Monitoring of CO_2 Flux and Contribution for Components in the Soil-Plant System in a Grassland from Northeastern Mexico

1 López-Santos Armando, **2** Cadena-Zapata Martín, **2** Zermeño-González Alejandro, **3** González-Cervantes Guillermo., **2** Gil-Marín José Alexander, **3** Sánchez-Cohen Ignacio

1 Unidad Regional Universitaria de Zonas Áridas de la UACh (alopez@chapingo.uruza.edu.mx), **2** División de Ingeniería UAAAN, Buenavista, Saltillo, Coah. Méx., **3** Centro Nacional de Investigación Interdisciplinario en Relaciones Agua Suelo Planta Atmósfera del INIFAP, Gómez Palacio, Dgo, Mex.

Abstract

The monitoring and quantification of CO_2 released to the atmosphere by the rural production systems is an uprising need when facing the actual challenge of global warming. It is known, that in the last decade the change of land use and silviculture have contributed in a significant manner in the net emissions of CO_2 to the atmosphere. However, is not quite clear the magnitude of the contribution of each individual ecosystem, and even it is least known the contribution of the separate action of the soil-plant system components. There are three methods for monitoring and quantifying the CO_2 flux in an extensive open area condition: i) Open or close use of interchange gas chambers; ii) Using the technique of the Bowen Relation Method; and iii) Using the Eddy Covariance Method. In this experiment, the last mentioned was used for its high reliability in the measurements of mass and energy flux in extensive land conditions. The experiment was carried out at Rancho Los Angeles Municipality of Saltillo, Coahuila, México (25º 6.650' N and 100º 59.413' W). It was measured the CO_2 flux, in plots of 2.4 ha after removing the native vegetation, dominated by three families (*Chenopodacea, Euphorbacea y Asteraceae*), using two tillage treatments: vertical tillage by chiseling (VT) and conventional tillage by disc ploughing (CT), the flux was measured as well in a reference plot without tillage treatment (NT). In all plots it was determined the magnitude of flux for each component at the soil-plant system. The results showed that under the predominant climatic conditions at Autumn 2006, when separating the components of the soil-plant system from the CO_2 total flux monitored (FCO_{2tm}), the more important contribution came from the soil in both tillage methods used (FCO_{2sLV}=66 % and FCO_{2sLC}=74 %).

***Key words*:** Eddy Covariance, Rural Production Systems, CO_2 flux.

Introduction

Mexico ranks second among the Latin-Americans countries as CO_2 emitter, with net emissions of 444.5 millions of metric tons for 1990, from this amount, it is estimated that the change in land use and silviculture contribute with 30.6 % (PNUMA-SEMARNAT, 2004). Considering the need to reduce release of CO_2 and maintain the quality of the soil to support food production, the role and importance of the tillage practices and its impact in the organic matter should be reexamined (So et al, 2001; Lokupitiya et al, 2006), this is also important because of the raise of carbon bonus market among the countries that signed the Kyoto protocol (Inclán, 2007; Cervantes, 2007).

The CO_2 emissions from the surface on bare soil give a direct assessment in the short time about the carbon dynamic in the soil, but when vegetation is present, the interpretation of the total soil respiration is difficult due to the root contribution in the CO_2 release (Rochete, 1999). It has been estimated that the rizosfera contributes with 40-50 % of the total soil respiration, and the 50-60 % remaining includes the decomposed microbial root exudates and other rhizodepotitions (Kuzyakov, 2002).

Some authors (Rochete, 1999) have utilized values of isotopic carbon (^{13}C) in order to measure CO_2 separating from the total soil respiration that which comes from the rhizosphere in a maize crop (Zea mays L.) by using a portable chamber for gas exchange (LI-Cor), from those experiments, and they found that the rhizosphere contributes with 45% of the total respiration, this value agrees also with that reported by Kuzyakov (2002). Also they observed as well that the values of the soil respiration decreased from 3.3 to 1.4 g $m^{-2}d^{-1}$.

Similarly, other authors (Qi et al, 2007) used a dark gas exchange fix chamber to measure total respiration, also the microbial and radicular from a grassland dominated by *S. balcalensis* and from bare soil, condition obtained by cutting the aerial part of the plants the day before the sampling, it was found that maximum spoil respiration occurred in July with a value of 6 g CO_2 $m^{-2}d^{-1}$.

In terrestrial ecosystems, the CO_2 movements, as well as, other energy flux energetic, can be measured basically by three methods: 1) Eddy Covariance, (EC); 2) Bowen Relation, (BR); and 3) Open or Close, exchange gas chamber (CIG). Every method have advantages and disadvantages in relation to the measurements to characterize the flux behavior, because they are affected by variability in the local and surrounding conditions during day and night, such as humidity, temperature, barometric pressure, wind direction, etc. (Peters et al, 2001; Clark , 2001).

