biannual rotation, with soil efficiently covered
319 by the crops in the rotation. The soil C stock change is significantly higher in the conventional and
320 alternative monoculture compared to the biannual rotation, roughly 114% higher ($p < 0.01$). This might
321 reflect the different composition and recalcitrance of residues incorporated to the soil. As a matter of
322 fact, in conventional and alternative monoculture systems, the aboveground C inputs from artichoke
323 residues, rich in lignin, are higher, namely 29 and 36% of the total (38 and 49% if we consider also the
324 roots C input), compared to those of biannual rotation (in average 15%).

325 After incorporation, the decomposition and mineralization are largely biological processes, mainly due
326 to the activity of the soil microorganisms (Kumar and Goh 2000; Zhu et al. 2015), and the
327 decomposition of residues is normally negatively related to the rate of recalcitrant compounds present
328 in their biomass, such as lignin, phenols, and tannins (Aber and Melillo 1982; Bertrand et al. 2006;
329 Castellano et al. 2015). So, probably, artichoke residues with 22% in weight of lignin might undergo a
330 slower degradation compared to the residues of the other crops, with less lignin content, namely around

331 6% and 11% in weight for cauliflower and bean respectively (Khedar et al., 2017, Puget and Drinkwater,
332 2001). This was also confirmed by the values of sequestration rates, namely 0.76 and 0.72 t C ha⁻¹ yr⁻¹
333 in conventional and alternative monoculture systems, whereas the average sequestration rate for the
334 biannual rotation is slightly negative (-0.2 t ha⁻¹ yr⁻¹), despite a higher C input to the soil. The average
335 negative C balance in the biannual rotation (-1.07 t C ha⁻¹) can be explained by two main factors: i) the
336 cauliflower has a C/N ratio and a lignin content (12 and 6% respectively) lower than artichoke, C/N 25
337 and lignin 22% Wt, and it was likely degraded faster; ii) the cover-crop (a leguminous species), rich in
338 N (C/N 10), might caused a sort of *priming* effect, i.e. a stimulation of organic matter degradation when
339 incorporated to the soil at the same time with cauliflower or artichoke residues (C/N 25) (Farina et al.
340 2018, Li et al., 2018). This accelerated decomposition phenomenon is also confirmed by the fact that,
341 despite 12% higher cumulative C input to soil in the alternative monoculture respect to the conventional,
342 the C sequestration rate is lower by 0.42 t C ha⁻¹ probably for the above mentioned effects of the N
343 added with plant residues of the leguminous cover-crop (Li et al., 2020). It should be also considered
344 that in biannual rotation there are two additional tillage operations that might accelerate oxidation of
345 organic matter by soil disturbance.

346

347 **3.2. RothC simulations**

348 Modification made to RothC regarding the DPM/RPM ratio of the artichoke residues, set to 1 (0.5 DPM
349 and 0.5 to RPM) instead of the default for herbaceous crop 1.44 (0.59 DPM and 0.41 RPM), produced
350 good simulation results (Figure 3). The modified DPM/RPM ratio for artichoke residues was adopted
351 to consider their peculiar characteristics, with high content of lignin ranging from 10 to 24% of the dry
352 matter (Fadda et al. 2018). For all the other C residues, namely weeds, cauliflower pea and bean, the
353 default value of DPM/RPM was used. The RothC predictions were closely associated with the measured
354 data. Indicators of performance were as follows: RMSE = 2 t ha⁻¹, R² = 0.84 (p<0.05) and EF = 0.78,
355 demonstrating a good accuracy of simulations. To evaluate the model performance, we compared
356 observed and predicted values, excluding the starting values used to initialize the model.

357

358 **Here Figure 3 Scatter plot of observed versus predicted soil organic carbon content. The dotted**
359 **line represents the 1:1 x:y relationship. Indicators of performance: RMSE = 2; R² = 0.84; EF =**
360 **0.78.**

361

362 **3.3. Change of C sequestration potential of the different systems**

363 The RothC simulations mimicked accurately the C dynamics in the different artichoke cropping
364 systems, as confirmed by the good score of the model performance indicators. Consequently, the model
365 could be used confidently to predict the influence of climate change on the soil C sequestration potential.
366 The three different climate scenarios allowed to explore a variety of combinations of temperature and
367 rainfall patterns variations in future climate compared to the baseline situation. Twenty years

368 predictions shown that all the systems, no matter of the climate scenarios considered, had a positive C
369 balance, e.g. accumulated C in the soil. In the period considered, the SOC change (in t C ha⁻¹ as
370 difference between initial and final value) as average for the three climate scenarios, were: conventional
371 monoculture +18% and +14% , alternative monoculture +24% and +22%, biannual rotation +10% and
372 +8%, monoculture with residues removal + 4% and +1% for baseline and future climate scenarios,
373 respectively (Table 3). Moreover, it is worth to mention that the two alternate systems of biannual
374 rotation, one starting with cauliflower and the other with artichoke, showed very different SOC change
375 at the end of the period, i.e. -5.2 and +1.36 t C ha⁻¹, wich is well mimicked also by simulations (Fig.
376 3).

