Journal of Agricultural Sciences Research

ISSN 2764-0973 vol. 5, n. 7, 2025

ARTICLE 12

Data de Aceite: 17/12/2025

YIELD, ATMOSPHERIC CARBON CAPTURE, AND SOIL ORGANIC CARBON SEQUESTRATION WITH AGRONOMIC PRACTICES IN RAIN-FED FORAGE CORN

Hugo Ernesto Flores López
Alto de Jalisco Experimental Field. National Institute of Forestry, Agricultural and Livestock Research. Tepatitlán de Morelos, Jalisco. Mexico

Lorena Jacqueline Gómez-Godínez
National Center for Genetic Resources. National Institute of Forestry, Agricultural and Livestock Research. Tepatitlán de Morelos, Jalisco. Mexico

Susana Elizabeth Ramírez Sánchez
Alto de Jalisco Experimental Field. National Institute of Forestry, Agricultural and Livestock Research. Tepatitlán de Morelos, Jalisco. Mexico

Javier Ireta Moreno
Centro Alto de Jalisco Experimental Field. National Institute of Forestry, Agricultural and Livestock Research. Tepatitlán de Morelos, Jalisco. Mexico

Juan Francisco Pérez Domínguez
Alto de Jalisco Experimental Field. National Institute of Forestry, Agricultural and Livestock Research. Tepatitlán de Morelos, Jalisco. Mexico

Abstract: High levels of greenhouse gases in the atmosphere emitted by human activity have created the global problem of climate change. Agriculture contributes to these emissions, but it has also been identified as part of the solution. The physiological processes of photosynthesis and respiration in plants capture CO_2 from the atmosphere in the form of dry matter, which, through management practices, can maintain carbon in organic form in soil. The objective of this study was to quantify atmospheric carbon capture and its sequestration as soil organic carbon using agronomic practices in rainfed forage corn in the Altos de Jalisco region of Mexico. A long-term experiment with agronomic practices was used, with an asymmetric factorial design with tillage, fertilization, crop residues, and no rotation. The following variables were measured: forage yield (RendForr) and dry matter (DMY), atmospheric CO2 capture, and soil organic carbon sequestration (SOC). The results showed that from July to September there was continuous and intense rainfall, which caused excess water and symptoms of nitrogen deficiency in corn, an effect attributed to the denitrification process. RendForr and DMY only showed statistically significant differences in the fertilization treatment, with higher yields in organic fertilization. Excess water and denitrification are also attributed to the fact that no statistical differences were observed in SOC sequestered and loss of organic carbon in almost all treatments.

Keywords: Soil recarbonization, *Zea mays*, denitrification.

INTRODUCTION

Humanity faces global problems, and climate change is one of them, caused by the emission of greenhouse gases (GHG), such as CO_2. Agriculture is one of the human activities that contribute to these emissions. In 2022, agriculture and livestock sectors of Mexico contributed more than 139.08 Mt of CO_2e, from CH_4 and N_2O emissions from livestock activity and CH_4, N_2O, and CO_2 emissions from agricultural activity, with CO_2 emissions corresponding to 18.4% of this sector's activities (SEMARNAT-INECC, 2022). On the other hand, agriculture has been identified as a possible solution to climate change by capturing atmospheric CO_2 through photosynthetic processes carried out by plants, where part of that CO_2 and oxygen are released into the atmosphere through respiration and another part is captured in plant biomass, situation that makes it possible to keep carbon in soil in organic form through the use of appropriate agronomic practices for cultivation (Fynn et al., 2009). This primary sector uses natural resources that have been misused, such as land use change, increased land use intensity, crops unsuitable for the production site, inefficient soil and water management practices, and shortages of some inputs in some years, such as fertilizers, among others (Lal, 2008). Recarbonizing soil on a large scale and at the agroecosystem level is complex, as sequestration rates vary according to climatic conditions, soil types, and agricultural management practices (Ghimire et al., 2022). One of the first actions is to identify strategies that include agronomic practices that efficiently capture SOC and then maintain it in that condition for a long time, more than 21 years (Poeplau et al., 2021), or even hundreds to thousands of years (Trumbore, 2000). Strong influences on SOC have been reported, including organic carbon input from roots and crop residues, clay content, average annual temperature, annual precipitation, and nitrogen content in the surface layer (Poeplau et al., 2021; Chen et al., 2013; Farage et al., 2003). Finally, these practices should be promoted among farmers, but their acceptance must maintain or even increase production and income so that they can improve their level of well-being (FAO, 2018; Damián Huato et al., 2007).

Globally, agronomic management practices that enable SOC sequestration have been identified. Lal (2004) mentioned two types of strategies can be implemented at the farm level to sequester SOC: 1) changing land use to crops that allow for the restoration of degraded soils, such as grasslands, and 2) adopting sustainable agronomic management practices, such as conservation tillage, cover crops, or crop rotation, combined with organic amendments using manure or compost, integrated nutrient management, efficient use of irrigation water or rainwater, and agroforestry practices (Poeplau and Don, 2015; Romero-Perezgrovas et al., 2014; Trivedi et al., 2020; Giovanna et al., 2016; Pareja-Sánchez et al., 2020; Parker et al., 2018).