In the present work, the total measure of CO_2 flux, is part of an investigation based in the Eddy Covariance method, which have the follow characteristics: i) Direct measurements of the heat flux, water vapor and carbon dioxide; ii) Not assumption is made of coefficient values; iii) measurements are independent; iv) Allow to evaluate the precision of energy balance (Rn=H+LE+G); and v) Is considered the most precise method to measure superficial fluxes (Peters et al, 2001; Clark , 2001).

Based on the above, the objectives of this work were: i) Monitoring CO_2 flux in extensive outdoor conditions and ii) To asses the contribution of native vegetation in the CO_2 sequestration by the separation of the soil-plant components system.

Materials and Methods

This investigation was carried out in the autumn 2006, at Rancho “Los Angeles”, municipality of Saltillo, Coah., México. This is a farm dedicated to the Charolais breed production, in a total surface around 6700 has. The site location is 25º 6.650’ N and

100º 59.413 W, in the sub province called Gran Sierra Plegada, located at north of the Physiographic Region Sierra Madre Oriental, as could be seen in the Figure 1.

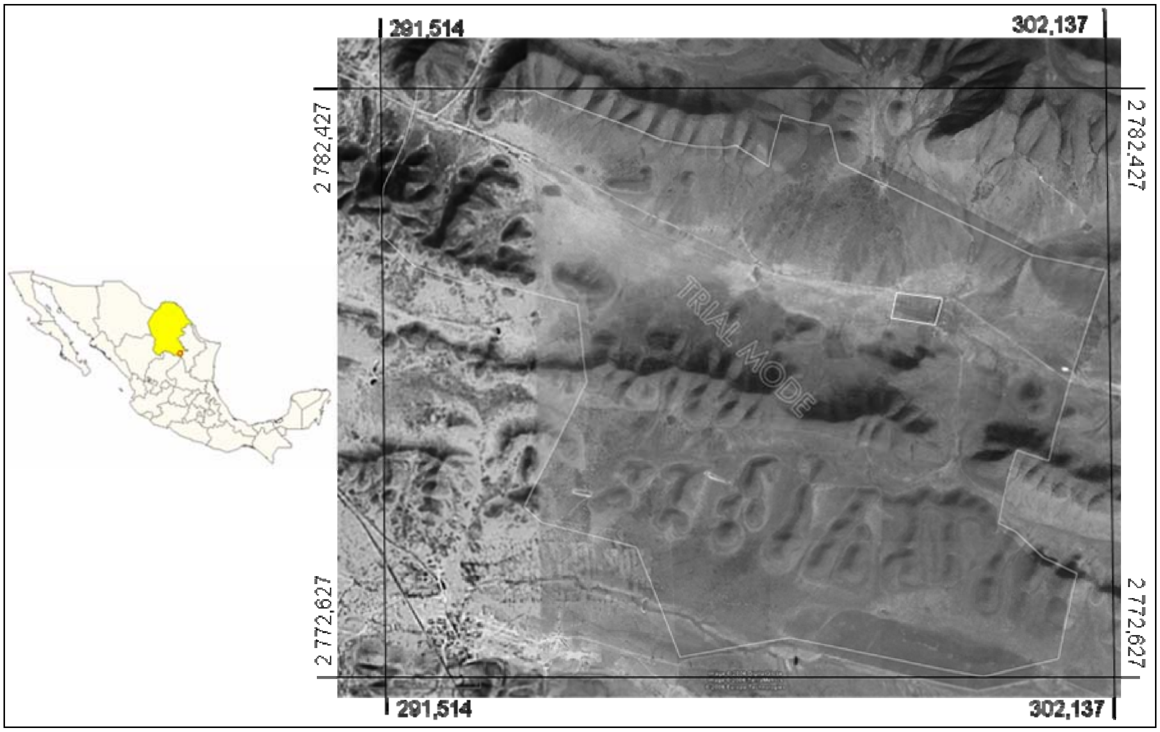

Figure 1. Field where was put the monitoring system (UTM coordinates system)

Two factors influence the cattle management in this place: One is the climate [BWhw(x´)(e)] which is semiarid (Garcia, 1975), having a precipitation of 350 mm per year, with a rainy season from May to September when falls 80 to 90 percent of total rain; the other factor is the landform; having to the north mountains like the Sierra Leona with a maxim altitude above sea level of 2850 m and to the south the Sierra Los Angeles with 2400 m above sea level, this condition have produced small valleys used as grazing lots, which have an average altitude of 2100 m. The soil type, is mainly Luvisol in a 40 % of total surface, the soils are deep with superficial horizons of dark color and high organic matter content (INEGI, 1976).