377

378 **Here Table 3 Modeled soil organic carbon change for each system averaged for the three climates**
379 **scenarios**

380

381 When we consider the soil C sequestration potential in future climate scenarios compared to baseline
382 conditions, all the predictions point toward a possible reduction in this capacity. This result underlines
383 the risk, reported also by other authors' modelling results, that changes of climate (e.g. rain and
384 temperature increase) might negatively affect and even compromise the long-term fertility of
385 intensively cultivated soils in Mediterranean regions (Francaviglia et al. 2012 for tilled vineyards,
386 Munos-Rojas et al. 2017 for irrigated crops). Figure 4 graphically explains how the different cropping
387 systems react to the projected climate changes, that in the considered area consists in increase of both
388 rain and temperature. The graph is a three-dimensional one, where temperature change, rainfall change
389 and soil organic potential sequestration of the systems, compared to baseline, are plotted to obtain an
390 area. The greenish areas indicate a good resilience of the systems, where losses of the soil C
391 sequestration capacity are at most 10%. In these conditions, any minor management adjustment (e.g
392 modulation of irrigation, timing of residues incorporation, etc.) can be implemented according to the
393 current climatic trend without substantial changes in the farming system. The yellowish areas indicate
394 a situation of attention, with a medium risk of loss of C and where the loss of C storage capacity might
395 be counterbalanced with changes in management practices devoted to C conservation (conservation
396 tillage, organic fertilizer application, etc.), selected on the basis of the current climatic evolution. These
397 types of adjustments might require a modification of the machinery, the selection of different sources
398 of fertilisers (organic) and might involve a higher financial investment. The reddish areas indicate a
399 high vulnerability of the system in terms of loss of C sequestration potential, with losses from 40% to
400 70% of the capacity to retain the C input into the soil. Systems that fall entirely within this area have
401 little/no options for improvement and might be discarded to the advantage of more resilient systems.

402

403 **Here Figure 4 3D surface plot of the potential soil C sequestration change (z axis) against**
404 **temperature (T) (x axis) and rainfall (R) (y axis) changes, categorized by cropping system. All**
405 **variables are expressed as rate of change from baseline to future climate values.**

406

407 The alternative monoculture (Figure 4b) was the most resilient system and might be confidently adopted
408 in the considered region, since it responded to all predicted climate changes with no significant
409 reductions of C storage capacity. At the opposite, the no-residue system (Figure 4d) falls entirely within
410 the red area: this means that, whatever the type of climate change, the conservation of soil C is at serious
411 risk and therefore the loss of fertility is a realistic scenario (Cherubin et. al 2018). The other two systems
412 (Figure 4a and 4c) fall partially in the green and in the yellow area, with notable differences. We show
413 for the first time that in a conventional monoculture system, in case of temperature increase up to 0.6
414 °C together with limited rain increase (7%), the storage capacity of the C remains almost constant. On
415 the other hand, with limited temperature increase but with maximum increase in rain (up to 16%), the
416 system falls into the area of attention and will therefore require adjustments. The water availability and
417 high temperature are considered the most important factors accelerating the breakdown of soil organic
418 matter, since they concur to increase microbial activity, which induces SOM mineralization (Manzoni
419 et al. 2012). This coupled effect of high temperature and soil moisture is duly considered in RothC, that
420 predicted an increase of SOC decomposition in such conditions. On the other hand, RothC does not
421 simulate crop development and possible positive effects of climate change on plant productivity, and
422 hence on C input to soil that might compensate higher C decomposition. However, a recent review from
423 Bisbis et al. (2018) questioned the positive effect of climate change on cauliflower productivity while
424 effects on artichoke productivity are not known. Hence, the reduction of water supply proportional to
425 rainfall increase appears a feasible adjustment, together with a proper planning of timing of irrigation
426 as long as productivity is not negatively affected (Zornoza et al, 2016). According to our simulation,
427 for both systems, increase of rainfall was the most important factor affecting negatively the C storage
428 potential. For the first time, we have shown in a temporal perspective the importance of residues
429 management in the Mediterranean artichoke-based systems to ensure the conservation of C stock in
430 soils. Moreover, we have identified best management practices for the farmers as well as highlighted
431 how the removal of the residues might lead to SOC depletion, with consequences on the overall soil
432 quality, food security, supply and quality of water, biodiversity (Lal, 2015).

433 **4. Conclusion**

434 This study, to our best knowledge, for the first time predicts SOC stocks changes in globe artichoke-
435 based cropping systems in Southern Europe using a biophysical model and a long-term experimental
436 dataset. We have revealed, for the first time, that the most critical practice is represented by the removal
437 of crop residues. This practice should be carefully considered when evaluating alternative options of
438 the residues use, different from the incorporation to soil, i.e. biorefinery feedstock. Wether this option
439 proves convenient for the farmer, C lost compensation strategies should be put in place to avoid OC

440 depletion in soil. Among the other systems analysed, conventional and alternative monoculture showed
441 a higher resilience to climate change, whereas the biannual rotation needs adjustments in the
442 management, likely on irrigation regimes or organic fertilization.