Within Mexico's agricultural sector, corn is the main crop harvested under rainfed conditions (SIAP, 2025). In Jalisco, crop intensification has led to the highest national yield of 6.66 t/ha. However, this intensification is carried out using unsustainable management practices that cause water erosion, deforestation, conventional agricultural systemas, land use change, with the consequent loss of SOC and soil degradation (Zamora-Morales et al., 2018; FAO, 2017; Paustian et al., 1997). For the Altos de Jalisco and Jalisco regions, low levels of SOC are reported in the soils, with less than 1.5% and 1.036% SOC, respectively, a situation that opens up an excellent option for sequestering SOC in rainfed corn (Flores López et al., 2025; Rojas-García et al., 2017).

In Mexico, although efforts have been made to quantify SOC sequestration (Balbontín et al., 2009), Cotler et al. (2016) refer to the need to identify cross-cutting issues related to soil organic carbon conservation, such as the development of public policies that recognize functions and ecosystem services provided by soils, institutional strengthening of soil issues, and incentives for soil conservation programs that incorporate carbon with agroecosystems adapted to diverse conditions of Mexico. In this context, Zamora-Morales et al. (2017) summarize technologies from the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) aimed at climate change mitigation and carbon sequestration in soil, among which the following stand out: conservation tillage (35.7%), biofertilization (14.3%), fertilization (12.7%), among others. These technologies require greater emphasis on research to quantify SOC through agronomic crop management, particularly rainfed corn and long-term studies of experimental platforms. The objective of this study was to quantify atmospheric carbon capture and its sequestration as soil organic carbon through use agronomic practices of rainfed forage corn in Highlands of Jalisco, Mexico.

MATERIALS AND METHODS

The experiment site. The experiment was conducted on the experimental platform established on land belonging to Research Station Centro Altos de Jalisco (CECEAJAL) of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) in Tepatitlán de Morelos, Jalisco, Mexico. This platform is 12 years old. The soil is classified as Udic Rhodustalf (INEGI, 1994), with 905 mm of annual rainfall and average annual maximum and minimum temperatures of 25.7 and 8.6°C, respectively.

Experimental design. The CECEAJAL long-term experimental platform has randomized complete block experimental design with three replicates. The distribution of 18 treatments is asymmetrical factorial, resulting from combination of the following factors: 1) tillage treatments: a) conventional with three harrow passes, b) conventional with fallow plus two harrow passes, c) conservation tillage, and d) no-till with subsoiling depth of 30 cm; 2) soil cover with residues from previous corn crop with 30%, 50%, and 100% residues; 3) corn-corn rotation; and 4) mineral and organic fertilization with use of uncomposted chicken manure. Each treatment had 8 furrows, each furrow was 25 m long and 0.76 m wide.

Crop management. Agronomic management was specific to each treatment. The planting date was June 7, 2024, but emergence did not occur until July 1 due to rains that began on June 18. The Antílope (Asgrow) corn hybrid was used, with planting density of 94,000 seeds/ha in 76 cm wide rows. Mineral fertilization was determined using the balance method for each treatment, with average dose of 368-77-87 micronutrients, plus 80 additional units of nitrogen applied due to observed nitrogen deficiencies, for dry matter yield target of 23 t/ha. Organic fertilization with chicken manure was 19.6 t/ha with 4.18% nitrogen. The biotic control recommendations for corn from CECEAJAL (INIFAP, 2017) were applied.

Measured variables

Corn forage yield (RendForr). Corn was harvested for forage when grain reached two-thirds stage in the milk line and the plant had 33% to 38% DM. The usable plot (UP) consisted of 5-meter-long and 0.76-meter-wide furrow, equivalent to an area of 3.8 m². Information required to estimate corn RendForr was total weight of green corn sampled in the UP (PTM), calculated using the expression: $RendForr = \frac{PTM * 10}{UP}$.

Dry matter yield (DMY). This was quantified using a sample of forage chopped into 1.5 cm pieces; to obtain the percentage of dry matter (porcDM), a 500 g sample was taken and dried to a constant weight at a temperature of 55 to 60°C. The following expression was used to calculate DMY: $DMY = RendForr * porcMS$.

Atmospheric$_{CO_2}$ capture by corn. Atmospheric$_{CO_2}$ capture by corn was estimated using dry matter (DM) production with expression indicated by the IPCC (Muller-Feuga, 2024; Chacho, 2019): $Cap\,CO_2 = CF * RendMS$, where C is the carbon captured in kg/ha, RendDM is the dry matter yield in kg/ha, and CF is the dry matter to carbon conversion factor given by the IPCC as equal to 0.50.