The vegetation have a distribution in relation to the topographic, edaphic, and microclimatic characteristics in this place, in the hillslope prevail the shrub and in the hilltop prevail the pine trees (*Pinus sp.*) combined with shrubs; In the valleys is well established the grasses which are a compound that includes the following gramineae: *Asistida, Buchloe, Boteloua, Mulenbergia, Steria e Stipia* (Mellado, 2007), that are sharing spaces with other plants from families like *Laminaceas*, *Chenopodaceas, Euphobaceas and Asteraceas*.

Selection, location and characteristics of the monitoring plot

The monitoring of CO_2 flux was made in an area of 35 has of the grazing lot number four located at the central part of the Ranch (rectangle at the Figure1 centre). Three plots of 2.4 ha each, with similar characteristics in soil type and vegetation were established. The dimensions of each plot were: a width of 120 m to N-S direction and a length of 200 m to E-W direction.

The soil horizons from 0-0.30 and 0.30-0.60 m depth were studied, the resulting data showed texture with clay content greater than 40% (Boyoucos Hydrometer), PH with more than 8 (potentiometer), color in the soil surface layer (Munsell tables: 10YR 5/2), and total carbonates content grater than 37% (neutralization volume), from this data and based on the INEGI (2001) methodology, it is deduced that the soil characteristics match with a Feozem luvic (Hl) (INEGI 1976; FAO-ISRIC-ISSS-AISS-IBG, 1994).

On the other hand, the native vegetation found in this season of the year and its relative importance value (RIV) was determined using line interception method and the more important species are shown in Table 1.

Table 1. Floristic list and RIV in the monitoring plots

Family	Technical name	RIV
Asteraceae	*Brickellia laciniata Gray*	7
Asteraceae	*Zinnia acerosa (DC.) Gray*	5
Asteraceae	*Aphanostephus ramosissimus DC.*	5
Acanthaceae	*Dischoryste linearis (T.&G.)O. Ktze*	7
Onagraceae	*Calylophus belandieri (Spach) Towner*	10
Euphorbiaceae	*Euphorbia furcillata H.B.K.*	2
Boraginaceae	*Tiquila canescens (DC.) Richardson*	8
Laminacea	*Marrubium vulgare L.*	50

It was noticed that in the grazing lot were experimental plots were established, the gramineae were not dominant spices due to this lot had been also used to establish winter forage crops like oats (*Avena sativa*) and barley (*Hordeum vulgare L.*), so other families as listed in table 1 were dominants.

Monitoring duration of FCO_2 and separation of components

In the first plot the monitoring of FCO_2 was made during space of 21 days (from October 20th to November 10th) under not disturbed soil-plant system, this condition was defined as total flux monitored or $FCO^2{}_{NT}$, in a second plot, the measurements of

FCO_2 was made during 18 days (from November 10th to November 28th) the condition of the plot was that the present vegetation was eliminated, with a chisel plough with delta wings at 25 cm depth. This condition of the system where vegetation were removed by vertical tillage was defined as FCO_{2SVT} the flux was monitored directly from the tilled soil. In a third plot the native vegetation was removed using a disc plough, to a depth of 25 cm. The measurements of CO_2 flux in this condition of bare soil defined as FCO_{2SCT} was made for 27 days (until December 8th) Figure 2, illustrates the condition of the second and third plot where the two types of tillage were carried out.

Figure 2. Exclusion vegetal cover by VT (left) and CT (right)

Instrumentation for monitoring the systems

The instruments used, were integrated in an automatic meteorological station (Eddy Station), which has the following components: (1) net radiometer Nr (model NR-LITE, Keep and Zonen Inc.) to measure the difference between short and long wave radiation, (2) a sensor to measure air temperature and water vapor, respectively (model HMP45C, Vaisala, Inc.) (3) two plates to measure heat flux soil (model HFT3, REBS Inc.), attached with two thermocouples of four tips (model TCAV, Campbell, Sci. Inc) for measuring the energetic gradient in the soil, G. The Eddy Station had other instruments like a sensor to measure wind speed and wind direction (model 03001-5, RM Young Inc.), an electronic pluviograph to measure the rain events (model TE525, Texas Instruments, Inc.). Also, were used two [datalogers] (models 23X and CR7, both of Campbell, Sci Inc.), and two solar panel one of 64 W and other of 20 W, which provided the energy required for the monitoring system.

Results and Discussion

The results that will be discussed correspond to the first step of an investigation about the measure and evaluation of energy and mass flux under different conditions of soil management and season of the year. The purpose of this is to asses the role of the agroproductive systems from semiarid condition in the FCO_2 dynamics. Figure 3, shows a flow chart for the analysis for the energy and mass flux from the data collected at the experimental plots.

