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Modeling future carbon stock in melon cultivation agroecosystems under different climate scenarios

Modelagem do estoque de carbono futuro em agroecossistemas no cultivo de meloeiro sob diferentes cenários climáticos

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ABSTRACT

Intensive melon cultivation is based on conventional monoculture models that can inefficiently use natural resources, which, combined with inadequate management, contribute to climate change. The main objective of this study was to model the future carbon stock in melon cultivation agroecosystems under different climate scenarios. The study was conducted at the Bebedouro Experimental Field of Embrapa Semi-arid, Petrolina/PE, Brazil, in an area cultivated with yellow melon cv. Gladial, and eight cultivation cycles were considered. The experimental design was composed of two types of soil management (with and without tillage), two treatments using green manures consisting of 14 species with different proportions of legumes, grasses and oilseeds, and spontaneous vegetation, containing four replications divided into randomized blocks. After 70 days of development, the plants were cut and placed in the soil. Temperature and precipitation data were acquired from the BCC-CSM, MIROC5, CESM1-BGC, IPSL-CM5B-LR, and HadGEM2-AO climate models, following the RCP 4.5 and 8.5 climate scenarios. The carbon (C) stock was estimated until the year 2071 using the RothC model.

RESUMO

O cultivo intensivo do melão é baseado em modelos convencionais de monocultivos, os quais podem utilizar de forma ineficiente os recursos naturais e, associados ao manejo inadequado, contribuir para alterações climáticas. O principal objetivo deste estudo foi modelar o estoque de carbono futuro em agroecossistemas no cultivo de meloeiro sob diferentes cenários climáticos. O estudo foi conduzido no Campo Experimental Bebedouro da Embrapa Semiárido, Petrolina/PE, em área cultivada com melão amarelo, cv. Gladial e foram considerados oito ciclos de cultivo. O delineamento experimental foi composto de dois tipos de manejo de solo (com e sem revolvimento), dois tratamentos utilizando adubos verdes compostos de 14 espécies com diferentes proporções de leguminosas, gramíneas e oleaginosas e a vegetação espontânea, contendo quatro repetições divididos em blocos casualizados. Após 70 dias de desenvolvimento as plantas foram cortadas e depositadas no solo. Dados de temperatura e precipitação foram adquiridos dos modelos climáticos BCC CSM, MIROC5, CESM1-BGC, IPSL CM5B LR e HADGEM2-AO, seguindo os cenários climáticos RCP 4.5 e 8.5. O estoque de carbono (C) foi estimado até o ano de 2071 usando o

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The treatment with a predominance of legumes and no rotation increased the C stock in the soil, regardless of the climate scenario. The soil tillage did not favor C accumulation, meaning that none of the treatments reached the same stock as the Caatinga. The MIROC5 model in the RCP 4.5 scenario favored greater C accumulation in the soil, while the lowest C stocks occurred in the CESM1-BGC and IPSL-CM5B-LR models under the RCP 8.5 scenario.

Keywords: *Cucumis melo* L; climate change; RothC.

modelo RothC. O tratamento com predominância de leguminosas e sem revolvimento aumentou o estoque de C no solo independentemente do cenário climático. O revolvimento do solo não favoreceu o acúmulo de C, fazendo com que nenhum dos tratamentos alcançasse o mesmo estoque que a Caatinga. No cenário RCP 4.5 o modelo MIROC5 favoreceu o maior acúmulo de C no solo; já os menores estoques de C ocorreram nos modelos CESM1-BGC e IPSL CM5B LR sob o cenário RCP 8.5.

Palavras-chave: *Cucumis melo* L; alterações climáticas; RothC.

Introduction

Brazil is currently one of the largest agricultural producers in the world. Among the cultivars produced in the country is the yellow melon (*Cucumis melo* L.), which is one of the most exported fresh fruits in the country (Deus et al., 2015; IBGE, 2019). According to the Brazilian Institute of Geography and Statistics (IBGE, 2019) data, Brazil produced around 587,692 thousand tons of this oleraceae in a planted area of 22,297 ha in 2019, generating R$578,666 for the country.

