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Article

Potential for organic carbon sequestration in quinoa simulated with the RothC-26.3 model

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Abstract

The present study was carried out in the INIFAP Experimental Field of Mexico Valley with the objective of estimating the potential sequestration of organic carbon from the soil (COS) in the quinoa varieties: Amarilla Maranganí and Blanca with the use of the RothC-26.3 model. The simulations of COS dynamics with the RothC included: three time periods: 20, 60 and 100 years, the annual systems: monoculture of quinoa (MQ), monoculture of corn (MM) and rotation of quinoa-corn (RQM); and the use of three contributions of carbon (C) to the soil from crop residues (RV): 60, 70 and 80% of total dry matter (MST). Considering that about 80% of the MST remains on the cultivation land after the quinoa harvest, the carbon accumulation (C) was evaluated by plant structure in three fertilization treatments. Fertilization had no significant effect on MST production, attributed to the favorable level of soil fertility at the study site and the hardiness of the crop. The MST Amarilla Maranganí was higher than Blanca. In both quinoas, the stems and inflorescences and the leaves and grain represented 76 to 84% and 11 to 23% of the MST, respectively. The changes in COS simulated by the RothC in both quinoa varieties indicated COS sequestration potential (Mg C ha^{-1} $year^{-1}$) in a period of time greater than 20 years, only in the MQ system with RV= 80% MST.

Keywords: edaphic carbon, exchange rate, farming systems, vegetable waste.

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Introduction

Agricultural soils have significant potential to sequester COS and mitigate greenhouse gas emissions (Zhang *et al*., 2014; Paustian *et al*., 2016). Globally, agricultural soils have lost between 30 and 75% of COS reserves (30 to 40 Mg C ha^{-1}) (Lal *et al*., 2007). However, 75% of these soils can be recovered through increased stored or sequestered COS. According to Lal (2004), the stored COS depends on management strategies such as waste retention and application of fertilizers, in addition to environmental conditions (Luo *et al*., 2010).

The RothC-26.3 model is one of the most widely used in predicting changes in soil C and has been applied in different systems and soils around the world, in addition to the availability and simplicity of the input data to execute it (Coleman *et al*., 1997). In Mexico, the performance of RothC-26.3 has been evaluated in short-term experiments, with the use of direct measurements in agricultural, forest, grassland and pasture systems (González *et al*., 2011). In agricultural systems, an efficiency of 0.78 to 0.87 (González *et al*., 2011) and 0.77 (González *et al*., 2017) was reported.

In the crops called pseudocereals such as quinoa, amaranth and chia, the information on the sequestration of COS by the contribution of the vegetable residues of the harvest is null. In the case of quinoa, it has the potential to store COS in the soil since, like the amaranth crop, in Mexico, after its harvest, around 80% of the aerial vegetable residues are left on the farmland, while corn, under conventional tillage, according to estimates by Pérez *et al*. (2000) from 15 to 30% of RV.

The objective of the present work was to estimate the potential of organic carbon sequestration from the soil of quinoa cultivation systems with the use of the RothC-26.3 model. Simulation scenarios were generated in time periods of 20, 60 and 100 years and with different contributions of harvest residues in the annual cultivation systems: monocultures of corn and quinoa; and quinoa-corn rotation.

Materials and methods

Characteristics of the experimental site

The study was carried out in the INIFAP Experimental Field of Mexico Valley, located in the town of Santa Lucía, Coatlinchan, State of Mexico. This site is characterized by its cold temperate climate with rains in summer, as can be seen in Table 1, where the geographical location and the climatic and edaphic characteristics are also indicated.

Table 1. Geographical location and climatic and edaphic characteristics of the experimental site.