443 The RothC model predictions under a climate change scenarios perspective allowed to identify the
444 potential of different artichoke-based cropping systems to sequester SOC, as well as to discriminate
445 such potential on the basis of the crops sequence. This kind of approach and the information obtained
446 represents a useful tool for policy makers, both for the assessment of the past agricultural policies effects
447 on SOC trends, and for future regional planning, because factors as climate change scenarios, land use
448 and land management modifications can be considered at the same time. The methodology can be
449 confidently applied to other regional estimations, also in other cropping systems, provided that relevant
450 and long-term data series are available, despite the uncertainty due to the fact that RothC does not
451 simulate plant growth. The other peculiarity of our study is that the database included actual cropping
452 sequences, and hence reproduced with a high degree of accuracy the farm management and results can
453 be already used to drive regional decisions.

454

455 **Declarations**

456 **Funding**

457 No funding was received to assist with the preparation of this manuscript.

458 **Conflicts of interest/Competing interests**

459 The authors declare that they have no conflicts of interest. The authors have no affiliation with any
460 organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

461 The authors declare that they have no known competing financial interests or personal relationships that
462 could have appeared to influence the work reported in this paper.

463 **Ethics approval**

464 Not relevant for this research

465 **Consent to participate**

466 Not relevant for this research

467 **Consent for publication (include appropriate statements)**

468 Not relevant for this research

469 **Availability of data and material (data transparency)**

470 The data that support the findings of this study are available from the corresponding author upon
471 reasonable request

472 **Code availability (software application or custom code)**

473 RothC is available and can be downloaded at Rothamsted Research (<https://www.rothamsted.ac.uk/>)

474 **Authors' contributions (include appropriate statements)**

475 Conceptualization, R.Fa. and L.L.; Methodology, R.Fa. and L.L.; Investigation, M.T.T.; Data Curation,
476 P.A.D. and M.T.T.; Writing – Original Draft, P.A.D, R.Fa. and L.L.; Writing –Review & Editing,
477 P.A.D., R.Fa., R.Fr., and L.L.

478

479 **References**

480 Aber JD, Melillo JM (1982) Nitrogen immobilization in decaying hardwood leaf litter as a function of
481 initial nitrogen and lignin content. *Can J Bot* 60:2263–2269. doi:10.1139/b82-277

482 Alvarenga P, Mourinha C, Farto M, Santos T, Palma P, Sengo J, Morais MC, Cunha-Queda C (2015)
483 Sewage sludge, compost and other representative organic wastes as agricultural soil amendments:
484 Benefits versus limiting factors. *Waste Manag* 40:44–52. doi:10.1016/j.wasman.2015.01.027

485 Beck HE, Zimmermann NE, McVicar TR, Vergopolan N, Berg A, Wood EF (2018) Present and future
486 Köppen- Geiger climate classification maps at 1- km resolution. *Scientific Data* 5:180214. doi:
487 10.1038/sdata.2018.214.

488 Bertrand I, Chabbert B, Kurek B, Recous S (2006) Can the biochemical features and histology of wheat
489 residues explain their decomposition in soil? *Plant Soil* 281:291–307. doi:10.1007/s11104-005-4628-7

490 Bianco VV, Calabrese N (2009) Carciofo in Puglia. In: Calabrese N (ed) *Il carciofo e il cardo*. Bayer
491 Crop Science Inc, Bologna, p 104.

492 Brennan EB, Acosta-Martinez V (2017) Cover cropping frequency is the main driver of soil microbial
493 changes during six years of organic vegetable production. *Soil Biol Biochem* 109:188-204. doi:
494 10.1016/j.soilbio.2017.01.014

495 Cassidy ES, West PC, Gerber JS, Foley JA (2013) Redefining agricultural yields: from tonnes to people
496 nourished per hectare. *Environ Res Lett* 8:34015. doi: 10.1088/1748-9326/8/3/034015

497 Castellano MJ, Mueller KE, Olk DC, Sawyer JE, Six J (2015) Integrating plant litter quality, soil organic
498 matter stabilization, and the carbonsaturation concept. *Glob Chang Biol* 21:3200–3209.
499 doi:10.1111/gcb.12982

500 Cherubin MR, Oliveira DMS, Feigl BJ, Pimentel LG, Lisboa IP, Gmach MR, Varanda LL, Moraes MC,
501 Satiro LS, Popin GV, Paiva SR, Santos AKB, Vasconcelos ALS, Melo PLA, Cerri CEP, Cerri CC
502 (2018) Crop residue harvest for bioenergy production and its implications on soil functioning and plant
503 growth: A review. *Sci Agric* 75:255-272. doi:10.1590/1678-992x-2016-0459

504 Coleman K, Jenkinson DS (1999) ROTHC-26.3. A Model for the turnover of carbon in soil. Model
505 description and windows users guide. Lawes Agricultural Trust, Harpenden, UK.