Agriculture is classified as an activity dependent on climatic conditions, such as air temperature, rainfall, soil humidity, and solar radiation (De Lima, 2002). Some factors, such as the intensive use of soil preparation, synthetic fertilizers, and irrigation cause a considerable reduction in soil organic carbon (C), increased soil salinization, and increased water scarcity, accelerating climate change (Smith et al., 2015; Müller Carneiro et al., 2019).

Carbon dioxide (CO_2) is one of the main greenhouse gases and one of its main production sources is land use change. Thus, it is possible to highlight the importance of studying the organic C stock in soils, not only focusing on its benefits related to nutrients and soil structure but also because it is the largest C reservoir in the biosphere compartments (Machado, 2005).

Crops with conventional management and originating from monocultures, such as melon produced in Northeast Brazil, can be a possible source of greenhouse gas emissions due to all the transformations that are performed in the area for maintaining and cultivating the crop, including: initial cleaning of the land (deforestation and burning of native vegetation); soil preparation; seed production; seedling production and planting; plant nutrition (irrigation and fertigation); crop management; control of invasive plants, pests and diseases; and post-harvest aspects (Barros et al., 2017).

Thus, reducing the impacts caused by the climate phenomenon on economic activities should be the focus of motivation for mitigating measures (Foguesatto et al., 2019). The current reality of the agricultural sector demands these types of measures, and so, adopting technologies that use vegetables cocktails for cover crops and soil preparation systems (conventional, direct planting) serve as components for agriculture strategies to improve soil C storage in semi-arid areas (Giongo et al., 2016, Deus et al., 2022).

It is important to highlight that C accumulation in the soil resulting from the use of these agricultural strategies can occur with diversified production and maintenance of vegetation cover. According to Jensen et al. (2012), the use of green manure in intercropping or rotation with other crops allows the system to be balanced with nitrogen, promoting primary production and C accumulation in the soil, among other benefits.

Besides, there are mathematical models subjected to different climate scenarios that simulate soil C dynamics. Among these models, the Rothamsted carbon model (RothC) is one of the most frequently used for simulating soil C dynamics in its surface layer due to the simplicity and availability of input data (Coleman et al., 1997; Herbst et al., 2018).

In this context, this study aimed to: 1. model the future C stock in different melon cultivation agroecosystems under different climate scenarios; 2. evaluate whether soil management associated with the use of vegetables cocktails as cover crops improves soil C stock; and 3. identify which types of management and vegetable cocktail can promote greater soil C accumulation.

Method

Study area description

The study was conducted to evaluate eight cycles of a long-term experiment which began in 2012 at the Bebedouro Experimental Field (9°08' S, 40°8' W, 365.5 m altitude), at the Brazilian Agricultural Research Company (Embrapa Semi-arid), located in the municipality of Petrolina (PE), Brazil. The soil in the area was classified as eutrophic plintic red-yellow argisol (Santos et al., 2018a) corresponding to Haplic Acrisol (IUSS Working Group WRB, 2022), medium/clayey texture, with flat relief. The local climate is semi-arid, classified as BSwh according to the Köppen climate classification system, with an average annual temperature of 26.8°C, average annual precipitation of 360 mm, and the Caatinga as native vegetation. The soil properties of the 0–5 cm layer before the implementation of the experiment were as follows: 87.8% sand; 10% silt; and 2.2% clay; pH (H_2O) 5.9; P 47.34 mg dm^{-3} (Mehlich-1); H+Al 2.14 $cmol_c\ dm^{-3}$ (KCl extraction); exchangeable K (Mehlich-1), Ca (KCl extraction), Mg (KCl extraction) and Na (Mehlich-1) of 0.35, 2.20, 0.40, and 0.04 $cmol_c\ dm^{-3}$, respectively; sum-of-bases (S) 2.99 $cmol_c\ dm^{-3}$; cation exchange capacity (CEC) 5.13 $cmol_c\ dm^{-3}$; and base saturation (V) 58% (Teixeira et al., 2017).