Location	Characteristics
Longitude	98° 53’ W
Latitude	19° 29’ N
Altitude (m)	2 240
Annual mean temperature§ (°C)	18.6

Location	Characteristics
Average annual rainfall[§] (mm)	590
Average annual evaporation[§] (mm)	54.7
Soil[€]	Feozem
Texture	Clay loam
Clay (%)	38
Bulk density (g cm^{-3})	0.87
pH	7
Organic material (%)	2.3
$N-NH_4$ (ppm)	21
$N-NO_3$ (ppm)	70
Olsen extractable P (ppm)	55

[§]= Chapingo station data from 1995-2016; [€]= INEGI (2007).

Determination of COS

The determination of the COS was carried out before the establishment of the experiment in the month of June 2016. Six soil samples were taken distributed on the experimental surface of 240 m^2, at the soil depth (Pm) of 0-30 cm with the following procedure: the soil samples were air dried, their weight was recorded; with the help of tweezers, visible roots, plant remains and animals were removed; they were sieved at 2 mm; and sub-samples were taken. The determination of the concentration of COS was carried out with the Walkley and Black method (1934) that reports the organic matter of the soil (MOS) and the factor 0.58 (1/1.724) was used to convert MOS to COS.

For the calculation of COS (Mg ha^{-1} $year^{-1}$), the apparent density (Da) (g cm^{-3}) was obtained by the cylinder method. The Da was the relationship between the weight of the dry soil and the volume of the soil: the weight of mineral soil plus the humidified one, without considering the weight of the roots, residues and stones and the volume of the soil, was calculated by discounting the total volume, the volume of roots, residues and stones. The amount of COS (Mg ha^{-1}) was the product of Pm, Da and the %COS.

Carbon contribution to the soil from plant residues

Quinoa

Considering that about 80% of the quinoa MST remains in the cultivation land after harvest, carbon (C) accumulation in dry matter by plant structure and total was evaluated in three in treatments of fertilization dose and a control. According to Bazile *et al*. (2014), in the harvest manually or mechanically, after cutting the panicles or inflorescences, these are left in the field grouped in heaps to dry completely.

Subsequently, the threshing is carried out, the panicles are placed on a canvas, with the help of an agricultural implement or by hitting them with a stick, the grain is dislodged, in this way, most of the crop residues remain on the cultivation land. The fertilization dose treatments were as follows: T1= 40-40-00; T2= 80-40-00; T3= 120-40-00 and T0= 00-00-00. The experimental units consisted of five grooves 0.8 m wide by 5 m long (20 m^2).

These treatments were evaluated in a randomized block experimental design with three replicates in a split plot arrangement. The Amarilla Maranganí and Blanca quinoa varieties were established in the plots and the fertilization dose treatments in the blocks, in total there were 24 experimental units (240 m^2). In addition to the RV, the contribution of C to the soil was due to the fertilizer that was placed on the soil along with the seed at the time of planting.

Dry matter was measured when the crop reached physiological maturity at 147 days after sowing and consisted of the following activities: four plants were cut at ground level, the plant structures were separated: leaves, stems, inflorescences and grain, the total fresh weight and dry weight of a 100-200 g subsample were obtained, the subsample was dried in an oven at a temperature of 65 °C. With these last data, the dry matter per organ was obtained by subtracting the moisture percentage from the weight of the total fresh biomass.

The moisture percentage was the wet weight minus the dry weight among the wet weight of the subsamples. The biomass of the roots was estimated as 10% of the total aerial biomass, considering that in other cereals such as wheat and barley it is 10 to 15% according to the study by Kuzyakov and Domanski (2000). Organ carbon was the product of dry matter (g) and the average carbon concentration of three replicates in plant tissue (%). The carbon concentration in the plant tissue was determined by dry combustion on an automatic total organic carbon analyzer (Shimadzu TOC 5000-A).

Growth and yield variables

To compare the growth and yield of the quinoa varieties under study, the following variables were measured in the physiological maturity stage: plant height, measured from the base of the stem to the tip of the main panicle, stem diameter, measured at 10 cm from the base of the plant, panicle length, total dry matter, grain yield per plant and per hectare; and harvest index (IC).