Soil Organic Carbon sequestration. Was quantified using Soil Organic Carbon (SOC) concentration in each treatment of experimental platform. This assessment was performed twice: once before the start corn cycle (SOCini) and another at end of rainy season and later harvest (SOCfin). The soil from each treatment was sampled at depth of 20 cm. Carbon sequestration (ΔSOC) was quantified using the difference between SOCini and SOCfin, using the expression: $\Delta SOC = SOC_{fin} - SOC_{ini}$. Soil analysis to measure SOC percentage was carried out at INIFAP Soil Fertility and Plant Nutrition Laboratory, Santiago Ixcuintla Research Station, Nayarit, Mexico. The Dumas method was used with Elemental Flash 2000 analyzer. The bulk density of soil was determined in laboratory using test tube method. The organic carbon content in soil (tSOC) was calculated using the following formula (Vela et al., 2012): $t\,SOC = \%\,SOC\, x Da x Prof$, where $t\,SOC$ is the SOC content in the soil in tSOC/ha, %SOC is percentage of soil organic carbon concentration, Da is bulk density of soil in t/m(3),and Prof is the depth of soil sampling in cm.

Climate records

We used climate records from the INIFAP CECEAJAL weather station, located at Tepatitlán de Morelos, Jalisco, with geographical coordinates: 20.87228° N latitude, 102.71253° W longitude, and 1930 m above sea level.

Statistical analysis

The SAS 9.0 program was used for the statistical analysis of information obtained. Descriptive statistics and analysis of variance, regression analysis, Pearson's correlation coefficient, and comparison of means using Duncan's test are presented.

RESULTS AND DISCUSSION

Climate records. The average maximum and minimum temperatures from June to October were 25.1 and 13.7°C, respectively, while normal conditions at experimental site for maximum and minimum temperatures were 25.7 and 11.6°C, respectively. Daily and cumulative precipitation in 2024 and the main phenological events of corn are shown in Figure 1. Precipitation from June to September 2024 was 862.8 mm, with normal precipitation of 804.7 mm during this period. However, in July, August, and September, rainfall occurred almost daily, causing waterlogging and excess water conditions during this period. After planting, it did not rain until June 18, but the moisture did not reach the seed until June 22. There was a loss of 17.5% of sown seed.

Corn forage yield (RendForr). Table 1 shows the analysis of variance (ANOVA) of corn RendForr in the rainy season, with treatments and their interactions under study. According to this table, only statistically highly significant differences (P > 1%) were identified in the fertilization treatment. The comparison of average RendMS means with organic fertilization resulted in 56.98 t/ha, while with mineral fertilization it was 48.86 t/ha.

Dry matter yield (DMY) of corn. Table 2 shows the ANOVA of corn DMY in rainfed season, with the treatments and their interactions under study. According to this table, statistically significant differences (P > 5%) were only identified in the fertilization treatment. The comparison of DMY means with organic fertilization was 20.98 t/ha, while with mineral fertilization it was 18.69 t/ha.

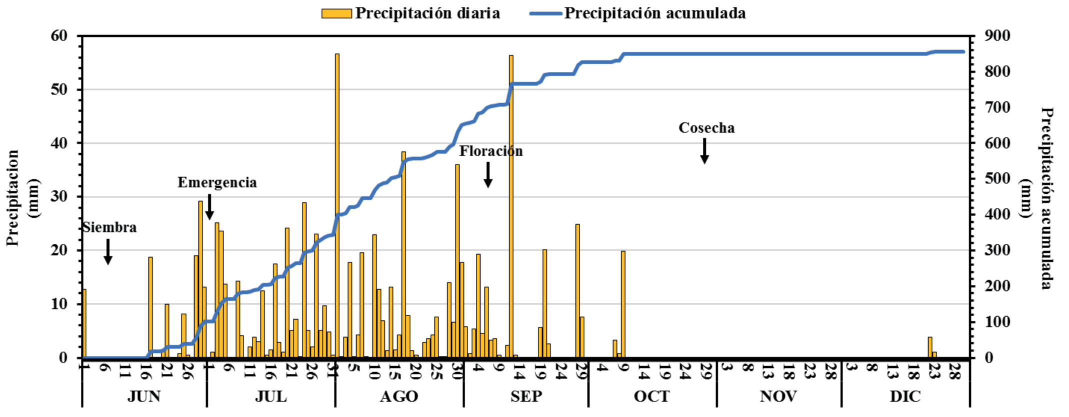

Figure 1. Daily and cumulative rainfall, with main phenological events of corn during the growing season occurred at ResearchStation Centro Altos de Jalisco experimental platform during the PV2024 cycle.

Source	DF	Sum of squares	Square of the mean	F-Value	Pr > F
Model	17	2830.762433	166.515437	1.80	0.0684
Error	36	3332.224850	92.561801		
Corrected total	53	6162.987283			
REP	2	299.8340333	149.9170167	1.62	0.2121
LAB	3	444.0476431	148.0158810	1.60	0.2066
RES	2	405.2781636	202.6390818	2.19	0.1267
FERT	1	889.3837500	889.3837500	9.61	0.0037
LAB*RES	2	159.5870850	79.7935425	0.86	0.4308
LAB*FERT	3	302.3131208	100.7710403	1.09	0.3663
RES*FERT	2	103.3848192	51.6924096	0.56	0.5770
LAB*RES*FERT	2	226.9338183	113.4669092	1.23	0.3055

Table 1. Analysis of variance of forage yield of treatments from the long-term experimental platform at the Campo Experimental Centro Altos de Jalisco. PV2024 cycle.

