SEASONAL VARIATIONS IN SOIL CO_2 EMISSIONS UNDER CONTINUOUS FIELD CROP PRODUCTION IN SEMI ARID SOUTHEASTERN TURKEY

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Abstract. Quantification of soil CO_2 emission under different cropping designs and relating it to the climate parameters can help better understanding the main mechanisms controlling its magnitude and mitigating its release to the atmosphere. Wheat and corn are the most produced crops worldwide contributing highly to total CO_2 emissions from agricultural lands to atmosphere. Long term fluctuations in the soil CO_2 emissions under continuous wheat and corn cropping and bare land were monitored for 509 weeks from 2009 to 2018 in semi arid conditions in the Harran Plain located in southeastern Turkey. The soil CO_2 emissions were modeled for each cropping seasons separately using available meteorological parameters (air temperature (AT), soil temperatures (ST), relative humidity (RH) and rainfall) and field soil moisture (SM) data. The quantity of long term soil CO_2 emission were following order; corn, wheat and bare land and it was around 38% higher (574 vs 792 kg ha^{-1} $week^{-1}$) in soils under field crops than bare soils. Overall there were n increasing trends in seasonal, yearly cumulative and average weekly soil CO_2 emissions over the years. The weekly soil CO_2 emission values were positively correlated with AT and ST but negatively with RH and SM. The linear models were able to explain variations in the long term weekly soil CO_2 emissions obtained during wheat, corn cultivations and bare land up to 77%, 55% and 50%, respectively.
Keywords: *global warming, soil CO_2 emission, wheat, corn, meteorological data, stepwise regression*

Introduction

Global warming increases the soil respiration causing the release of more CO_2 emissions (Lu and Cheng et al., 2009). Among other three greenhouse gases CO_2 has the highest concentration in the atmosphere. Measurements and modeling of the soil CO_2 emissions under different soil types and crop managements are cost effective and crucial for global warming, carbon cycling as well as international agreements that aim to mitigate the amount of carbon released to atmosphere (Allaire et al., 2012). Quantification of the CO_2 emission from soils under different land uses is also important for developing strategies for reducing the CO_2 emissions to atmosphere. A number of researchers have shown atmospheric CO_2 increase very recently. The soil CO_2 respiration consists of basically two parts; roots respiration and microbial respiration as a result of organic matter decomposition (Morell et al., 2012; Zhang et al., 2015). Roots and microbial activities are responsible of 40% and 60% of total the soil respiration, respectively (Kuzyokav and Larionova, 2006).

Methods such as edycovariance or with closed chamber combined with gas chromatography are generally used for measurement of the soil CO_2 emissions. Another most commonly used technique in measuring the soil CO_2 emissions is soda lime (Edwards, 1982). This is advantageous, because it is cheap and easy to perform, enabling the soil CO_2 measurements at higher number of locations simultaneously compare to aforementioned methods which can only be obtained only at limited number of locations.

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In addition, the earlier researchers comparing soda lime method reported that there is no statistically significant different between soda lime method and them (Raich et al.1990).

There are nearly two times more carbon in the soils than atmosphere (Lehmann and Joseph, 2009) and according to Lal (2004) that may be more than that. Depending upon agricultural management, soils can either be source or sink for CO_2 in the atmosphere and the amount of CO_2 released from soils to atmosphere can change based on the soil type, land use type or vegetation type, agricultural management as well as the time of measurement (i.e. seasonal variability) (Iqbal et al., 2009; Panosso et al., 2009, 2011; Mancinelli et al., 2010). Soil CO_2 emissions in the agricultural soils are generally between 0.1 and 6 g CO_2 m^{-2} h^{-1} (Sauerbeck, 2001).

Average soil CO_2 emissions reported by earlier studies were 59 to 527 mg m^2 h^{-1}, 37-498 mg m^2 h^{-1}, 32-397 mg m^2 h^{-1} for forest, grassland and cropland (Wang et al., 2008). The amount of soil CO_2 emissions in peat, sandy and clay soils respectively were obtained as 650 mg m^2 d^{-1}, 300 mg m^2 h^{-1} and 500 mg m^2 h^{-1} (Koizumi et al., 1999). Bauer et al. (2006) for the soils under conservation tillage measured soil CO_2 emissions as 840 mg m^2 h^{-1}. Akbolat et al. (2009) reported as 300-700 mg m^2 h^{-1}. The cropped soils release CO_2 2 to 3 fold higher than bare soils (Rastogi, 2002).