Corn

In the estimation of the RV that provides the corn to the ground, the information was considered for the area median productivity under strict temporal of Texcoco which is similar to the conditions under which the cultivation of quinoa was evaluated. A yield of 3 Mg ha^{-1} was considered according to SAGARPA (2015) and a harvest index of 0.34. This information gave an annual RV input of 3.5 Mg C ha^{-1} $year^{-1}$ which corresponds to 40% of the total dry matter, 10% is provided by the roots according to the estimates of Kuzyakov and Domanski (2000) for cereals and 30% corn stems (Pérez *et al*., 2000).

RothC model

Coleman and Jenkinson's (2005) RothC model divides COS into compartments containing materials with different decomposition rates, four are active and one is passive: (i) easily decomposable plant material (MVF); (ii) resistant plant material (MVR); (iii) microbial biomass (BIO); (iv) humified organic matter (HUM); and (v) inert organic matter (MOI).

The active compartments undergo decomposition by first order kinetics, according to the following expression: $Y= Y_0 (1 - e^{-abckt})$. Where: Y_0 is the initial C of the active compartment; k is the constant annual decomposition rate; t is 1/12 to obtain the decomposition rate at the end of each month; and a, b and c are the factors that modify k and are temperature, humidity and soil cover, respectively. The value of k for each compartment presents the following values: MVD (10), MVR (0.3), BIO (0.66) and HUM (0.2).

The passive compartment, MOI (Mg ha^{-1}) was obtained with the equation of Falloon *et al*. (1998) expressed by $MOI= 0.049 \times COT^{1.139}$, where COT is organic carbon (Mg ha^{-1}). The RothC model input data are: 1) climatic factors: monthly average air temperature (°C), precipitation (mm) and evaporation (mm), TPM, PPM and EPM, respectively; 2) edaphic: COS content (Mg ha^{-1}), clay content (%) and depth of soil sampling; 3) monthly entry of C into the soil from plant residues (RV) and organic fertilizers (AO); 4) monthly vegetation cover of the soil; that is, if the soil is bare or with vegetation cover; 5) the MVD/MVR ratio, which according to Coleman and Jenkinson (2005) was 1.44 (59% are for MVD and 41% are for MVR); (6) the MOI value obtained from the Falloon *et al*. (1998).

Simulations with the RothC model

The simulation of COS changes included initialization and development of scenarios. At initialization, the initial C content of the active compartments in the equilibrium soil condition was obtained. This was achieved by running the RothC iteratively 10 000 years with the information on climate, soil, MVD/MVR ratio, MOI and input of C of the RV to the soil obtained by the model. The scenarios were executed with the C value of the active and passive compartments, which were obtained at initialization and with the information on climate, soil, MVD/MVR, ground cover and MOI.

The simulations of the COS dynamics scenarios with the RothC were performed with the information: three time periods: 20, 60 and 100 years; the annual systems: monoculture of quinoa (MQ), monoculture of corn (MM), rotation of quinoa-corn (RQM) and the use of contribution of C to the soil from the RV: 60, 70 and 80% of the MST of quinoa and 40% of the MST of corn.

The contribution of C per hectare (Mg ha^{-1} $year^{-1}$) in quinoa was calculated as the product of the proportion of the MST (%) and the population density (plants ha^{-1}): 129, 166 and 136, 458 for Amarilla Maranganí and Blanca, respectively. To determine the change rate (TC) of COS in the 20, 40 and 60 year time periods, the following expression was used: $TC\ COS_{20\ years}= COS_{year\ 2000} - COS_{yea\ r2020}$. A summary of the assumed model input information and measurement of the study site is shown in Tables 1, 2 and 3.

Table 2. Information required in the initialization and simulation of scenarios in quinoa varieties with the RothC model.

Varieties	COS	MOI	clay	CVS	MVD/MVR
	(Mg ha^{-1})		(%)	(months)	
Amarilla Maranganí	34.7	2.78	38	8	1.44
Blanca	34.7	2.78	38	8	1.44
Corn	34.7	2.78	38	8	1.44

Table 3. Entry of carbon into the soil by plant residues in the initialization and simulation of scenarios in quinoa varieties with the RothC model.