Experimental design

The experimental design consisted of four replications divided into randomized blocks with a split-plot arrangement (containing six treatments). The plots consisted of two soil management types: no tillage (NT) and soil tillage (ST); and the subplots, by three types of treatments using vegetables cocktails: VC1 (75% legumes+25% grasses and oilseeds); VC2 (25% legumes+75% grasses and oilseeds); and SV (spontaneous vegetation). The analyzed treatments were a combination of soil management factors and type of vegetables cocktails, described as follows: VC1NT with 75% legumes+25% grasses and oilseeds and no tillage; VC2NT with 25% legumes+75% grasses and oilseeds and no tillage; SVNT with spontaneous vegetation and no tillage; VC1ST with 75% legumes+25% grasses and oilseeds and soil tillage; VC2ST with 25% legumes+75% grasses and oilseeds and soil tillage; and SVST with spontaneous vegetation and soil tillage. The plots were 10 × 10 m long and wide. A total of 198 melon seedlings were transplanted annually at a spacing of 2.0 × 0.3 m in this area.

Vegetable cocktails 1 and 2 were composed of a mixture of legume, grass and oilseed species proportions. The oilseeds used included: sesame (*Sesamum indicum* L.), castor bean (*Ricinus communis* L.), and sunflower seeds (*Helianthus annuus* L.); legumes: calopogonium (*Callopogonium mucunoides* Desv.), black velvet beans (*Stizolobium aterrimum*/Piper & Tracy), grey velvet beans (*Mucuna cochinchinensis* Lour.) A.Chev., sunn hemp and rattlebox (*Crotalaria juncea* L. and *Crotalaria spectabilis* Roth), jack beans (*Canavalia ensiformis* (L.) DC.), pigeon pea (*Cajanus cajan* (L.) Millsp.) and lab-lab beans (*Dolichos lablab* L.); and grasses: corn (*Zea mays* L.), millet (*Pennisetum americanum* (L.) Leeke), and sorghum (*Sorghum vulgare* Pers.). The following predominant species were identified in the spontaneous vegetation: tropical spiderwort (*Commelina benghalensis* L.), siratro (*Macroptilium atropurpureum* Urb.), dixie ticktrefoil (*Desmodium tortuosum* (Sw.) DC.), and bristly starbur (*Acanthospermum hispidum* DC).

Field management

Vegetable cocktails were sown annually in July in furrows spaced 0.5 m apart. Cocktails were cut to 5 cm above the soil surface around 70 days after sowing. Evaluation of shoot dry matter production in each subplot was performed by collecting three subsamples of 1 m^2. Phytomass was deposited on the soil in plots without soil management using a manual brush cutter, while phytomass in plots with soil management was incorporated 20 cm deep through plowing and harrowing.

Yellow melon (cv. Gladial) was sown every year in October in polystyrene trays using commercial substrate and kept in a greenhouse where they were manually irrigated twice daily with a common watering can for 12 days. After this period, transplantation took place in the field. Irrigation and fertilization occurred according to the plants' needs via fertigation during the 65 days the plants remained in the field. Then, the fruits were harvested and the plants were removed.

Laboratory sampling and measurement

First, 1 × 1 m trenches were opened annually in one of the randomly chosen blocks for root sampling of vegetable cocktails and melon plants. The samples were taken in small blocks of 20 cm^3 at depths of 0–20, 20–40, 40–60, 60–80, and 80–100 cm.

Stratified soil sampling was carried out annually in mid-December at depths of 0–5 cm, 5–10 cm, and 10–20 cm. The samples were air-dried and passed through 2.0 mm sieves to obtain air-dried fine soil for analysis. The samples of vegetable cocktails, melon plants, and roots were dried in an oven with forced air circulation at 65°C for 72 hours to determine the dry mass, with the results expressed in g $plant^{-1}$. The C content was determined using a LECO TruSpec CHN-900 elemental analyzer (LECO USA).