The soil CO_2 emissions are mostly impacted from the factors such as soil temperature and moisture (Bauer et al., 2006; Ngao et al., 2012; Xu et al., 2016; Iqbal et al., 2009; Reth et al., 2005), weather parameters, soil organic matter, C/N ratio, bulk density (Lin et al., 2008; Morell et al., 2012).

Wheat and corn are the most produced grain crops in the world and Turkey is one of the largest producers of both. Yearly around 653 355 000 and 19 674 000 tonnes wheat is produced in 217 312 000 ha and 8 103 000 ha areas in the world and in Turkey, respectively (FAOSTAT, 2010). Worldwide wheat grows on 215 million hectares of land each year (CGIAR, 2017).

Emissions of CO_2 from most of the forest crops, orchards, grasses are well documented (Frank et al., 2006; Almaraz et al., 2009). On the other hand, soil CO_2 emissions from soils under field crops with long terms field studies are limited. The studies available are mostly performed in a short term period which may not be sufficient to construct reliable models. Therefore, information about soil CO_2 emissions of soils under wheat plantation makes it significant.

The goals of this study were to: 1) quantify weekly and seasonal distributions of the long terms (from 2009 to 2018) CO_2 emissions from the soil under wheat and corn plantation 2) compare CO_2 emissions estimations obtained from the soils under field conditions compared with bare soils located nearby field crops, and 3) model the relationships between the soil CO_2 emissions from the soils under different managements (wheat, corn cultivation and uncultivated bare soils) and meteorological parameters and field moisture data at the same locations with soil CO_2 measurements.

Materials and methods

Study site and field management

The study was performed in a field under continuous wheat (2009-2017) and corn (2016-2018) cultivations, in addition to bare land located in the experimental farm of the Harran University, southeastern Turkey (37° 10' N Lat; 38° 59' E Long; *Fig. 1*). The study area has a semi arid climate with an average annual temperature, precipitation, evaporation and altitude values of 17.2 °C, 365.2 mm, 1848 mm and 520 m, respectively.

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The soils of the study area are high in percent clay content, pH, percent $CaCO_3$ content and cation exchange capacity (CEC) but low in soil organic matter (<1.5 g kg^{-1}) (Dinç et al., 1998). Detailed information about the soil properties of the area is given in *Table 1*. Soils were clay loam and classified as Vertisol, according to Soil Taxonomy (Dinç et al., 1998).

Table 1. *Soil properties of bare field and the experimental areas under field crops*

Location	Sampling depth (cm)	EC (dS/m)	CaCO3 (%)	pH	P	K	Organic matter	Total N (%)	Sand	Clay	Silt	Texture
Bare area	(0-30)	0.73	17.40	7.70	2.71	112.5	1.36	0.09	22	60	18	Clay
Bare area	(30-60)	0.82	17.40	7.76	0.82	82.0	0.85	0.08	22	60	18	Clay
Field crops	(0-30)	0.83	23.50	7.76	3.04	82.0	1.45	0.09	32	50	18	Clay
Field crops	(30-60)	0.82	25.40	7.84	0.41	36.70	1.01	0.09	26	56	18	Clay

Wheat crops were planted in 2009-2017. Also during the experiment, in 2016-2018, corn crop following wheat was planted. Wheat and corn received regular care which included application of water as flood irrigation, fertilizer and pest control with sowing, 40 kg da^{-1} compose fertilizer as 20+20+Zn has been applied as base fertilizer and as top fertilizer 50 kg da^{-1} urea was applied. The same fertilizer practice was repeated in each year.