Initialization		Scenarios RV (% total dry matter)				Fertilizer
Varieties	RV_{RothC}	40	60	70	80	
			(Mg C ha^{-1} year $^{-1}$)			
Amarilla Maranganí	4.77		3.84	4.48	5.12	0.24
Blanca	4.77		3.52	4.08	4.72	0.24
Corn	4.77	3.5				0

RV= vegetable waste.

Statistical analysis of the study variables

The accumulation of C in the dry matter by plant and total structure, and the growth and yield variables were subjected to an analysis of variance with the SAS LGM procedure. Tukey’s test (p= 0.05) was used to compare means.

Results and discussion

Carbon distribution in biomass

The results of the comparison of means of the growth and yield variables for the Amarilla Maranganí and Blanca quinoas (Table 4) indicated statistical differences for plant height, stem diameter, total dry matter and grain yield per hectare, in all Amarilla Maranganí cases were superior to Blanca.

Table 4. Comparison of means for growth and yield variables in the study quinoa.

Quinoa/Variables	Alt	D	LP	Yield	RP	MST	IC
	(cm)	(cm)	(cm)	(kg ha^{-1})	(g $plant^{-1}$)	(g $plant^{-1}$)	
Amarilla Maranganí	214 a	15 a	74 a	2 509 a	18.2 a	109 a	0.18 a
Blanca	149 b	13 b	72 b	1 172 b	17.6 a	94 a	0.17 a
DMSH	13.66	0.57	0.62	472.24	6.7	35.29	0.032

Alt= plant height; D= diameter; LP= panicle length; RP= yield per plant; MST= total dry matter; IC= harvest index. DMSH = honest minimal significant difference. Values that share the same letter in the same column are statistically equal (Tukey p= 0.05).

The yield per hectare in Amarilla Manangani was close to the national average of 2.8 Mg ha^{-1} and in both it was high in the T3 fertilization treatment (120-40-00), although it did not show significant differences between fertilization treatments. Panicle length was within the range of 30 to 80 cm, reported by Mujica *et. al*. (2003) for Peruvian quinoas. The IC obtained in the present study was less than the average range reported in other studies, Mujica *et al*. (2003) who reported a range in quinoa of 0.24 to 0.45.

The yield (kg ha^{-1}) of this study was higher than the average reported experimentally by Mújica *et al*. (2003) in the same varieties cultivated in Perú (0.93 kg ha^{-1}) and it was also higher in the case of Amarilla grown in Viacollo, Chile, where it had a production of 1 350 kg ha^{-1} (Delatorrre *et al*., 2008).

Contribution of plant carbon to the soil

The mean of the accumulation of C in leaf, inflorescence, and grain, MST and IC were statistically equal in both quinoas, the exception was in the stems, with higher value in Amarilla Maranganí (Table 5).

Table 5. Comparison of means of carbon content per organ per plant in the study quinoa.

Quinoa/Variables	Stem	Leaf	Inflorescence	Grain	MST	IC
			(g $plant^{-1}$)			
Amarilla Maranganí	20 a	0.79 a	16 a	8.2 a	45 a	0.18 a
Blanca	14 b	0.43 a	17 a	7.9 a	39 a	0.2 a
DMSH	6.04	0.5	7.35	1.29	14.55	0.043

MST= total dry matter; IC= harvest index; DMSH = Honest significant minimum difference. Values that share the same letter in the same column are statistically equal (Tukey p= 0.05).

The Table 6 shows the contribution of C to the soil by quinoa and corn. The distribution of C by organ: stem, leaf, inflorescence, grain and root, in the quinoa fertilization treatments did not show significant differences despite this, T3 (120-40-00) had the highest amount of C per organ and total MST.

Table 6. Carbon in vegetable residues of quinoa (g) Amarilla Maranganí, Blanca and corn in physiological maturity.