Stocks were calculated based on C concentrations and volume and density of each soil layer, following Equation (1):

$$C\ (Mg\ ha^{-1}) = C_{conc} \times AD \times T \qquad (1)$$

In which:
C_{conc} = concentrated carbon (%);
AD = apparent density in the soil layer (g m^{-3}); and
T = thickness of the sampled soil layer (cm);

Estimation of exudates

The estimate of exudates for the crops (Equation 1) was calculated from the root dry biomass according to Bolinder et al. (2007). The authors proposed a method to estimate net primary productivity, annual C, and inputs to the soil in some agroecosystems based on a series of C allocation coefficients in plants. Equation (2):

$$\text{Root exudate} = \text{root biomass} \times 0.65 \qquad (2)$$

Climate models

The models most used by the Intergovernmental Panel on Climate Change (IPCC) were selected to model the effect of vegetable cocktails on soil C stocks under climate change conditions. The selected models were: BCC-CSM, MIROC5, CESM1-BGC, HadGEM2-AO, and IPSL-CM5B-LR, following climate scenarios 4.5 and 8.5. The daily temperature and precipitation data closest to the coordinates of the study site were selected, up to the year 2071 (Table 1). These values were used as input data for the RothC.

Table 1 – Average year climate data from different models in multifunctional agroecosystems in Petrolina (PE), Brazil.

Climate model		T (°C)	E (mm)	E (mm)	P (mm)	P (mm)	I (mm)	I (mm)	P+I (mm)	P+I (mm)
		Daily average	Daily average	Annual accumulated	Daily average	Annual accumulated	Daily average	Annual accumulated	Daily average	Annual accumulated
	Current	26.13	8.93	3,267.11	1.55	565.98	2.51	918.18	4.04	1,479.80
RCP 4.5	BCC CSM	26.05	10.90	3,987.95	1.91	698.62	2.62	958.07	4.53	1,656.69
	MIROC5	25.60	10.73	3,926.00	1.56	572.16	2.57	938.80	4.13	1,510.97
	CESM1-BGC	27.22	11.34	4,148.72	2.86	1,047.44	2.75	1,004.88	5.61	2,052.32
	HadGEM2-AO	27.52	11.45	4,189.26	3.00	1,098.70	2.77	1,013.55	5.77	2,112.26
	IPSL CM5B LR	26.30	10.99	4,022.75	1.92	701.59	2.64	965.16	4.55	1,666.75
RCP 8.5	BCC CSM	26.39	11.02	4,035.03	1.97	719.90	2.65	968.74	4.61	1,688.63
	MIROC5	25.98	10.87	3,978.25	1.54	563.08	2.60	950.42	4.14	1,513.50
	CESM1-BGC	27.52	11.45	4,189.26	3.00	1,098.70	2.77	1,013.55	5.77	2,112.26
	HadGEM2-AO	26.45	11.05	4,043.53	1.95	712.88	2.64	967.86	4.59	1,680.74
	IPSL CM5B LR	26.51	11.07	4,050.96	1.78	650.56	2.66	972.38	4.43	1,622.94

T: temperature, E: evapotranspiration, P :precipitation, I: irrigation, P+I: precipitation+irrigation; RCP: representative concentration pathway (scenarios 4.5 and 8.5); BCC-CSM: Beijing Climate Center Climate System Model; MIROC5: Model for Interdisciplinary Research on Climate, version 5; CESM1-BGC: Community Earth System Model, version 1– Biogeochemistry; HadGEM2-AO: Hadley Centre Global Environment Model, version 2 – Atmosphere Ocean simulation; IPSL-CM5B-LR: Institut Pierre Simon Laplace-Coupled Model, version 5B – Low Resolution.

Carbon modeling using the Rothamsted carbon model (RothC)

Data by Giongo et al. (2020) on the average annual C input for each vegetable cocktail analyzed were used to estimate the future C stock until the year 2071. Future temperature and precipitation data were acquired from each climate model. For this study, daily temperature, precipitation, evapotranspiration, and irrigation data were used to enable a realistic simulation of soil moisture and C dynamics through the RothC (Table 1). The model execution followed the procedure and calibration performed by Giongo et al. (2020).