Soil laboratory analysis

A composite soil sample was taken as representative of orchard field at the surface (0-30 cm) and subsurface soil (30-60, 60-90 cm). Soil samples were air dried and passed through a 2 mm sieve and analyzed according to the routine soil analyses methods. Particle size distributions were determined by the hydrometer method (Bouyoucos, 1926); organic matter content by the Walkley-Black method (Nelson and Sommers, 1982); $CaCO_3$ content using a calcimeter (Kacar, 1994); soil pH with a 1:2.5 from soil/water suspension using pH meter (McLean, 1982); electrical conductivity (EC) in soil extraction using a conductivity meter (Janzen, 1993), soil N according to Kjeldahl method (Kacar, 1994). Soil available P and K were determined using an ICP-AEAS (Varian-Vista, Palo Alto, CA, USA), after $NaHCO_3$ extraction (pH 8.5) (Olsen and Sommers, 1982) and NH_4OAc extraction (Knudesen et al., 1982), respectively.

Soil CO_2 emissions and meteorological variables

In addition to soil CO_2 emission measurements under wheat and corn plantation, the measurements were also performed in bare soils with no cultivation fields. The soil CO_2 emissions measurements were performed as weekly basis during total of 509 weeks between January, 2009 and October, 2018, using soda lime method (Edwards, 1982).

Soda lime method is advantageous because it is easy to perform and also doe not require expensive equipments. Around 40 g soda lime was oven dried at 105 °C during 24 h, weighted and added in the numbered plastic PVC containers (3 cm tall, and 100 cm^2 area top). The containers that have a known amount of soda lime was placed under a chamber (23 cm width and 33 cm length) inserted 2 cm in soils in order to prevent interaction between soda lime and atmosphere in order to avoid any gas leakage underneath of the chamber as much as possible. A PVC lid (50 cm by 50 cm) was used to provide shadow for the chambers to reduce the temperature difference between inside

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and outside of the chambers. After one week in the field, the chambers were left and PVC containers with soda lime were weighted in the laboratory to measure changes in weight during one week incubation period. The soil CO_2 emissions were performed with five replications and then averaged to obtain a final emission values.

The amount CO_2 emission was obtained as below:

$$F_{CO2} = \frac{(C_{adsorbed} - C_{initial}) * W}{t_{incubation} * A} \quad \text{(Eq.1)}$$

Here:
F_{CO2} = emitted CO_2 g^{-1} cm^2 h^{-1}
$C_{adsorbed}$: Weight of soda lime after incubation (g)
$C_{initial}$: Weight of soda lime before incubation (g)
W: coefficient of water, taken as 1.69
$t_{incubation}$: Incubation period (week)
A: Area of the chamber, cm^2

Emission of CO_2 calculated as g cm^2 hour was converted into total weekly and monthly amounts.

Meteorological variables used in the study were obtained from Sanlıurfa city meteorological station located around 5 km away from the study site. Daily measurements were converted to weekly basis. The meteorological variables included air temperature (AT), soil temperature (ST) at different depths (5, 10, 20, 50 and 100 cm), relative humidity (RH) and rainfall (mm). Field soil moisture data were obtained gravimetrically from the soils samples taken at the same location where soil CO_2 emissions were measured.

Figure 1. *Photo showing the experimental design set up for soil CO_2 emissions*

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Statistical analyses and modeling

The relationships between CO_2 emissions at different sites (wheat and corn fields, and bare soils) and meteorological parameters and field soil moisture data were examined using correlation analyses and multiple linear regression (MLR) models.

MLR models the relationships between response (soil CO_2 emissions) and predictor variables (meteorological parameters and field soil moisture data) using a linear function between two (*Eq. 2*):

$$y_i = \beta_o + \beta_1 X_{1i} + \cdots\cdots \beta_p X_{pi} + \varepsilon_i \quad \text{(Eq.2)}$$

where y_i refers to response variable which is modeled by a linear function of predictor variables; X_i. β are coefficients; ε is error term.

The models were also validated using independent data set splitting the whole data into two groups; as 70 and 30%; while the former was used for calibration, the latter was used for validation of the model which was constructed using General Linear Model (GLM).

The models were constructed for the data in each sampling sites and each year separately and also for complete years (2009-2018). Correlation analyses and MLR modeling were performed using SPSS program. GLM model used in model validation (testing) was performed using R program.

Results

Soil properties

Averaged soil properties measured at different depths and sites are given in *Table 1*. Soils are high in $CaCO_3$ (>15%) and low in soil organic matter (<2%) contents. These were due to no organic residues given in to soils, conventional tillage and warm climate environment of the study area. Soils have a basic soil pH, a heavy clay texture and do not have any salinity problem which is indicated by low soil EC values (<4 dS m^{-1}). While total nitrogen and plant available P contents in the soils were low, K levels were high. Soil P and organic matter were higher in the soils under field crop rotation but it was opposite for K which was found higher in bare soils compare to the soils under wheat and corn crop rotation. It may be because of plant uptake.