Organ/Fertilization treatments	T0	T1	T2	T3
Amarilla Maranganí				
Stem	18.45 a	19.24a	18.71a	21.99 a
Leaf	0.42 a	0.71 a	1.12 a	0.91 a
Inflorescence	17.11 a	15.76 a	13.91 a	18.97 a
Grain	8.97 a	7.68 a	6.57 a	9.46 a
Roots	4.5 a	4.5 a	4 a	5.1 a
MST	49.4 a	47.7 a	44.3 a	56.5 a
Blanca				
Stem	13.55 a	13.2 a	12.37 a	13.8 a
Leaf	0.33 a	0.46 a	0.48 a	0.44 a
Inflorescence	17.75 a	17.15 a	15.12 a	19.44 a
Grain	9.17 a	7.57 a	6.29 a	8.53 a
Roots	4.1 a	3.8 a	3.4 a	4.2 a
MST	44.9 a	42.2 a	37.7 a	46.4 a

T1= 40-40-00; T2:80-40-00; T3= 120-40-00; T0= 00-00-00. Values that share the same letter in the same column are statistically equal (Tukey p= 0.05).

Based on these results, to perform the simulations with the RothC, the average value of the treatments (g of C plant^{-1}) was used and with this, the percentages C of RV input of 60, 70 and 80% were obtained of the MST, the latter were close to those reported by González *et al*. (2017) for corn under conservation tillage in the Bajío region (2.6 to 5.9 Mg of C ha^{-1} year^{-1}).

In the comparison of means of the growth and yield variables by variety of quinoa in the fertilization treatments, there were no significant differences (Table 5), which is explained by the favorable fertility level of the soil where the quinoa was established, with a content of organic matter in the soil of 2.3% and mineral nitrogen of 91 ppm, since quinoa is a crop that maintains its productivity even in soils with low fertility, low humidity and even high salinity (Ruiz *et al*., 2014). About the distribution of C by organ in the fertilization treatments (Figure 1).

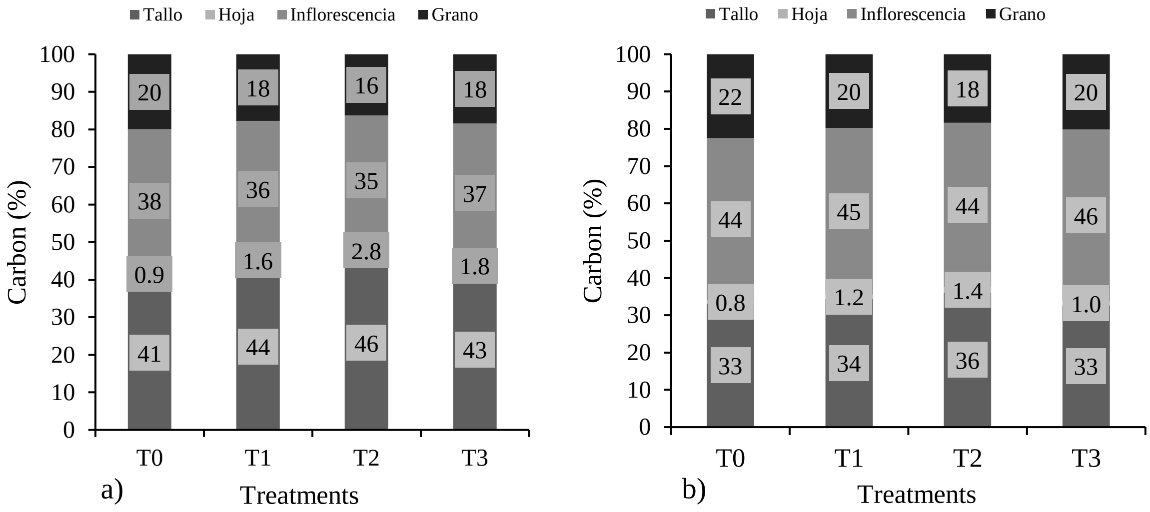

Figure 1. Carbon distribution by plant structure in fertilization treatments at physiological maturity in quinoas (a) Amarilla Maranganí and (b) Blanca. T1: 40-40-00; T2: 80-40-00; T3: 120-40-00; and T0: 00-00-00