Results and discussion

Regardless of the climate model analyzed, green manures combined with no soil tillage management promoted C accumulation in the soil throughout the years of cultivation, reaching higher stocks than those found in the preserved Caatinga (Figure 1). Vegetable cocktail 1 with no tillage composed in high quantities of legumes provided a greater C stock in the soil throughout the modeled period (2020–2071). Spontaneous vegetation with tillage continued to present the lowest C stocks in the soil (Figure 1).

The melon cultivation agroecosystems composed of green manures and with no tillage over the years provided greater C stocks in the soil than the Caatinga (Figure 1), mainly due to the increased biomass input in these systems and maintained soil structure (Zhang et al., 2019; Morais et al., 2021). The vegetable cocktail with a greater predominance of legumes had a higher C stock when compared to the other green manures through the biological nitrogen fixation (BNF) process. Higher nitrogen concentration in ecosystems increases C stocks due to an increase in net primary production (Peng et al., 2020; Deus et al., 2022). Agricultural soils with low nitrogen levels tend to increase C accumulation when N is added, which does not occur in soils that have already received significant amounts of nitrogen fertilizers (Huang et al., 2020). On the other hand, as spontaneous vegetation produces less biomass compared to vegetable cocktails (Giongo et al., 2020), they presented a C variation between 0.4 and 0.18 Mg C year^{-1} (Table 2), contributing less to the C stock, while treatments composed of green manures and no tillage contributed with 0.27 to 0.32 Mg C year^{-1} (Table 2).

Among the climate models, the C stock was positively higher in RCP 4.5 MIROC5 than in the other models analyzed in all treatments, while the greatest negative impact occurred in the RCP 8.5 CESM1-BGC model for treatments with tillage, and in RCP 8.5 IPSL-CM5B-LR for those without tillage (Figure 1). The difference in C stock between the models was mainly influenced by temperature, and the CESM1-BGC model promoted an increase of 1.09°C in RCP 4.5 (moderate greenhouse gas emissions scenario) and 1.39°C in RCP 8.5 (a scenario that foresees high greenhouse gas emissions) (Table 1). The IPSL-M5B-LR in the RCP 4.5 scenario had an increase of 0.17°C and 0.38°C in the RCP 8.5 scenario. This increase in temperature intensified the precipitation and irrigation regime in the melon crop, while the MIROC5 model presented a lower temperature than the current climate, with minus 0.53°C in RCP 4.5 and minus 0.15°C in RCP 8.5. We observed that even though MIROC5 presented a lower average temperature than the current climate, the C stock in the soil with the characteristics of the current climate was always higher in the climate models analyzed for the tillage treatments (Figure 1).Climate models adapt to the location in which they are simulated. Therefore, depending on the climate, latitude, and vegetation there may be greater or lesser variation in temperature and precipitation (Xu et al., 2020).