Source	DF	Sum of squares	Square of the mean	F-Value	Pr > F
Model	17	311.5912333	18.3288961	1.46	0.1673
Error	36	452.6419000	12.5733861		
Corrected total	53	764.2331333			
REP	2	62.78803333	31.39401667	2.50	0.0965
LAB	3	47.96768333	15.98922778	1.27	0.2987

RES	2	46.56594417	23.28297208	1.85	0.1716
FERT	1	70.40658519	70.40658519	5.60	0.0235
LAB*RES	2	5.15773917	2.57886958	0.21	0.8155
LAB*FERT	3	40.68390370	13.56130123	1.08	0.3704
RES*FERT	2	15.13563861	7.56781931	0.60	0.5532
LAB*RES*FERT	2	22.88570583	11.44285292	0.91	0.4115

Table 2. Analysis of variance of dry matter yield of treatments from the long-term experimental platform at Research Station Centro Altos de Jalisco. PV2024 cycle.

Figure 2. Corn plant with symptoms of nitrogen deficiency, observed at the flowering stage on the experimental platform. PV2024.

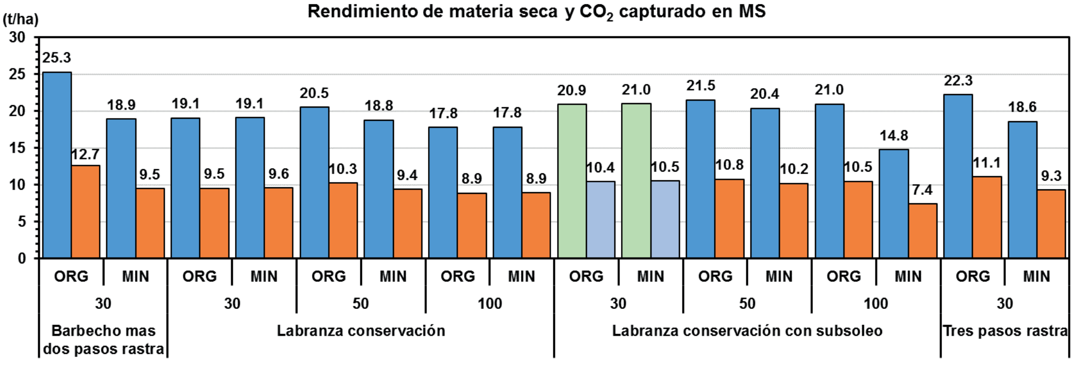

Figure 3. Corn dry matter yield and atmospheric$_{CO_2}$ capture in treatments and interactions of tillage, residue percentage, and fertilization type at the Research Station Centro Altos de Jalisco experimental platform. PV2024.

During V6 to flowering stage, corn showed nitrogen (N) deficiencies, with symptoms shown in Figure 2. For this reason, an additional 80 kg of N/ha was applied to the calculated dose in order to minimize the effect of N deficiency on yield (Kaur et al., 2017). Under conditions of excess water, such as those that occurred from July to September (Figure 1), Singh and Ghildyal (1980) reported that corn, although less susceptible to excess water, absorbs less N, with the consequent deficiency of this nutrient. In addition, Kaur et al. (2019) mentioned that respiration was main metabolic process affected by excess water, with loss of nitrates through runoff and leaching. Under these conditions of excess water, the denitrification process is also intensified, with mineralization of organic matter and use of nitrates from fertilizer by bacteria, leading to the emission of nitrous oxide into atmosphere (Kaur et al., 2019; Schenke et al., 2014).

Figure 3 shows the averages of DMY and atmospheric$_{CO_2}$ capture in the treatments under study and their interactions. It is important to note that DMY in the treatments with organic fertilization almost all had higher yields than with mineral fertilization, except in the conservation tillage treatment with subsoiling and 30% residues. Flores-López et al. (2025) indicated that DMY is highly variable in the Highland of Jalisco region of Mexico, as it depends on rainfall, which varies throughout the region during the growing season (GS) and across years, with variable results in the quantity and quality of forage produced.

Figure 3 also shows that DMY variability was high due to management practices. In this specific year, there was a significant effect of tillage with fallow plus two harrow passes and three harrow passes, both with organic fertilization, where highest DMY were observed, but not with mineral fertilization. Along with weather conditions, climate also has an impact on use of other resources applied in rainfed cropping, such as corn fertilization and good agricultural practices of nutrient use (Giovanna et al., 2016; Subedi and Ma, 2009), particularly nitrogen applied to corn (Giulia-Ronchetti et al., 2024).

It can be said that rainfall during 2024 growing season was the driver of the response observed in the DMY, with water and nitrogen availability for crop having a particular influence on DMY.