506 D'Avino L, Di Bene C, Farina R, Razza F (2020) Introduction of Cardoon (*Cynara cardunculus* L.) in
507 a Rainfed Rotation to Improve Soil Organic Carbon Stock in Marginal Lands. *Agronomy* 10(7) 946
508 doi: 10.3390/agronomy10070946

509 Deligios PA, Tiloca MT, Sulas L, Buffa M, Caraffini S, Doro L, Sanna G, Spanu M, Spissu E, Urracci
510 GR, Ledda L (2017) Stable nutrient flows in sustainable and alternative cropping systems of globe
511 artichoke. *Agron Sustain Dev* 37:54. doi: 10.1007/s13593-017-0465-3

512

513 EIP-AGRI Focus Group (2015) Soil organic matter in Mediterranean regions. Available online at:
514 Eurostat, 2015. Statistics Explained. Available online at: [https://ec.europa.eu/eurostat/statistics-](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Main_Page)
515 [explained/index.php?title=Main_Page](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Main_Page)

516 Fadda A, Viridis A, Barberis A, Melito S (2018) Variation in secondary metabolites contents of Spinoso
517 Sardo artichoke (*Cynara cardunculus* L.) under different day lengths. *Turk J Agric For* 42:372-381.
518 doi:10.3906/tar-1711-27

519 FAO (2017). Food and Agriculture Organization of the United Nations, Statistics Division. Available
520 online at: <http://www.fao.org/statistics/en/>

521 Farina R, Testani E, Campanelli G, Leteo F, Napoli R, Canali S, Tittarelli F (2018) Potential carbon
522 sequestration in a Mediterranean organic vegetable cropping system. A model approach for evaluating
523 the effects of compost and Agro-ecological Service Crops (ASCs). *Agric Syst* 162:239-248. doi:
524 10.1016/j.agry.2018.02.002

525 Francaviglia R, Coleman K, Whitmore AP, Doro L, Urracci G, Rubino M, Ledda L (2012) Changes in
526 soil organic carbon and climate change - Application of the RothC model in agro-silvo-pastoral
527 Mediterranean systems *Agric Syst* 112:48-54. DOI: 10.1016/j.agry.2012.07.001

528 Gomiero T, Pimentel D, Paoletti MG (2011) Environmental impact of different agricultural
529 management practices: conventional vs organic agriculture. *Crit Rev Plant Sci* 30:95-124. doi:
530 10.1080/07352689.2011.554355

531 Heitkamp F, Wendland M, Offenberger K, Gerold G (2012) Implications of input estimation, residue
532 quality and carbon saturation on the predictive power of the Rothamsted Carbon Model. *Geoderma*
533 170:168-175. doi: 10.1016/j.geoderma.2011.11.005

534 Khedkar, MA, Nimbalkar, PR, Chavan, PV, Chendake, YJ, Bankar, SB. (2017)Cauliflower waste
535 utilization for sustainable biobutanol production: revelation of drying kinetics and bioprocess
536 development. *Bioprocess Biosyst Eng* 40, 1493–1506. <https://doi.org/10.1007/s00449-017-1806-y>

537 Knowler D, Bradshaw B (2007) Farmers' adoption of conservation agriculture: a review and synthesis
538 of recent research. *Food Policy* 32:25-48. doi: 10.1016/j.foodpol.2006.01.003

539 Kumar K, Goh KM (2000) Crop residue management: Effects on soil quality, soil nitrogen dynamics,
540 crop yield, and nitrogen recovery. *Adv Agron* 68:197–319.

541 Lal, R, Negassa, W, Lorenz, K, (2015) Carbon sequestration in soil. *Current Opinion in Environmental*
542 *Sustainability*, 15, 79-86. <https://doi.org/10.1016/j.cosust.2015.09.002>

543 Ledda, L, Deligios, P, Farci, R, Sulas, L, (2013) Biomass supply for energetic purposes from some
544 *Cardueae* species grown in Mediterranean farming systems. *Industrial Crops and Products*, 47, 2018-
545 226. <https://doi.org/10.1016/j.indcrop.2013.03.013>

546 Li, LJ., Zhu-Barker, X, Ye, R, Doane, TA., & Horwath, WR, (2018). Soil microbial biomass size and
547 soil carbon influence the priming effect from carbon inputs depending on nitrogen availability. *Soil*
548 *Biology and Biochemistry*, 119, 41-49. <https://doi.org/10.1016/j.soilbio.2018.01.003>