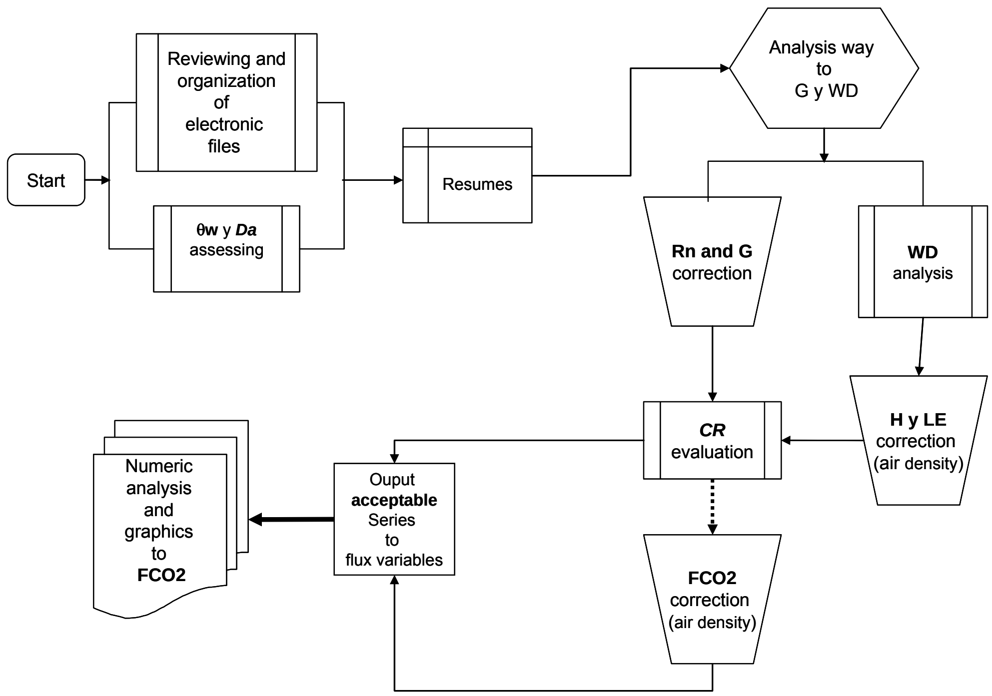

Figure 3. Diagram to analysis for the energy and mass flux

As a first step, the data of the experiment was arranged in two sets, the data from the eddy station was tabulated for analysis in excel files. Other data from laboratory, and field properties of soil and characteristics of the vegetation was arranged in another set for analysis.

In a second step, the analysis of G and the wind direction (WD) was used as a criterion to correct every one of the flux variables. According to the experimental site prevailing wind direction, the acceptable range of WD were from 0 to 90^{o} NE and from 270 to 360^{o} NW.

As a third step, energetic fluxes were determined, with the exception of Rn under soil surface and in soil surface with W m^{-2}. The first is represented by the heat flux at the edaphic layer (G) at 0.08 m depth. The second is represented by the sensible heath (H) and latent heath or water vapor (LE) which were measured at 1.4 m above the soil surface.

The correction of G was made using the formula:

$$G = G_{D8} + \frac{[(Cds+\theta w \bullet Cw)\ \rho d \bullet \Delta T \bullet \Delta z]}{\Delta t} \qquad (1)$$

Were G_{D8} is the heath flux, measured at 8 cm depth from the soil surface; Cds is caloric capacity of the minerals (840 $J \bullet Kg^{-1}K^{-1}$); θw is the volumetric water content, Cw is the caloric capacity of the water (4190 $J \bullet Kg^{-1}K^{-1}$); ΔT is the average change in temperature (^oC) by the sensors placed from 2 to 6 cm depth. Δz is the depth at which the plate for sensing the heath flux is placed (0.08m); and Δt is the variation of time in seconds.

For H and L, there were utilized the following equations (2) and (3):

$$H = \rho_a \bullet C_p \bullet \overline{w'\ Ts'} - 0.51 \bullet Ta \left[\frac{\rho_a \bullet Cp}{\lambda} \right] \lambda E \qquad (2)$$

$$LE = \overline{\lambda w'\ \rho_{wv}'} \qquad (3)$$

Were, ρ_a is the air density (kg m^{-3}); C_p is the caloric capacity of the air (J kg^{-1} K^{-1}); T_s is the sonic temperature measured whit the anemometer; T*a* is the air temperature; w**'** is the vertical win speed (m s^{-1}); λ is the heat water vapor (J kg^{-1}). w'T*s*', $w'\rho_{wv'}$ represents the covariance among the variables and the top bar means the average in a time interval that was established as 20 minutes. The frequency of data gathering for w', Ts, and ρ_{wv}, and T*a* were of 10 Hz.
A fourth step was the correction of FCO2 according to the next formula (4).

$$FCO2 = \overline{\rho_{CO2}' \bullet w'} \qquad (4)$$

Where ρ_{CO2} is the density of carbon dioxide (μmol CO_2 m^{-3}) and ρ_{wv} is the density of the water vapor (kg m^{-3}). The frequency on the measurements was the same as indicated before for the other variables.