Atmospheric$_{CO_2}$ capture by corn (Cap-CO_2). Given that atmospheric CapCO_2 is directly related to DMY, the correction factor (CF = 0.5) was used on DMY. This factor corresponds to removal of water in corn biomass (Muller-Feuga, 2024). CO_2 capture is shown in Figure 3 for the treatments and interactions in this study. The ANOVA for this variable showed a similar result to DMY, where only the fertilization treatment was statistically significant (P > 5%). The organic fertilization treatments showed higher CO_2 capture, except for conservation tillage treatment, with 30% residues and mineral fertilization.

Soil Organic Carbon (SOC) sequestration with corn. Table 3 shows the ANOVA of SOC sequestered during growing season of PV2024 cycle. This table shows that no treatment had a statistically significant difference.

Figure 4 shows SOC sequestered in the treatments under study. Virtually all treatments showed SOC loss, with an overall average of -2.51 tSOC/ha. Only conservation tillage treatments with 100% residue and

		Sum of	Squared		
Source	DF	squares	the mean	F-Value	Pr > F
Model	17	564.134224	33.184366	0.85	0.6252
Error	36	1397.362452	38.815624		
Corrected total	53	1961.496676			
REP	2	85.1638481	42.5819241	1.10	0.3448
LAB	3	149.8229759	49.9409920	1.29	0.2937
RES	2	55.0478442	27.5239221	0.71	0.4988
FERT	1	25.7232019	25.7232019	0.66	0.4210
LAB*RES	2	24.1999725	12.0999862	0.31	0.7341
LAB*FERT	3	139.8136204	46.6045401	1.20	0.3234
RES*FERT	2	20.1254753	10.0627376	0.26	0.7731
LAB*RES*FERT	2	64.2372858	32.1186429	0.83	0.4453

Table 3. Analysis of variance of soil organic carbon sequestered in treatments of the long-term experimental platform at the Research Station Centro Altos de Jalisco. Tepatitlán de Morelos, Jalisco. PV2024.

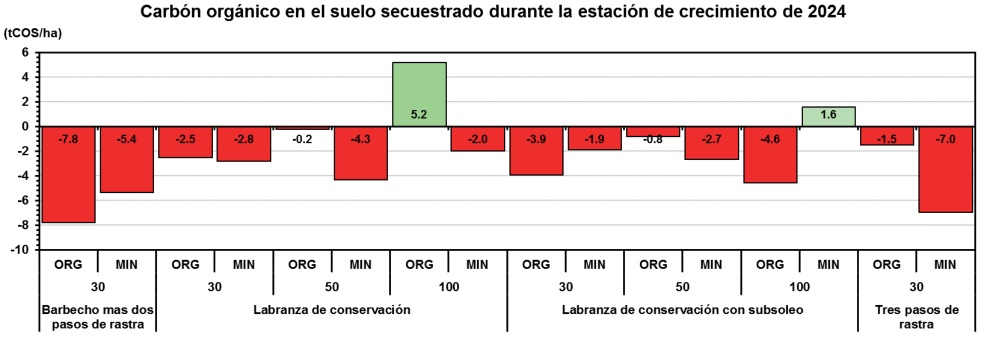

Figure 4. Soil organic carbon sequestered with the treatments evaluated at Research Station Centro Altos de Jalisco experimental platform. PV2024.

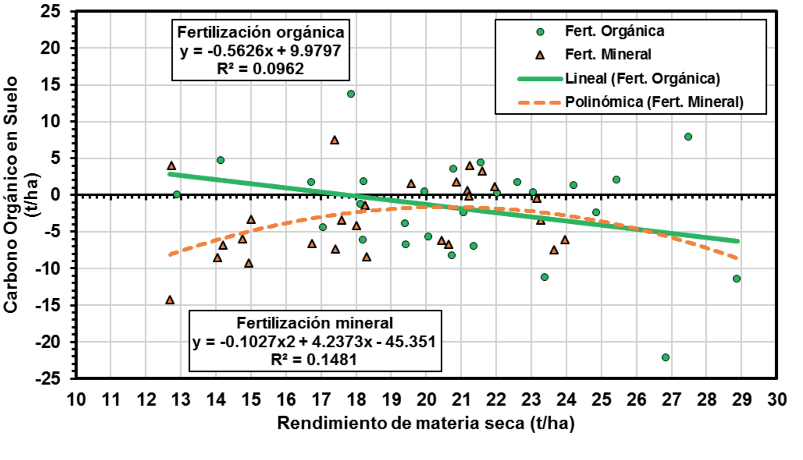

Figure 5. Trend of soil organic carbon sequestration with dry matter yield according to the fertilization, in treatments at the Research Station Centro Altos de Jalisco experimental platform. PV2024.

organic fertilization contributed 5.2 tSOC/ha, and conservation tillage plus subsoiling, with 100% residue, and mineral fertilization contributed 1.6 tSOC/ha.

Although SOC sequestration is linked to fertilization according yield to be achieved by the crop (Gregorich et al., 1996), the quantity and quality of soil organic matter, the use of mineral fertilization (Hua et al., 2014), and carbon input into the cropping system (Zhao et al., 2016; Khan et al., 2007; Kong et al., 2005). However, other factors may be present and limit SOC sequestration, such as continuous and intense rainfall, which causes waterlogging and excess water for short or long periods of time, which has been reported as an important factor in the loss of soil organic matter and nitrates (Kaur et al., 2019). In this situation, the denitrification process is present and too is reported as a major cause of nitrogen and soil organic matter loss (Schwenke et al., 2014). This explains loss of SOC and DMY in the treatments, but it is necessary to evaluate denitrification on DMY, SOC, and management practices in the experimental platform.