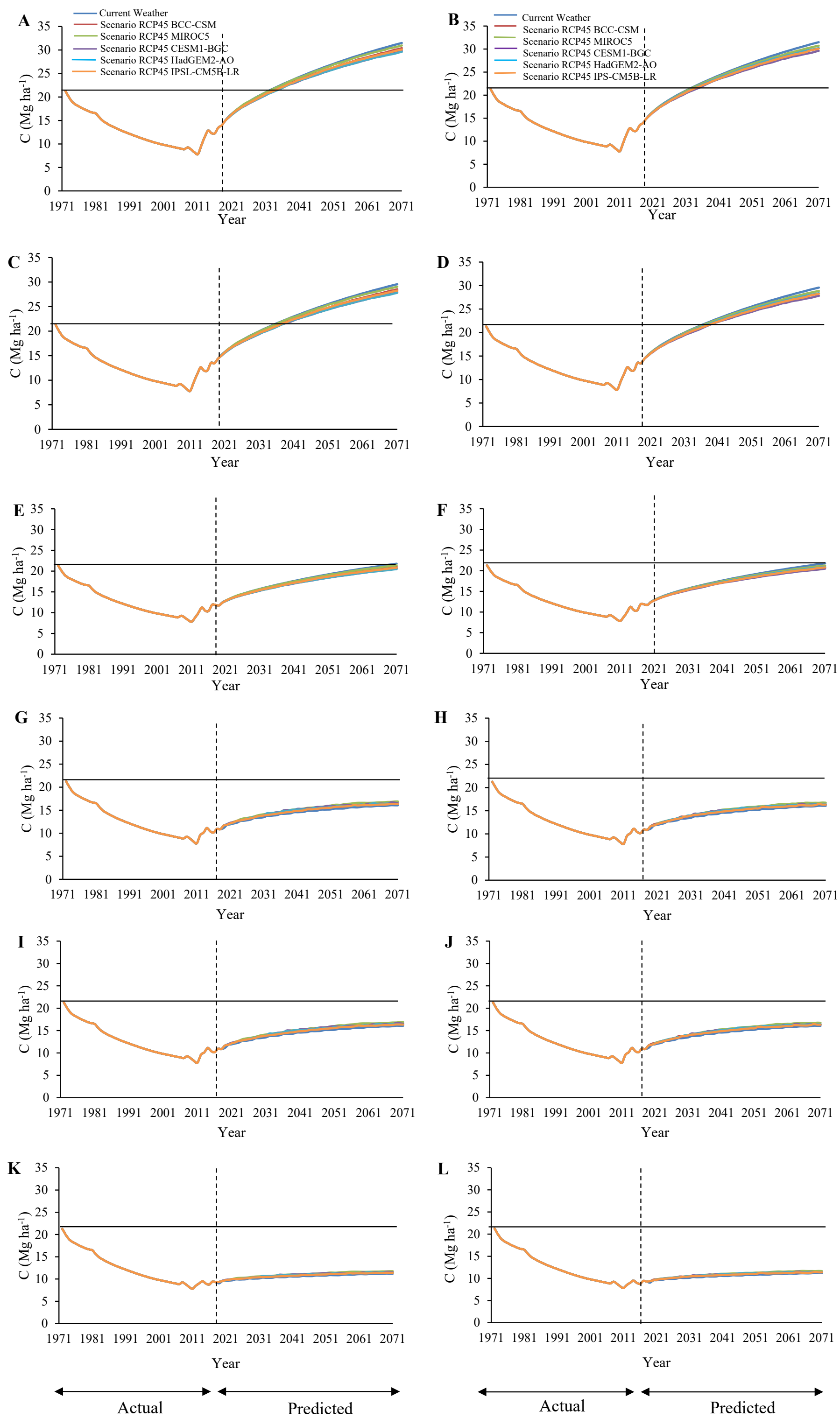

Figure 1 – Actual and predicted carbon stock by the RothC 2.3 model in five climate models in 6 multifunctional designs in an argisol cultivated with melon in the Brazilian semi-arid region modeled in the period 1971–2071.

*A (RCP 4.5) and B (RCP 8.5): 75% legumes+25% grasses and oilseeds with no disturbance; C (RCP 4.5) and D (RCP 8.5): 75% grasses and oilseeds+25% legumes with no tillage; E (RCP 4.5) and F (RCP 8.5): spontaneous vegetation with no tillage; G (RCP 4.5) and H (RCP 8.5): 75% legumes+25% grasses and oilseeds with tillage; I (RCP 4.5) and J (RCP 8.5): 75% grasses and oilseeds+25% legumes with tillage; K (RCP 4.5) and L (RCP 8.5): spontaneous vegetation with tillage.

*Dashed line corresponds to the threshold between actual and predicted stock and the solid line corresponds to the C value in the Caatinga.

Table 2 – Annual carbon variation of different models in multifunctional agroecosystems in Petrolina (PE), Brazil.