As a fifth step for the data from the accepted ranges of WD, the CR is determined according to the following equation:

$$CR = \frac{[Rn-G]}{[H + LE]} \qquad (5)$$

In this case it is important to mention the instantaneous values measured with the carbon dioxide analyzer and the air water content from the 3D sonic anemometer.

Those data are valid when corrected according to the local air density and correspond to values between 0.7 and 1 (Zermeño-Gonzalez, 2001; Ham, 2003).

The sixth and last part of the process was to make the numerical and graphic analysis of FCO_2 considering that as mass flux μmol $m^{-2}s^{-1}$ is independent from the calculations in equation (5). However, it is used as a reference, the data series that fall in the ranges that meet the criteria indicated for CR.

FCO_2 measured above the soil-plant system

In the first plot (reference plot) not disturbed by the tillage was made the total measuring of FCO_2. In this phase of monitoring as can be seen in the Figure 4 for the day number 294, had a typical behavior represented for diurnal assimilation and nocturnal release. The first, due to the photosynthetic process from the phototropic organisms, with a rate maxim of assimilation close to 3 μmol de CO_2 $m^{-2}s^{-1}$, which occurred around 13:00 hs; and the second like product from breakdown organic matter by macro and microorganism whit a maxim releaser of -3 μmol de CO_2 $m^{-2}s^{-1}$, occurred between the 19:00 and the 20:00 hs. These results are similar to other reported (Scow, 1999; Pumpanen et al 2003; Qi et al, 2007).

These allow to found the general characteristics in the FCO_2 dynamic, for the release as well as assimilation, and whit this was estimated the proportion of the contribution from every component of the soil-plant system.

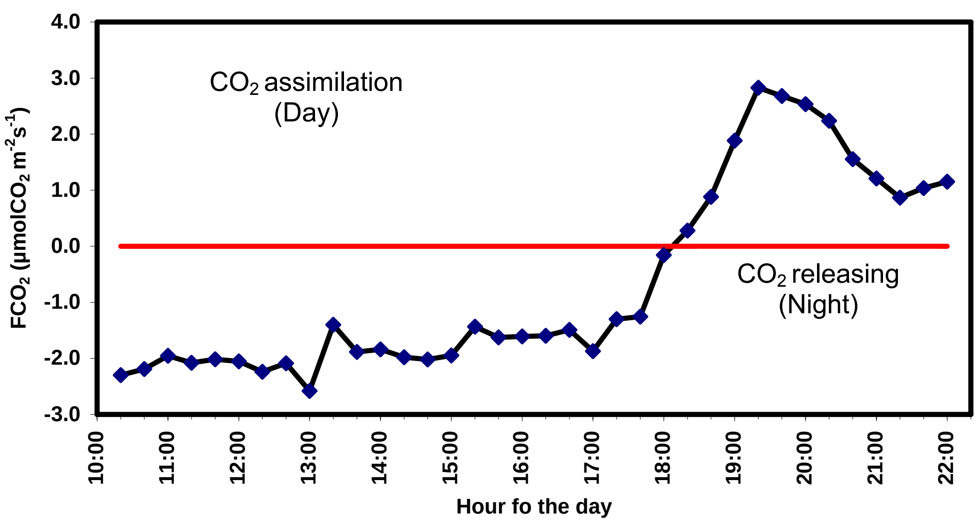

Figure 4. CO2 flux from the soil with native vegetation (FCO2NT), observed at day 294

FCO_2 monitored whit native vegetation excluded by tillage

The temporal elimination of the vegetation at the soil surface and the exposition of the root system to the action of environmental factors, allowed to have an exclusion of the vegetal cover and its root system, like can see in the Figure 5. From that, it was established that the flux measured under those soil management conditions correspond to the FCO_2 produced or released under the soil condition left by both tillage system used VT and CT. This is FCO_{2SVT} and FCO_{2SCT}, respectively.