Stems and inflorescences were found in both quinoas to be about 80% of the MST. In Amarilla Maranganí the C in stems is higher, 41-46% of the MST, while in Blanca it is higher in the inflorescences, 44-46% of MST. In both quinoas, the leaves and grain represent a lower proportion of the MST, from 0.8 to 2.8% and from 16 to 22% of the MST, respectively. This resulted in a low IC (0.17-0.18) that is reflected in high MST production in leaves, stems and inflorescences and low production of MST in grain. Results that were close to that reported by Mujica *et al*. (2003) for quinoa, with 45% for the stems, 29% for the leaves and inflorescences and 26% for the grain.

Simulation of COS scenarios with different contributions from RV

The simulation results of scenarios with different contributions C and in different periods of time are presented in Table 7 and Figure 2. In the periods of time evaluated, there was sequestration of COS only in MQ with the contribution of C to the RV soil of 80% of MST

(0.02-0.1 Mg C ha^{-1} year^{-1}), while the order of COS losses from lowest to highest was as follows: MQ with RV of 70% MTS< MQ with RV of 60% MST (between 0 to - 0.16)< RQM (-0.02 to -0.18); and MM (between -0.11 to - 0.19).

Table 7. Changes in soil organic carbon at 20, 60 and 100 years of continuous cultivation in three plant residue inputs at 0-30 cm soil depth.

Year (% MST)	Quinoa monoculture			Quinoa + corn rotation			Monoculture corn
	60	70	80	60+40	70+40	80+40	40
				(Mg ha^{-1} year^{-1})			
				Amarilla Maranganí			
20	-0.11	-0.01	0.1	-0.15	-0.09	-0.03	-0.19
40	-0.08	0	0.07	-0.11	-0.07	-0.02	-0.14
60	-0.06	0	0.06	-0.08	-0.05	-0.02	-0.11
				Blanca			
20	-0.16	-0.07	0.03	-0.18	-0.13	-0.07	-0.19
40	-0.12	-0.05	0.02	-0.13	-0.09	-0.05	-0.14
60	-0.09	-0.04	0.02	-0.1	-0.07	-0.04	-0.11

MST= total dry matter.