549 Li, F, Sørensen, P, Li, X Olesen, JE (2020). Carbon and nitrogen mineralization differ between
550 incorporated shoots and roots of legume versus non-legume based cover crops. *Plant Soil* 446, 243–257
551 (2020). <https://doi.org/10.1007/s11104-019-04358-6>

552 Manzoni, S, Schimel, JP, Porporato, A, (2012), Responses of soil microbial communities to water stress:
553 results from a meta- analysis. *Ecology*, 93(4), 930-938. <https://doi.org/10.1890/11-0026.1>

554 Mondini C, Coleman K, Whitmore AP (2012) Spatially explicit modelling of changes in soil organic C
555 in agricultural soils in Italy, 2001–2100: potential for compost amendment. *Agric Ecosyst Environ*
556 153:24-32. doi: 10.1016/j.agee.2012.02.020

557 Muñoz-Rojas M, Abd-Elmabod SK, Zavala LM, De la Rosa D, Jordán A (2017) Climate change
558 impacts on soil organic carbon stocks of Mediterranean agricultural areas: A case study in Northern
559 Egypt. *Agric Ecosyst Environ* 238:142–152.

560 Norris CE, Congreves KA (2018) Alternative management practices improve soil health indices in
561 intensive vegetable cropping systems: a review. *Front Environ Sci* 6:50. doi: 10.3389/fenvs.2018.00050

562 Pardo G, del Prado A, Martínez-Mena M, Bustamante MA, Rodríguez Martín JA, Álvaro-Fuentes J,
563 Moral R (2017) Orchard and horticulture systems in Spanish Mediterranean coastal areas: Is there a real
564 possibility to contribute to C sequestration? *Agric Ecosyst Environ* 238:153-167. doi: 10.1016/S0016-
565 740 7061(97)00043-8

566 Poeplau C, Don A (2015) Carbon sequestration in agricultural soils via cultivation of cover crops – a
567 meta-analysis. *Agric Ecosyst Environ* 200:33–41. Doi:10.1016/j.agee.2014.10.024

568 Piras F (2013) Coding of phenological stages and dynamic of nutrient absorption in *Cynara cardunculus*
569 var. *scolymus*. PhD Dissertation, University of Sassari, Italy. Available:
570 <https://core.ac.uk/reader/11693970>.

571 Puget, P., Drinkwater, L. E. (2001). Short- term dynamics of root- and shoot- derived carbon from a
572 leguminous green manure. *Soil Science Society of America Journal*, 65(3), 771-779,
573 doi.org/10.2136/sssaj2001.653771x

574 Raccuia SA, Melilli MG (2010) Seasonal dynamics of biomass, inulin, and water-soluble sugars in roots
575 of *Cynara cardunculus* L. *Field Crop Res* 116:147-53. doi: 10.1016/j.fcr.2009.12.005

576 Robertson F, Nash D (2013) Limited potential for soil carbon accumulation using current cropping
577 practices in Victoria, Australia. *Agric Ecosyst Environ* 165:130-140. doi: 10.1016/j.agee.2012.11.004

578 Sgroi F, Fodera M, Di Trapani AM, Tudisco A, Testa R (2015) Profitability of artichoke growing in the
579 Mediterranean area. *HortSci* 50:1349–1352

580 Urra J, Alkorta I, Garbisu C (2019) Potential benefits and risks for soil health derived from the use of
581 organic amendments in agriculture. *Agronomy* 9:542. doi:10.3390/agronomy9090542

582 USDA (United States Department of Agriculture) (1999) Soil taxonomy: a basic systems of soil
583 classification formaking and interpreting soil surveys. In: USDA-NRCS agriculture handbook, 2nd edn.
584 ftp://ftp-fc.sc.egov.usda.gov/NSSC/Soil_Taxonomy/tax.pdf

585 Zhu LQ, Hu HJ, Zhang ZW, Xu JL, Tao BR, Meng YL (2015) Short-term responses of soil organic
586 carbon and carbon pool management index to different annual straw return rates in a rice-wheat
587 cropping system. *Catena* 135:283-289.

588 Zornoza, R, Rosales, RM, Acossta, JA, de la Rosa, JM, Arcenegui, V, Faz, A, Pérez-Pastor, A, (2016)
589 Efficient irrigation management can contribute to reduce soil CO₂ emissions in agriculture. *Geoderma*,
590 263: 70-77. <https://doi.org/10.1016/j.geoderma.2015.09.003>

591

Table 1 Mean cumulative carbon inputs from crop residues over the 2006–2016 period and changes in soil organic C stock

Cropping systems	Plant C input (t ha ⁻¹)								Soil organic C change (t ha ⁻¹)	
	Artichoke		Cauliflower		Cover crop		Weeds			Total*
	Aboveground	Roots ^{§§}	Aboveground	Roots ^{§§}	Aboveground	Roots ^{§§}	Aboveground	Roots ^{§§}		
Conventional monoculture	18.96 b	6.26 b	-	-	-	-	30.58	10.00	65.80 b	7.59 a
Alternative monoculture	26.86 a	10.74 a	-	-	6.11 b	2.38 b	21.24	8.28	75.61 ab	7.17 a
Biannual rotation	12.02 b	4.81 b	3.55	1.37	23.45 a	8.31 a	21.10	7.61	82.21 a	-1.95 b
Monoculture with residues removal [§]	4.74	6.26	-	-	-	-	30.58	10.00	51.58	1.02 ^{§§§§}

*The total C input is the sum of C from artichoke residues + C from cauliflower residues + C from weeds + C.