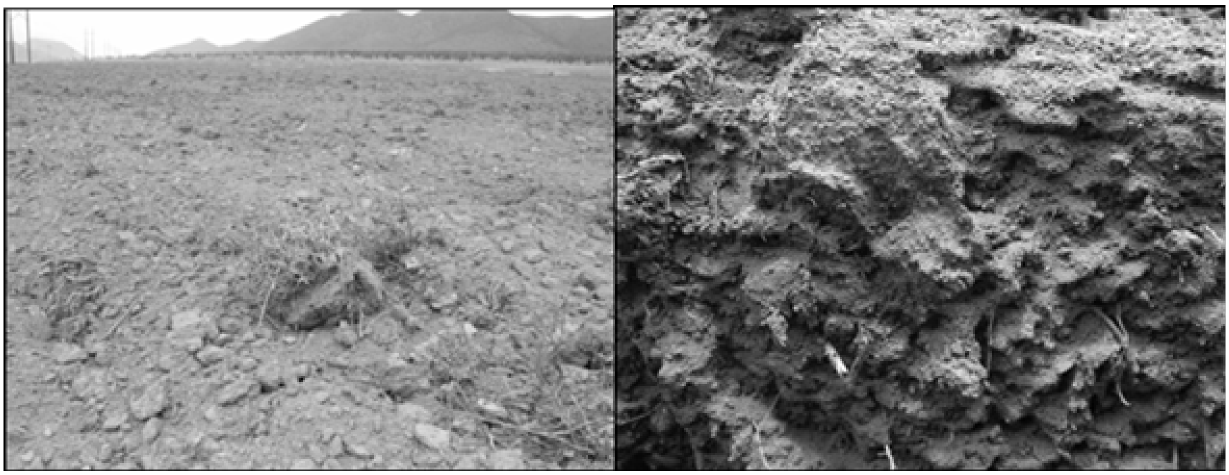

Figure 5. Exclusion vegetation effect. Aboveground (left) and root in the profile view (right)

As a result of the use of both tillage method it could be observed a significant change in the FCO_2 typical behavior, because it changed from capture source to release source; in both management systems the assimilation was negligible, and this situation was maintained for eight and nine continuing days. The release, although with a decrement trend on time was observed day and night in both cases, from 1.14 to 0.99 μmol CO_2 m^{-2} s^{-1} and for 1.3 to 0.87 μmol CO_2 m^{-2} s^{-1} for VT y CT, respectively.

For VT, as it can be seen in the Figure 6, that a maximum value of 2 μmol CO_2 m^{-2} s^{-1}, occurred at the 14:00 h, it could be observed that the curve that represent the release, was maintained day and night being more pronounced for the last case, similar condition was present for CT as it can be seen en the Figure 7, also, in this tillage system can see a frequent variation in the releases of CO_2 from the soil, the maximum value registered was almost same at 2 μmol CO_2 m^{-2} s^{-1} and values of assimilation of less than 0.5 μmol CO_2 m^{-2} s^{-1}.

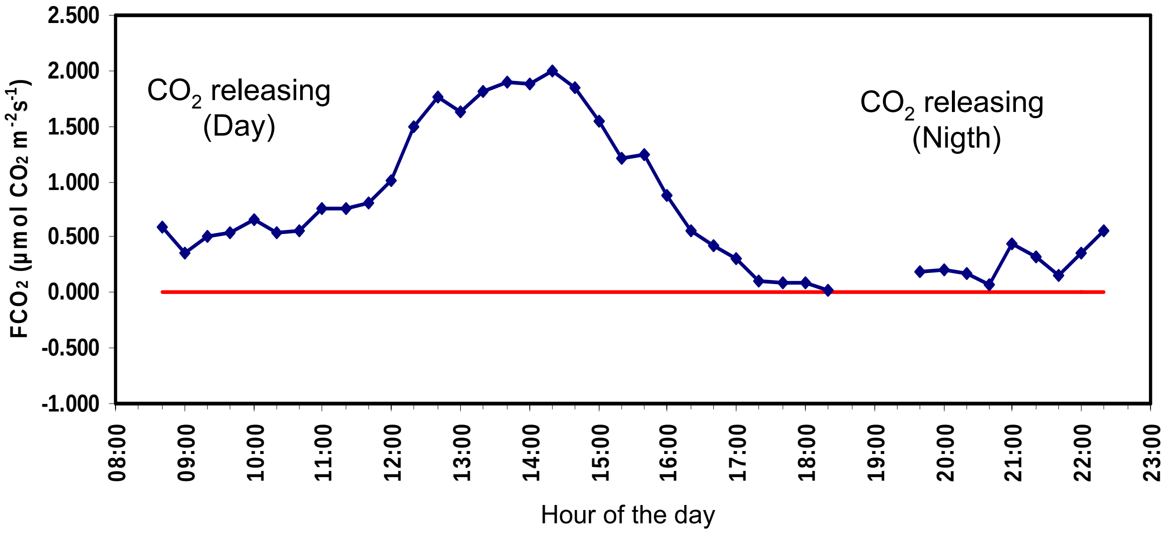

Figure 6. CO_2 flux from the soil without vegetation observed at day 316, two days after VT

The data gathered in the different treatments allow to separate and to quantify the participation of each component of the soil-plant studied, it also make the possibility to determine the impact of tillage in the flux dynamics of this production system.