Climate model		VC1NT ΔC	VC2NT ΔC	SVNT ΔC	VC1ST ΔC	VC2ST ΔC	SVST ΔC
		C Mg year⁻¹	C Mg year⁻¹	C Mg year⁻¹	C Mg year⁻¹	C Mg year⁻¹	C Mg year⁻¹
	Current	0.33	0.30	0.19	0.10	0.10	0.04
RCP 4.5	BCC-CSM	0.31	0.29	0.17	0.11	0.11	0.04
	MIROC5	0.32	0.30	0.18	0.11	0.11	0.05
	CESM1-BGC	0.30	0.27	0.17	0.11	0.11	0.04
	HadGEM2-AO	0.30	0.27	0.16	0.10	0.10	0.04
	IPSL-CM5B-LR	0.30	0.28	0.17	0.10	0.10	0.04
RCP 8.5	BCC-CSM	0.30	0.28	0.17	0.10	0.10	0.04
	MIROC5	0.32	0.29	0.18	0.11	0.11	0.04
	CESM1-BGC	0.30	0.27	0.16	0.10	0.10	0.04
	HadGEM2-AO	0.31	0.28	0.17	0.10	0.10	0.04
	IPSL-CM5B-LR	0.30	0.28	0.17	0.10	0.10	0.04

VC: vegetable cocktails; VC1: 75% legume species+25% grasses/oilseeds; VC2: 25% legume species+75% grasses/oilseeds; ΔC: carbon variation; NT: no tillage; ST: soil tillage; SV: spontaneous vegetation. RCP: Representative Concentration Pathway; BCC-CSM: Beijing Climate Center Climate System Model; MIROC5: Model for Interdisciplinary Research on Climate, version 5; CESM1-BGC: Community Earth System Model, version 1– Biogeochemistry; HadGEM2-AO: Hadley Centre Global Environment Model, version 2 – Atmosphere Ocean simulation; IPSL-CM5B-LR: Institut Pierre Simon Laplace-Coupled Model, version 5B – Low Resolution.

The MIROC5 model developed by Japanese researchers showed a lower temperature increase for the studied area, with a consequent lower water depth for irrigation. Thus, the lower impact on temperature led to a higher ΔC among the treatments analyzed, varying from 0.32 in the cocktail with a greater predominance of legumes and no tillage to 0.04 in the spontaneous vegetation with soil tillage in both climatic scenarios (Table 2).

Vegetable cocktail 1, composed of a greater proportion of legumes with no tillage, reached the same C stock as the native forest in 2031, while vegetable cocktail 2 with a greater proportion of grasses and oilseeds only reached the stability of native vegetation from 2041 onwards (Figure 1). When spontaneous vegetation with no tillage is used as soil cover, the C stock in the soil only reaches the same values as the preserved Caatinga in 50 years (in 2071), and only reaches this balance in the projections of the BCC-CSM model in the RCP45 scenario, and in the MIROC5 model in both the RCP 4.5 and 8.5 scenarios. The tillage treatments did not reach the same C stock as the native forest in any of the modeled years, indicating that tillage is one of the main drivers for C loss in the soil in a semi-arid environment (Giongo et al., 2020). Soil disturbance (tillage) promotes the incorporation of plant biomass into the soil, increases aeration, and favors the rupture of soil aggregates. These processes together make soil C susceptible to microbial decomposition and C loss to the atmosphere (Lal, 2018; Falcão et al., 2020).

A recent study pointed out that the future soil C stock depends on how the plant responds to the stimuli of CO_2 available in the atmosphere. The C stock in the soil decreases when plant biomass is stimulated by CO_2; on the contrary, soil C storage increases when biomass is weakly stimulated (Terrer et al., 2021). Legumes are plants with a C3 photosynthetic cycle that produce greater amounts of carbohydrates than grasses with a C4 photosynthetic cycle under elevated CO_2 (Barbehenn et al., 2004). Biological nitrogen fixation performed by legumes makes N available for subsequent crops, increasing the net primary production of crops, which guarantees greater biomass production and increased C sequestration by both natural and anthropized soils (Wieder et al., 2015). It is estimated that N could contribute about 28% of C accumulation by 2100 (Peng et al., 2018). Therefore, the increase in N input into the system can influence the greater C stock in the soil in treatments with a predominance of legumes (Figure 1 and Table 2).