Different letters indicate significant differences among cropping systems for each residue component ($p < 0.05$) according to Kruskal-Wallis test or Mann–Whitney U-tests. [§] Data estimated and used for modelling the hypothetical scenario. ^{§§} Calculated as percentage (30%) of the measured aboveground biomass ^{§§§} Average of the two alternate biannual rotations. ^{§§§§} Average of the three baseline climate scenarios

Table 2 Modelled soil organic carbon change in twenty years for each system averaged for the three climates

Cropping systems	Soil Organic C change*		Soil C sequestration potential change under future climate (%)
	(t ha ⁻¹)		
	Baseline**	Future climate**	
Conventional monoculture	11.7	10.9	-0.07
Alternative monoculture	8.9	7.2	-0.19
Biannual rotation	5.7	4.0	-0.30
Monoculture with residues removal	2.0	0.6	-0.70

*Difference between final and initial SOC stock values averaged for the three climate scenarios

** Average of the three climate scenarios: METO-HC, DMI-HIRHAM5-ECHAM5 and ETHZ-CLM-HadCM3Q0.



Figure 1 The two phases of the biannual rotation system. The picture on the left shows the cauliflower phase, and the picture on the right the globe artichoke phase. In the biannual rotation management globe artichoke is grown in sequence to cauliflower. By contrast, in the traditional globe artichoke cultivation practice globe artichoke is grown in monoculture for many consecutive years.

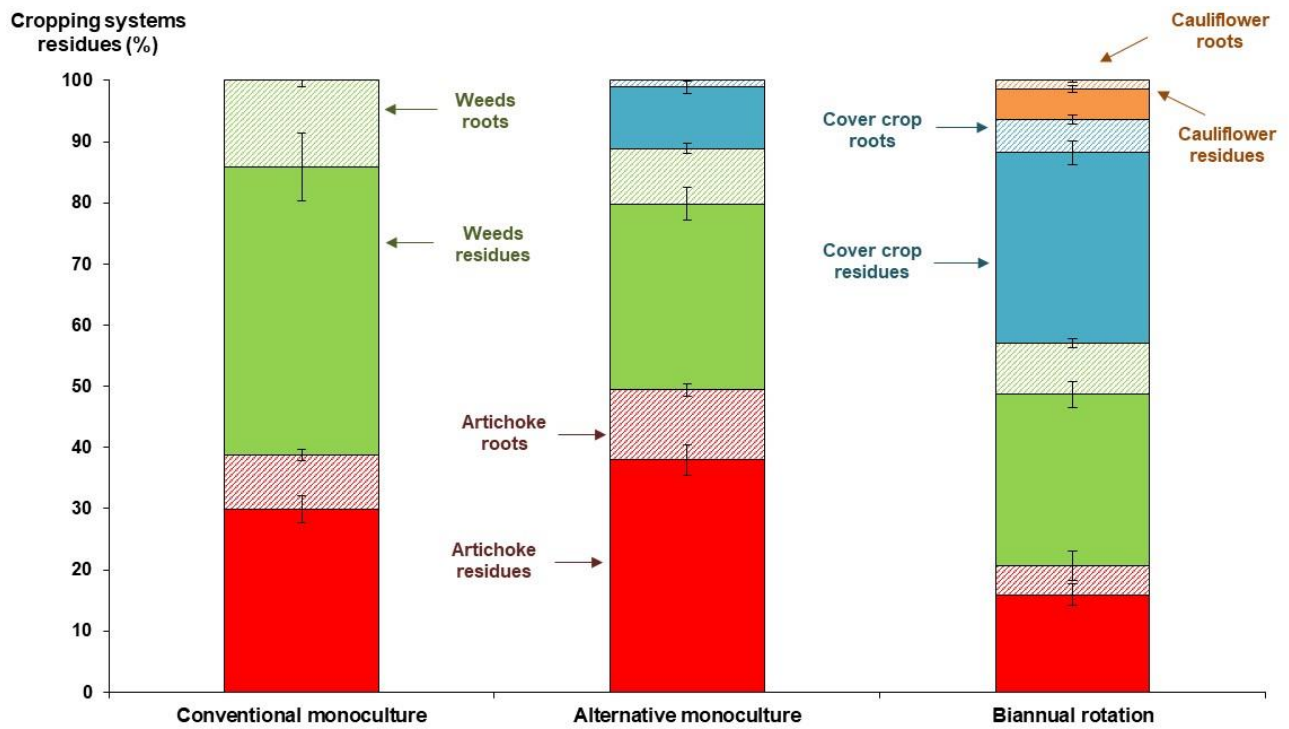


Figure 2 Figure 2 The percent contribution of each system component in terms of residues (above ground and belowground ones) towards conventional monoculture, alternative monoculture and biannual rotation cropping systems at the end of the 10-year period (2006-2016). Error bars indicate standard error of the mean, n=10.