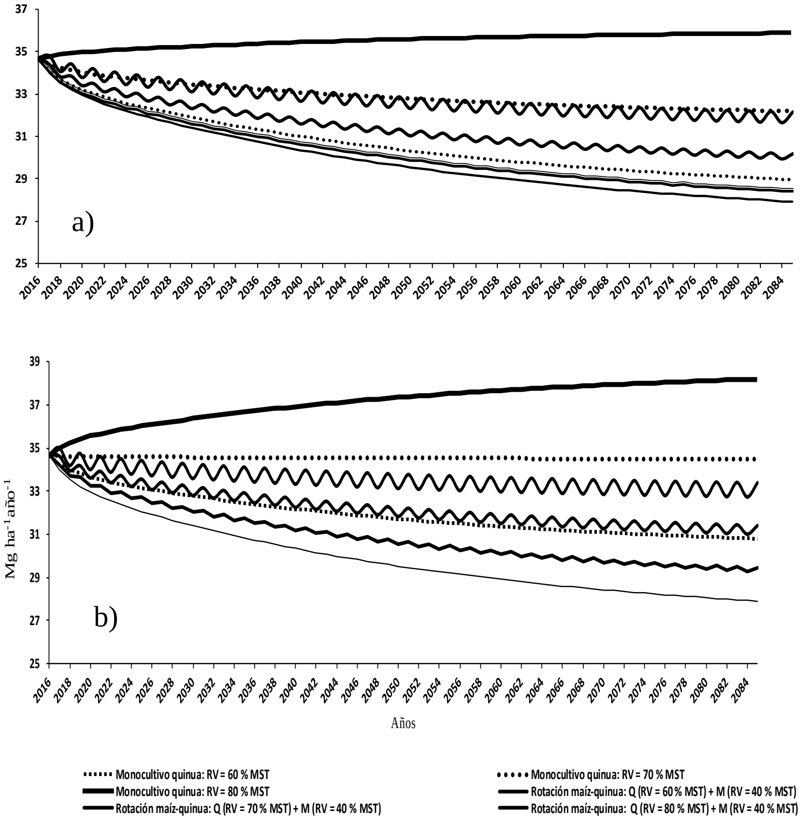

Figure 2. Scenarios of changes in soil organic carbon with different contributions of carbon to the soil in quinoas: (a) Blanca and (b) Amarilla Maranganí.

This can be explained by the COS conversion or change time, which according to Jenkinson and Rayner (1977), is the movement of organic C, through a given volume of soil, and is obtained from the relationship between COS and the annual RV entry. The average conversion time (years) for the different simulation periods with the RothC in the studied systems had the inverse order of the hijacked COS: MM (9.3)> RQM (8.5)> MQ with 40% MST (8.9)> MQ with 60% MST (7.7)> MQ with 80% MST (6.7).

The highest COS: MM and RQM conversion values indicated the stabilization of C in the soil, and the lowest: MQ with 80% MST indicated that there was a faster migration of C and, therefore, indicated that the soil is farther from the equilibrium state due to a greater input of RV (Figure 1, Table 4). The stored or sequestered COS was within the globally reported by Lal (2004), who reports from 0.02 to 0.76 Mg ha^{-1} year^{-1} in the case of agricultural systems that adopt improved management systems.

In general, the Amarilla Maranganí quinoa in monoculture and low rotation with corn exceeded the exchange rates of COS de la Blanca in monoculture and monoculture of corn with the inputs of C to the soil evaluated with the RorhC, results that had a linear relationship with his best growth, yield and C inputs to the soil in relation to Blanca. The inputs of C to the soil by the RV evaluated had a linear relationship with the sequestration rates (Table 5 and Table 6).

Similarly to what was found by Wang *et al*. (2017) who, globally in cereals with different inputs of C to the soil, had a high correlation with changes in COS. Particularly, the COS change rates found in quinoa from our work responded to the particular conditions of dry matter productivity influenced by the climate and waste retention, application of fertilizers and the outflow of MST, as reported by Smith *et al*. (2008); Luo *et al*. (2010) in agricultural systems. Scenario runs with the RothC detected that both quinoas respond to current needs for the use of crops with COS sequestration potential and to keep the soil in a condition of equilibrium between profits and losses of this element (Figure 2).

Conclusions

Fertilization to the soil in the quinoa crop did not have a significant effect on the carbon accumulation in the dry matter by plant structure and total dry matter, this was attributed to the favorable level of soil fertility where they were established and to the hardiness of the crop. Amarilla Maranganí in monoculture was the one with the highest sequestration of organic carbon from the soil with RV= 80% MST. Both quinoas showed greater potential for sequestration under monoculture conditions than cultivated in rotation with corn and corn in monoculture, in periods of time greater than 20 years.

Cited literature

Bazile, D.; Bertero, D. y Nieto, C. 2014. Estado del arte de la quinua en el mundo en 2013: FAO (Santiago de Chile) y CIRAD, (Montpellier, Francia). 724 p.

Coleman, K.; Jenkinson, D. S.; Crocker, G. J.; Grace, P. R.; Klir, J.; Korschens, M.; Poulton, P. R. and Richter, D. D. 1997. Simulating trends in soil organic carbon in long-term experiments using RothC-26.3. Geoderma. 81(1-2):29-44.