Figure 5 shows that fertilization (organic and mineral) had significant effects on the relationship between DMY and SOC sequestration. With organic fertilization, there was a linear trend toward reducing SOC at rate of -563 kgSOC per ton of DMY. It was also found that an increase in DMY above 17.7 t/ha led to SOC losses. With mineral fertilization, a quadratic trend was observed between SOC sequestration and DMY. With increase in DMY, SOC increased to 20.6 t/ha, after which point SOC tended to decrease. In case of mineral fertilization, this DMY can be considered the critical point for achieving SOC sequestration.

In years with characteristics similar to the PV2024, continuous rainfall events in terms of quantity and intensity, SOC sequestration is likely to be limited in production systems in the Highland region of Jalisco due to excess water and denitrification processes.

CONCLUSIONS

Daily rainfall events from July to September were continuous and intense, causing excess water. Symptoms of nitrogen deficiency were observed in corn, an effect attributed to excess water and the denitrification process.

Forage and dry matter yields showed statistically significant differences only in the fertilization treatment, with higher yields with organic fertilization, a result associated with excess water and denitrification. Atmospheric$_{CO_2}$ capture behaved in the same way as DMY. The fallow tillage treatments with two harrow passes and three harrow passes showed the highest forage and dry matter yields, but only with organic fertilization.

No statistical differences were observed in SOC sequestration. Almost all treatments had SOC loss, with overall average of -2.51 tSOC/ha. Conservation tillage treatments with 100% residues and organic fertilization contributed 5.2 tSOC/ha, and conservation tillage plus subsoiling, 100% residues, and mineral fertilization contributed 1.6 tSOC/ha.

The relationship between sequestered organic carbon in soil and dry matter yield with organic fertilization showed a linear relationship with a negative slope of around -563 tSOC/tDM and a critical point at

17.7 t/ha. With mineral fertilization, this relationship was quadratic, with a critical point at 20.6 tSOC/ha.

The denitrification process is attributed to the loss of nitrogen and organic matter from soil and SOC, but it is necessary to evaluate this process on these variables in experimental platform.

REFERENCES

Balbontín, C., C. Omar-Cruz, F. Paz, and J. D. Etchevers. 2009. Soil Carbon Sequestration in Different Ecoregions of Mexico. In: Soil Carbon Sequestration and the Greenhouse Effect, 2nd edition. SSSA Special Publication 57. Madison, WI, USA.

Chacho R., J.M. 2019. Evaluación De La Capacidad De Captura De Carbono De Los Sistemas Hortícolas, Parroquia San Joaquín, Cantón Cuenca. Tesis licenciatura Ingeniería Ambiental. Universidad Politécnica Salesiana Sede Cuenca, Cuenca, Ecuador. 75 pag.

Chen, T., Y. Zhang, J. Fu, L. Yang, Y. Chi, P. Wu, X. Yin, H, Wang, K, Yang, and Y. Wang. 2020. No-tillage increased corn yields and carbon sequestration. Agronomy Journal, 112:4467–4481.

Cotler, H., M. Martínez y J. D. Etchevers. 2016. Carbono orgánico en suelos agrícolas de México: Investigación políticas públicas. Terra Latinoamericana 34: 125-138.

Damián Huato, M. Á., B. Ramírez Valverde, F. Parra Inzunza, J.A. Paredes Sánchez, A. Gil Muñoz, A. Cruz León y J. F. López Olguín. 2007 Apropiación de tecnología por productores de maíz en el Estado de Tlaxcala, México. Agricultura Técnica en México, 33(2):163-173.

FAO, 2018. Guía de buenas prácticas para la gestión y uso sostenible de los suelos en áreas rurales. Editorial FAO. Bogotá, Colombia. 144 pág.

FAO. 2002. Capítulo 1. Tendencia general de la captura de carbono en el suelo. In: Captura de Carbono en los Suelos para un Mejor Manejo de la Tierra. Informes sobre recursos mundiales de suelos 96. FAO, Roma, Italia.

FAO. 2017. Carbono Orgánico del Suelo: el potencial oculto. Organización de las Naciones Unidas para la Alimentación y Agricultura Roma, Italia. 77 pág.

FAO. 2022. ¿Qué es el Secuestro de Carbono? Tomado de: http://www.fao.org/soils-portal/soil-management/secuestro-de-carbono-en-el-suelo/es/ Fecha de acceso: 03-03-2022

Farage P., J. Pretty, and A. Ball. 2003. Biophysical Aspects of Carbon Sequestration in Drylands. University of Essex, UK. Tomado de: https://www.fao.org/fileadmin/templates/nr/images/resources/pdf_documents/cseqbiophysicalaspectsdrylands.pdf Fecha de acceso: 03-03-2022

Flores-López, H.E., G. Vidrio-Llamas, I.J. González-Acuña, C. Mora-Orozco y H. Ramírez-Vega. 2021. Captura de carbono con prácticas de manejo agronómico en maíz para grano de temporal. En: Memorias del LVI Reunión Nacional de Investigación Agrícola. Memoria. Ciudad de México, 10-12 nov. 2021.