The 8.5 models indicate a more drastic climate change scenario, providing a greater increase in temperature than the 4.5 models. This increase in temperature intensified precipitation in the BCC-CSM and CESM1-BGC models, but reduced it in the MIROC5 and IPSL-CM5B-LR. Models with higher temperature, irrigation, and precipitation generally reduced ΔC (Table 2). The temperature rise also increased evapotranspiration, precipitation, and irrigation levels (Table 1). Studies indicate that human-caused climate change will affect water and food security due to the greater demand for water by agricultural crops, as plants increase water absorption in order to develop at high temperatures (Döll, 2002; Li et al., 2020). Currently, around 70% of the world population's water demand is needed to irrigate crops; however, climate change scenarios indicate that water demand could increase by 20% by 2100 in the Northern hemisphere, generating uncertainty regarding future water availability (Wada et al., 2013). It is already recorded that there was a 40% reduction in the volume of lakes in the most populated regions in China in the last 30 years due to greater irrigation intensity and climate change (Fang et al., 2018).

Climate models indicate that there will be an increase in precipitation with temperature rise (Table 1); however, it is estimated that precipitation will occur in shorter periods with greater intensity, which could compromise social, food, and water security (Dunning, et al., 2018). Climate scenarios indicate an increase in future evapotranspiration in the Brazilian semi-arid region from 2.3 to 6.3%, which will consequently increase the need for irrigation water from 2.8 to 16.7%; in addition, the annual course of rivers will decrease (Gondim et al., 2018). Another study that analyzed the impact of climate change on the São Francisco River found a 25% reduction in precipitation between the years 1961 and 1990, and depending on the climate scenario, precipitation could decrease by up to 50% by 2100, resulting in an accentuated drop in water availability (Jong et al., 2018). The impact on irrigation will affect the net primary productivity of crops, which in turn, will reduce C increments in the soil.

The use of green manures composed of legume species, grasses and oilseeds is an alternative to reduce the impact of climate change in the Brazilian semi-arid region, as there was an increase in the accumulation of soil C regardless of the climate scenario. Furthermore, the increase in organic residues on the soil reduces evapotranspiration in agricultural areas and consequently increases the water efficiency of agricultural systems. The melon crop grown in the São Francisco Valley has an average need for gross irrigation water of around 255.53 mm per cycle, with an average production of 40 Mg ha^{-1} of melon (Santos et al., 2018b). Thus management practices that reduce C and water footprints in the face of climate change need to be encouraged.

Conclusions

Regardless of the climate scenarios, the vegetable cocktail with a predominance of legumes and no tillage increased the C stock in the soil, potentially reaching the same stock as the native forest in ten years (2031). The soil tillage did not favor C accumulation, meaning that none of the treatments reached the same stock as the preserved Caatinga. The MIROC5 RCP 4.5 scenario was the only model that favored C accumulation in the soil in treatments with tillage (1 Mg year^{-1} C, corresponding to 10% more than that stored in the current climate), at the same time that it led to loss of C in treatments with no rotation (~ 3%). C stocks were around 16% lower in the CESM1-BGC and IPSL-CM5B-LR models under the RCP 8.5 scenario with a predicted temperature increase of 1.4°C and 0.38°C, and an increase in precipitation of 533 and 85 mm, respectively. Using climate models and RothC to predict future C allows us to understand how climate and management practices interact and impact soil C in order to intervene and strategize.

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Authors' contributions

SILVA, V.C.: conceptualization, data curation, formal analysis, acquisition, research, methodology, project management, supervision, validation, visualization, writing – original writing. SANTANA, M.S.: formal analysis, software, data curation, supervision, writing – review & editing. PARENTE, A.G.: software, data curation. GONDIM, R.S.: software, data curation. SILVEIRA, C.S.: software, data curation. SALVIANO, A.M.: conceptualization, formal analysis, procurement, resources, software, oversight, visualization. DEUS, T.RV.: project management, supervision. VALLADARES, G.S.: conceptualization, formal analysis. GIONGO, V.: conceptualization, funding, resources, oversight, validation, writing – review & editing.

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