Coleman, K. and Jenkinson, D. 2005. ROTHC-26.3. A model for the turnover of carbon in soil. Model description and Windows Users' Guide. Rothamsted, U. K. Harpenden: Rothamsted Research. 1-43 pp.

Delatorre, H. J.; Salinas B. A. and Sánchez, M. M. 2008. The cultivation of quinoa. Universidad Arturo Prat Iquique. Chile. 135 p.

Falloon, P.; Smith, P.; Coleman, K. and Marshall, S. 1998. Estimating the size of the inert organic matter pool from total soil organic carbon content for use in the Rothamsted carbon model. Soil Bio. and Biochem. 30(8-9):1207-1211.

González, M. L.; Etchevers, B. J. D.; Paz, P. F.; Díaz Solís, H.; Fuentes, P. M. H.; Covaleda, O. S. and Pando, M. M. 2011. Performance of the RothC-26.3 model in short-term experiments in Mexican sites and systems. J. Agric. Sci. 149(4):415-425.

González, M. L.; Moreno, P. E. del C. and Baéz, P. A. 2017. Simulation of soil organic carbon changes in Vertisols under conservation tillage using the RothC model. Sci. Agr. 74(3):235-241.

INEGI (Instituto Nacional de Geografía e Informática). 2007. Conjunto de datos vectorial edafológico, Serie II, escala 1:250 000 (Continuo Nacional). México.

Jenkinson, D. S. and Rayner, J. H. 1977. The turnover of soil organic matter in some of the Rothamsted classical experiments. Soil Sci. 123(5):298-305

Kuzyakov, Y. and Domanski, G. 2000. Carbon input by plants into the soil. Review. J. Plant Nutrit. and Soil Sci. 163(4):421-431.

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. Geoderma. 123(1-2):1-22.

Lal, R.; Follet, R. F.; Stewart, B. A. and Kimble, J. M. 2007. Soil carbon sequestration to mitigate climate change and advance food security. Soil Sci. 172(12):943-956.

Luo, Z.; Wang, E. and Sun, O. J. 2010. Soil carbon change and its responses to agricultural practices in Australian agro-ecosystems: A review and synthesis. Geoderma. 155(3-4):211-223.

Mujica, A.; Marca, S. and Jacobsen, S-E. 2003. Current production and potential of Chenopodium quinoa Willd.) in Peru. Food Rev. Int. 19(1-2):149-154.

Paustian, K.; Lehmann, J.; Ogle, S.; Reay, D.; Robertson, G. P. and Smith, P. 2016. Climate-smart soils. Nature. 532(7597):49-57.

Pérez, O. A.; Etchevers, J. D.; Navarro, G. H. y Nuñez, E. R. 2000. Aporte de los residuos del cultivo anterior al reservorio de nitrógeno en tepetates. Agrociencia. 34(2):115-125.

Smith, P. 2008. Land use change and soil organic carbon dynamics. Nut. Cycl. Agroecosyst. 81(2):169-178.

Ruiz, K. B.; Biondi, S.; Oses, R.; Acuna, R. I. S.; Antognoni, F.; Martínez, M. E. A.; Coulibaly, A.; Canahua, M. A.; Pinto, M.; Zurita, S. A. and Bazile, D. 2014. Quinoa biodiversity and sustainability for food security under climate change: a review. Agron. Sustain. Dev. 34(2):349-359.

SAGARPA (Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación). 2015. Agenda Técnica Agrícola Estado de México. México. Segunda edición. México, DF. 288 p.

Walkley, A. and Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 37(1):29-38.

Wang G.; Zhang, W.; Sun, W.; Li, T. and Han, P. 2017. Modeling soil organic carbon dynamics and their driving factors in the main global cereal cropping systems. Atmos. Chem. and Phys. 17(19):11849-11859.

Zhang, W.; Yu, Y.; Li, T.; L.; Sun, W. and Huang, Y. 2014. Net greenhouse gas balance in China's Croplands over the last three decades and its mitigation potential. Environ. Sci. Tech. 48(5):2589-2597.