Flores-López, H.E., I.J. González-Acuña, S. E. Ramírez-Sánchez y H. Ramírez-Vega. 2025. Efecto del clima y manejo agronómico sobre el rendimiento de forraje de maíz de temporal en los Altos de Jalisco, México. Brazilian Journal of Animal and Environmental Research, Curitiba, 8(1):1-13.

Fynn, A.J., Álvarez, P., Brown, J.R., George, M.R., Kustin, C., Laca, E.A., Oldfield, J.T., Schohr, T., Neely, C.L., Wong, C.P. 2009. Soil Carbon Sequestration in U.S. Rangelands: Issues Paper or Protocol Development. Environmental Defense Fund, New York, USA.

Ghimire, R., Clay, D. E., Thapa, S., & Hurd, B. 2022. More carbon per drop to enhance soil carbon sequestration in water-limited environments. Carbon Management, 13(1), 450–462. doi.org/10.1080/17583004.2022.2117082

Giovanna S., I.I., R. Farina, R. Orsini, G. Iezzi, and P.P. Roggero. 2016. Long term effects of tillage practices and N fertilization in rainfed Mediterranean cropping systems: durum wheat, sunflower and maize grain yield. European Journal of Agronomy, 77:166-178.

Giulia Ronchetti, F. P., F. Dentener, M. van der Velde, M. van den Berg, and E. Lugato. 2024. Quantifying the impact of an abrupt reduction in mineral nitrogen fertilization on crop yield in the European Union. Science of The Total Environment, 954:176692.

Gobierno de México. Secretaría de Medio Ambiente y Recursos Naturales e Instituto Nacional de Ecología y Cambio Climático. 2025. México: Informe del Inventario Nacional de Emisiones de Gases y Compuestos de Efecto Invernadero, 1990-2022. Tomado de: https://www.gob.mx/cms/uploads/attachment/file/1018303/INEGYCEI__Dif_250725.pdf Fecha de acceso: 31-10-2025

Gregorich, E.G., B.H. Ellert, C.F. Drury, and B.C. Liang. 1996. Fertilization Effects on Soil Organic Matter Turnover and Corn Residue C Storage. Soil Sci. Soc. Am. J., 60:472-476.

Hua, K., D. Wang, X. Guo, and Z. Guo. 2014. Carbon Sequestration Efficiency of Organic Amendments in a Long-Term Experiment on a Vertisol in Huang-Huai-Hai Plain, China. PLOS ONE 9(9): e108594. https://doi.org/10.1371/journal.pone.0108594

INEGI. 1994. Tour description. Tramo Guadalajara, Jalisco – Zamora, Michoacán. In: Guide for technical tours “1” and “10”: Guadalajara – México city. 15° Congreso Mundial de la Ciencia del Suelo. 10 – 16 de Julio. Acapulco, México.

Kaur, G., B.A. Zurweller, K.A. Nelson, P.P. Motavalli, and C.J. Dudenhoeffer. 2017. Soil Waterlogging and Nitrogen Fertilizer Management Effects on Corn and Soybean Yields. Agronomy Journal, 109:97–106. Doi:10.2134/agronj2016.07.0411

Kaur, G., G. Singh, P.P. Motavalli, K.A. Nelson, J.M. Orlowski, and B.R. Golden. 2020. Impacts and management strategies for crop production in Waterlogged/Flooded soils: A review. Agronomy Journal, 112: 1475–1501. Doi.org/10.1002/agj2.20093

Khan, S.A., R.L. Mulvaney, T.R. Ellsworth, and C.W. Boast. 2007. The Myth of Nitrogen Fertilization for Soil Carbon Sequestration. J. Environ. Qual., 36: 1821-1832. Doi-org.wdg.biblio.udg.mx:8443/10.2134/jeq2007.0099

Kong, A. Y. Y., Six, J., Bryant, D. C., Denison, R. F., Van Kessel, C. 2005. The relationship between carbon input, aggregation, and soil organic carbon stabilization in sustainable cropping systems. Soil Sci. Soc. Am. J. 69, 1078–1085.

Lal, R. 2004. Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science, 304:1623-1627.

Lal, R. 2008. Carbon sequestration. *Phil. Trans. R. Soc. B* 363:815–830. doi.org/10.1098/rstb.2007.2185

Mchunu, C., and V. Chaplot. 2012. Land degradation impact on soil carbon losses through water erosion and CO2 emissions. Geoderma, 177–178. 72-79. doi.org/10.1016/j.geoderma.2012.01.038.