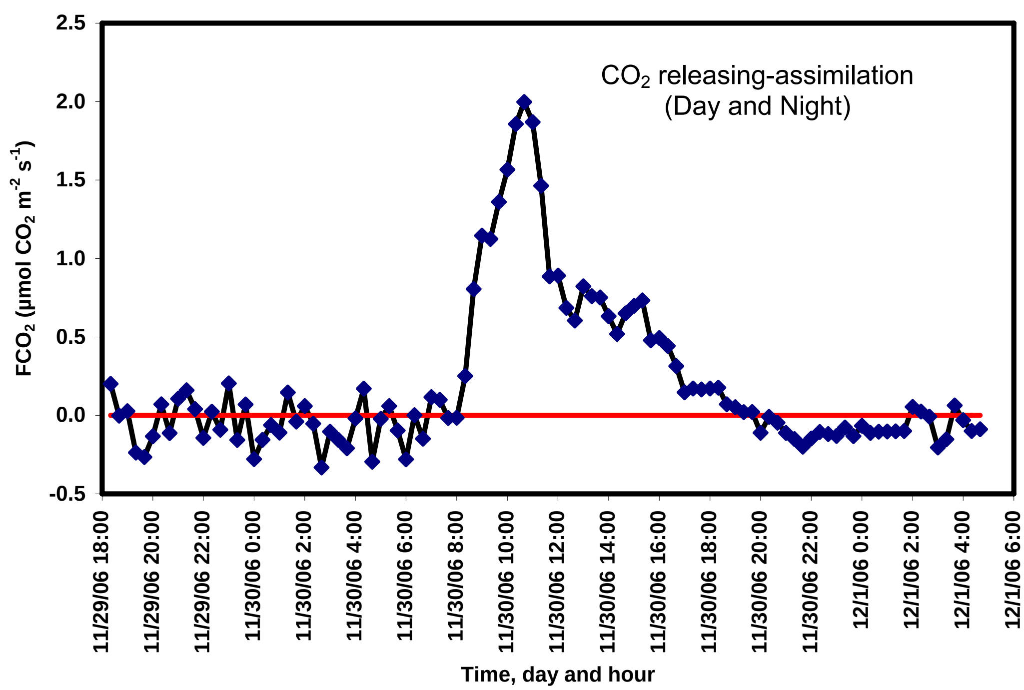

Figure 7. CO_2 flux observed days from 333 to 335, between two and fourth days after CT

FCO2 estimated for components fro the soil-plant system

The net contribution for each component of the soil-plant system, to the release and assimilation of CO_2 was estimated taking as a reference the average of four events of the instantaneous rates recorded by the sensor in the undisturbed plot, representing as FCO_{2mt}. The difference resulting from the fluxes in the reference plot (undisturbed condition) and those rates measured in the plots disturbed for each type of tillage are the contribution of each condition to the CO_2 released as it is presented in table 2.

It should be also stated that under certain environmental condition some abiotic processes such as the dissolution of carbonates and chemical oxidation could be contributing also to the total CO_2 flux (Hashimoto and Suzuki, 2002).

Table 2. Average of rate release of CO_2 measured and estimated for components from the soil-plant system

		LV		**LC**	
Events	$FCO2_{mt}$ (†)	FCO2 from the soil-plant system ($FCO2_{SPVT}$)‡	FCO2 from the soil ($FCO2s_{VT}$) §	FCO2 from the soil-plant system ($FCO2_{SPCT}$)¶	FCO2 from the soil ($FCO2_{SCT}$)#
	$\mu mol\ CO_2 m^{-2} s^{-1}$				
1	1.600	0.200	1.400	0.730	0.870
2	1.270	0.295	0.975	0.020	1.250
3	1.710	1.030	0.680	0.170	1.540
4	1.618	0.628	0.990	0.741	0.877
Averages	**1.527**	**0.508**	**1.011**	**0.415**	**1.134**
Percents	100	34%	66%	26%	74%

† $FCO2_{mt}$ total instant rate measured in the NT plot.
‡ $FCO2_{SPVT}$, estimated rate for difference among $FCO2_{mt}$ and $FCO2s_{VT}$.
§ $FCO2s_{VT}$, Instant rate measured in the plot with VT.
¶ $FCO2_{SPCT}$, estimated rate for difference among $FCO2_{tm}$ and $FCO2s_{CT}$
# $FCO2s_{CT}$, Instant rate measured in the plot with CT.

Conclusions

It was possible to establish the importance that vegetation has (where not gramineae are dominant) in the sequestration of carbon. The rhizosphere in the described soil condition for the experiment contributes with 26 to 34 % of the total flux of CO_2.

Both soil tillage methods used promotes the liberation of CO_2 to the atmosphere, this is particularly important when land use have to be changed or when tillage is performed early in the season 4 or 6 months before the rainy season as it is the case in the region.