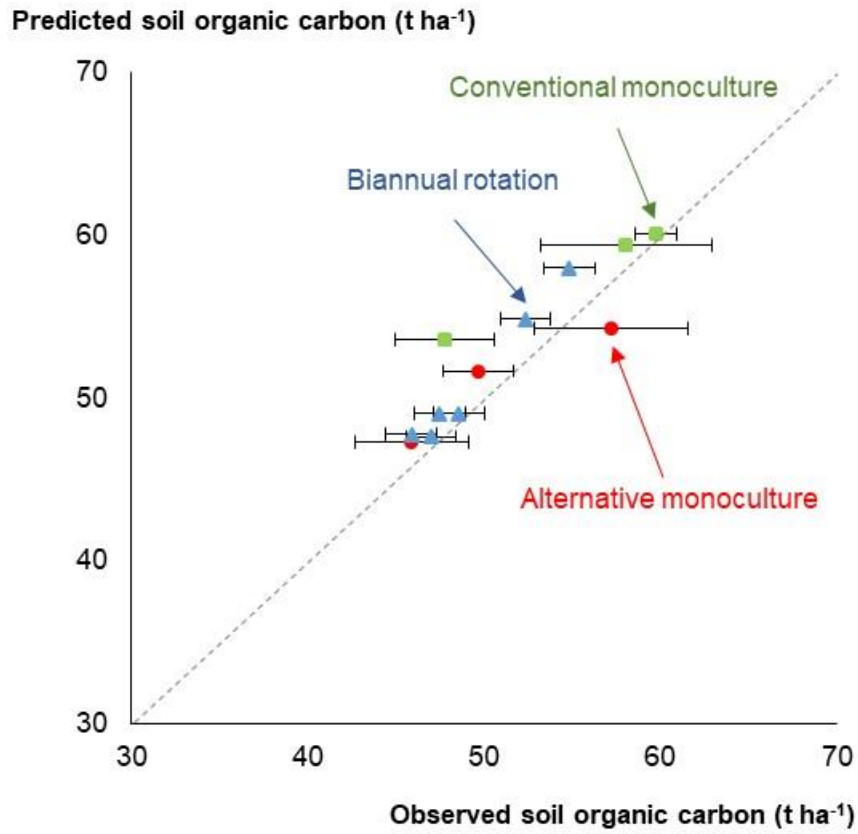
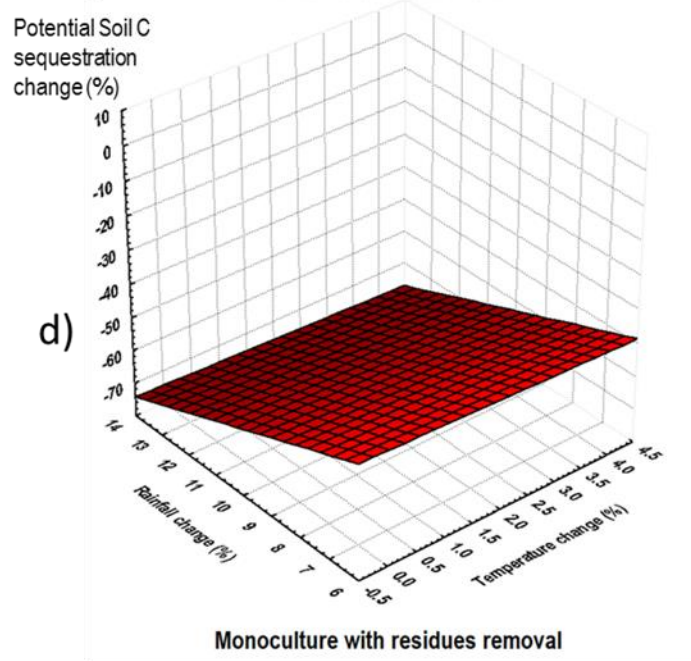
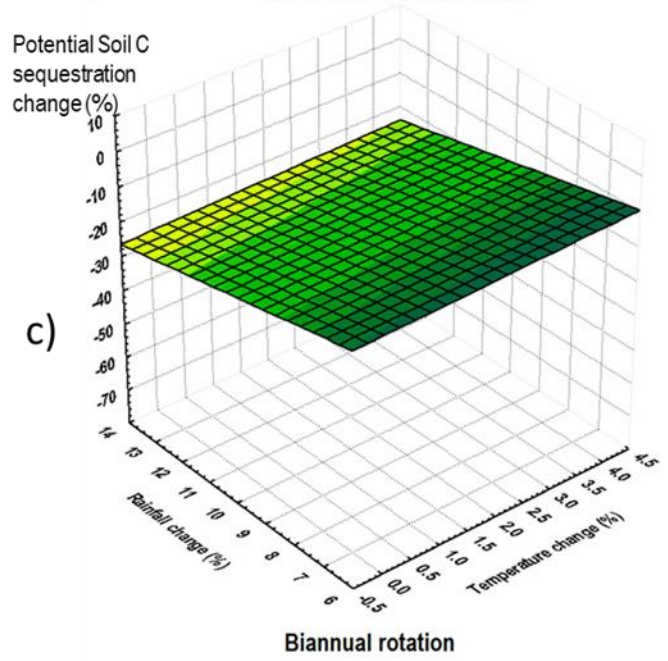
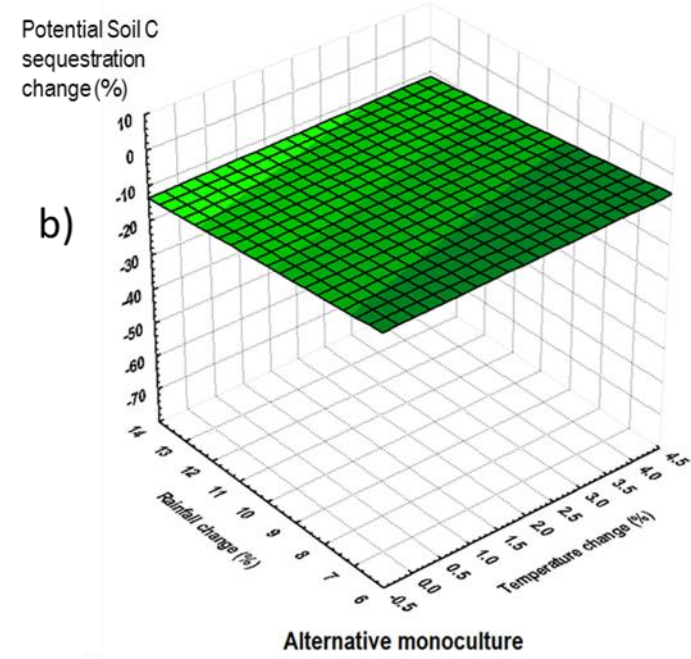
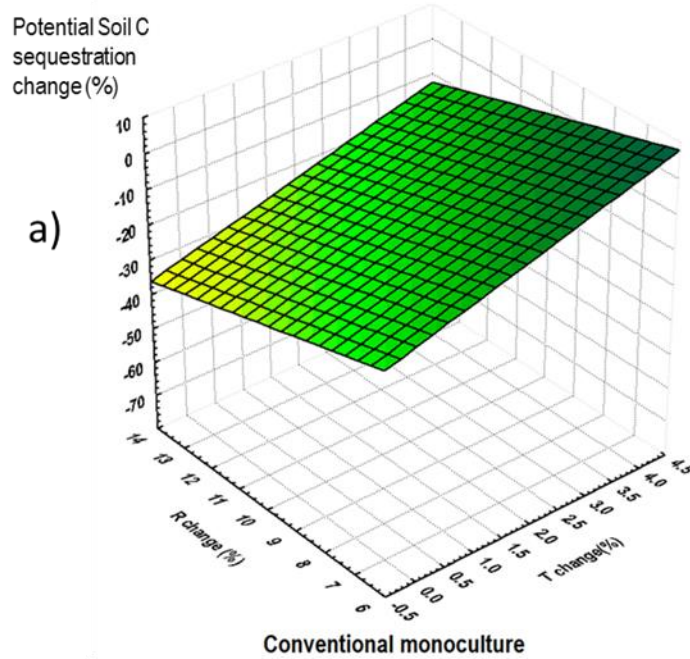


Figure 3 Scatter plot of observed versus predicted soil organic carbon content (N=12). The dotted line represents the 1:1 x:y relationship. Indicators of performance: RMSE= 2 t C ha⁻¹, R²=0.84, EF=0.78



Legend of potential Soil C stock change of future vs baseline climate (%)

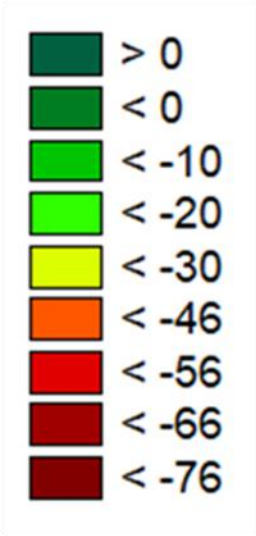


Figure 4 3D surface plot of the potential soil C sequestration change (z axis) against temperature (T) (x axis) and rainfall (R) (y axis) changes, categorized by cropping system. All variables are expressed as % rate of change from baseline to future climate values.