Muller-Feuga, A. 2024. The Recognition of Carbon Capture and Storage by Plants. Journal of Agricultural Science, 16 (7):1-9. Doi.org/10.5539/jas.v16n7p1

Pareja-Sánchez, E., C. Cantero-Martínez, J. Álvaro-Fuentes, D. Plaza-Bonilla. 2020. Soil organic carbon sequestration when converting a rainfed cropping system to irrigated corn under different tillage systems and N fertilizer rates. Soil Sci. Soc. Am. J. 84:1219–1232.

Parker, D., D. Venhaus, C. Robinson, T. Marek, and J. Sweeten. 2018. Corn Yield and Soil Fertility with Combined Use of Raw or Composted Beef Manure and Inorganic Fertilizers on the Texas Northern High Plains. Compost Science & Utilization, DOI: 10.1080/1065657X.2017.1366376

Paustian, K., 0. Andrén, H.H. Janzen, R. Lal, P. Smith, G. Tiad, H. Tiessen, M. Van Noordwijk, and P.L. Woorner. 1997. Agricultural soils as a sink to mitigate CO2 emissions. Soil Use and Management, 13:230-244.

Poeplau, C., and A. Don. 2015. Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis. Agriculture, Ecosystems and Environment, 200:33–41.

Poeplau, C., A. Don, and F. Schneider. 2021. Roots are key to increasing the mean residence time of organic carbon entering temperate agricultural soils. *Global Change Biology*, 27:4921–4934. https://doi.org/10.1111/gcb.15787

Rojas-García, F., G. H. Santoyo-Gómez, E. González-Montiel, A. Velázquez Rodríguez y J. I. Pulido-Ponce. 2017. La ciencia del suelo en el ciclo del carbono de México. Elementos para Políticas Públicas, 1(2):69-96.

Romero P., R., N. Verhulst, D. de La Rosa, V. Hernández, M. Maertens, J. Deckers, and B. Govaerts. 2014. Effects of tillage and crop residue management on maize yields and net returns in the Central Mexican highlands under drought conditions. Pedosphere. 24: 476-486.

Schwenke, G., M. Bell, M. Conway, and C. Dowling. 2014.Denitrification. Reducing Potential N Losses. Fact Sheet. Grains Research and Development Corporation. Tomado de: https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/12/denitrification Fecha de acceso: 25-11-2025

SIAP-SADER. 2023. Anuario Estadístico de la Producción Agrícola. Tomado de: https://nube.siap.gob.mx/cierreagricola/ Fecha de acceso: 10 de mayo de 2023.

Singh, R., and B. Ghildyal. 1980. Soil submergence effects on nutrient uptake, growth, and yield of five corn cultivars. *Agronomy Journal*, *72*, 737–741. doi.org/10.2134/agronj1980.00021962007200050011x

Subedi, K. D. and B. Ma. 2011. Chapter. Corn crop production: growth, fertilization and yield. Pp. 1-85. In: Corn Crop Production Growth, Fertilization and Yield. Nova Publisher. DOI: 10.13140/2.1.3515.9040.

Trivedi, A., R. Bhattacharyya, D. R. Biswas, S. Das, T. K. Das, P. Mahapatra, D. K. Shahi, and C. Sharma. 2020. Long-term impacts of integrated nutrient management with equivalent nutrient doses to mineral fertilization on soil organic carbon sequestration in a sub-tropical Alfisol of India. CARBON MANAGEMENT. 11(5):483–497.

Trost, B, A. Prochnow, K. Drastig, A. Meyer-Aurich, F. Ellmer, and M. Baumecker. 2013. Irrigation, soil organic carbon and N2O emissions. A review. Agron. Sustain. Dev., 33:733–749.

Trumbore, S. 2000. Age of soil organic matter and soil respiration: Radiocarbon constraints on belowground C dynamics. Ecological Applications, 10, 399–411.

Vela C., G., J. López B. y M. L. Rodríguez G. 2012. Niveles de carbono orgánico total en el Suelo de Conservación del Distrito Federal, centro de México. Investigaciones geográficas, 77:18-30.

Vergara S., M. A., J. D. Etchevers B. y M. Vargas H. 2004. Variabilidad del carbono orgánico en suelos de ladera del sureste de México. Terra Latinoamericana 22: 359-367.

Zamora-Morales, B. P., M. Mendoza-Cariño, D. Ma. Sangerman-Jarquín, A. Quevedo Nolasco, y A. Navarro Bravo. 2018. El Manejo Del Suelo En La conservación De Carbono orgánico». *Revista Mexicana De Ciencias Agrícolas* 9(8): ME:1787-99. doi.org/10.29312/remexca.v9i8.1723.

Zamora-Morales, B.P., M. Mendoza-Cariño y M. P. Guerrero-Ibarra. 2017. Tecnologías del INIFAP con relación a la mitigación del cambio climático y la captura de carbono en el suelo. Elementos para Políticas Públicas, 1(2):97-110.

Zhao, Y., Zhang, Y., Liu, X., He, X. and Shi, X. (2016), Carbon sequestration dynamic, trend and efficiency as affected by 22-year fertilization under a rice–wheat cropping system. J. Plant Nutr. Soil Sci., 179: 652-660. Doi-org.wdg.biblio.udg.mx:8443/10.1002/jpln.201500602