Recommendations

It should be further investigations on the natural soil capacity to return to the inicial condition after the tillage impact because this could be occur at different time scales for some morphologic and biologic properties. It is important to give a value to the roll played by grassland in the sequestration of carbon, given the importance that in the present and future will have the environmental services and the market of green bonus of carbon.

Thankfulness

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Cited references

Cervantes, 2007. El mecanismo de desarrollo limpio y las reducciones certificadas de emisiones. Dirección de Proyectos de Cambio Climático en la Secretaría de Medio Ambiente y Recursos Naturales, SEMARNAT

Clark DA, Brown S, Kiclighter WD, Chambers QJ, Thomlinson RJ, Ni J. 2001. Measuring Net Primary Production in Forest: Concepts and Field Methods. Ecological Society of America. Ecological Applications 11(2): 356-370

FAO-ISRIC-ISSS-AISS-IBG, 1994. World Reference Base for Soil Resources. Wagening, Rome. P 56.

García E. 1975. Climas Coahuila y Nuevo León, precipitación y probabilidad de lluvia en la República Mexicana y su evolución. CETENAL, México, D.F.

Ham JM, Heilman JL. Experimental Test of Density and Energy-Balance Corrections on Carbon Dioxide Flux as Measured Using Open-Path Eddy covariance. American Society of Agronomy, 2003; 95: 1393 – 1403.

Hashimoto S, Suzuki M. 2002. Vertical Distribution of Carbon Dioxide Diffusion Coefficients and Production Rates in Forest Soil. Soil Sci. Soc. Am. J. 66: 1151-1158

Inclán GU. 2007. Mercado de Bonos de Carbono y sus beneficios potenciales para proyectos en México. Dirección de Cambio Climático-SENER. Consulted (07/19/07), in http://www.conae.gob.mx/work/sites/CONAE/resources/LocalContent/2962/1/images/22_sener.pdf.

INEGI. Thematic Cartography of: Edaphology, Geology, Topography, Vegetation and Land Use. Maps: Agua Nueva (G14-C43) y Huachichil (G14-C44). Escale 1:50,000. 1976

Kuzyakov Y. 2002. Separating Microbial Respiration of Exudates from Root Respiration in non-sterile soils: a comparison of four Methods. Soil Biology & Biochemistry, 34: 1621-1631

Lokupitiya E, Paustian K, 2006. Agricultural Soil Gas Emissions: A Review of National Inventory Methods. J. Environ. Qual. 35: 1413-1427

Mellado M. 2007. Traslape de Dietas entre el Perrito de la Pradera (Cynomys mexicanus) y Bovinos en un Pastizal. Mediano Abierto. Consulated (08/19/08) in http://www.uaaan.mx/DirInv/Rdos2003/Zaridas/dietas.pdf s/f.

Peters G, Fischer B, Munser H. 2001. Eddy Covariance Measurements with Closed-Path Optical Humidity Sensors: A feasible Concepts? Journal of Atmospheric and Oceanic Technology, American Meteorological Society..

PNUMA-SEMARNAT, 2004. El Cambio Climático en América Latina y El Caribe (Preliminar Version). Consultated (07/07/07) in http://www.pnuma.org/Cambioclimatico/CAMBIO%20CLIMATICO-web.pdf

Pumpanen J, Ilvesniemi H, Hari P. 2003. A process Based Model Predicting Soil Carbon Dioxide Efflux and Concentrations. Soil Sci. Soc. Am. J. 67: 402-413

Qi YCh, Dong Y, Liu J, Domroes M, Geng Y, Liu L, et al. 2007. Effect of the Conversion of Grassland to Spring Wheat Field on the CO2 Emission Characteristics in Inner Mongolia, China. Soil and Tillage Research. 94: 310-320

Rochete P, Flanagan LB, Grgorich EG. 1999. Separating Soil Respiration into Plant and Soil Components Using Analyses of the natural Abundance of Carbón-13. Soil Sci. Soc. Am. J. 63: 1207-1213

Scow MK. 1999. Soil Microbial Communities and Carbon Flow in Agroecosistems. Ed. Academic Press, Editado por Jakson, L. E. Carolina University, USA. Pp 367-413.

So HB, Dalal RC, Chan KY, Menzies NM, Freebarm DM. 2001. Potential of conservation tillage to reduce carbon dioxide emission in Australian soils. In D.E Sttot, RH Mothar and GC Steinhardt (eds). Sustaining the global farm. Selected papers from the 10Th International Soil Conservation Organization meeting.

Zermeño-González A. 2001. Métodos Micrometeorológicos para medir flujos de calor y vapor de agua entre los cultivos y la atmósfera. XIII Semana Internacional de Agronomía, 2001