Soil CO_2 emissions

Average, minimum and maximum of the soil CO_2 emissions (kg ha^{-1} $week^{-1}$) measured in the soil during the study periods (2009–2018) are given in *Table 2*. Long term weekly, seasonal and cumulative yearly fluctuations of the soil CO_2 emissions are given in *Figures 2-5*. The results showed that CO_2 emissions were highly variable and the higher emission peaks were obtained in the summer seasons.

The soil CO_2 emissions were highly variable, both seasonally and locally ranging from 54 to 2504 kg ha^{-1} $week^{-1}$. The CO_2 emissions in bare soils ranged from 57 to 1690 kg ha^{-1} $week^{-1}$ with average values of 791 and 523 kg ha^{-1} $week^{-1}$, respectively (*Table 2*). When the fields are under either wheat or corn plantation (excluding the weeks when there is no crop in the field), average soil CO_2 emissions were 534 and 850 kg ha^{-1} $week^{-1}$ for bare soils (CO_2-Bare) and field soils (CO_2-Field), respectively.

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Average weekly CO_2 emissions of the soils under wheat plantations in 2009-2017 were 310, 480, 516, 481, 400, 535, 680 and 696 kg ha^{-1} $week^{-1}$, respectively, which showed a consistent increase over time. Similar to the soils under wheat plantations, average weekly CO_2 emissions of soils under corn plantation were higher compared to the previous years. It was 914 and 1056 kg ha^{-1} $week^{-1}$ in 2016 and 2017, respectively. The average weekly soil CO_2 emissions from bare soils (CO_2-Bare) were always lower than those obtained in the soils under both wheat and corn cultivation (*Table 2*). Average weekly soil CO_2 emissions from the bare soils corresponding to the same weeks when fields under wheat plantation were 310, 480, 516, 481, 400, 535, 680 and 696 kg ha^{-1} $week^{-1}$, respectively in 2009-2017. Average weekly soil CO_2 emissions from bare soils corresponding to the same weeks when the fields under corn plantation in 2016 and 2017 were 687 and 621 kg ha^{-1} $week^{-1}$, respectively.

Table 2. *Descriptive statistics of long term soil CO_2 emissions under different field management and meteorological parameters*

		CO_2-B	CO_2-F	SM-B	SM-F	AT	RH	ST5	ST10	ST20	ST50	ST100	Rainfall
		kg ha^{-1} $week^{-1}$		%		°C	%	°C					mm
2009	Avg.	**310**	**506**	**24**	**29**	**15**	**53**	**16**	**16**	**15**	**15**	**15**	**8.1**
WHEAT	Min.	93	195	9	10	2	21	3	4	5	8	11	0.0
(n†=25)	Max.	505	1041	33	49	30	80	33	31	29	28	25	38.6
2010	Avg.	**480**	**575**	**28**	**24**	**15**	**56**	**16**	**16**	**16**	**16**	**17**	**10.7**
WHEAT	Min.	257	274	10	5	5	25	6	6	7	10	12	0.0
(n=34)	Max.	860	1000	36	35	30	85	35	33	30	28	26	57.0
2011	Avg.	**516**	**1128**	**27**	**24**	**14**	**55**	**15**	**15**	**15**	**15**	**15**	**12.8**
WHEAT	Min.	366	275	9	6	5	31	6	7	8	9	11	0.0
(n=28)	Max.	1015	2316	34	36	29	79	29	29	27	27	23	57.2
2012	Avg.	**481**	**786**	**27**	**31**	**14**	**50**	**14**	**14**	**14**	**14**	**14**	**14.3**
WHEAT	Min.	68	54	14	21	3	15	5	5	6	7	9	0.0
(n=29)	Max.	831	1476	42	42	33	87	34	32	30	29	24	84.7
2013	Avg.	**400**	**853**	**28**	**30**	**14**	**58**	**14**	**14**	**14**	**15**	**15**	**14.6**
WHEAT	Min.	225	278	13	20	3	24	6	6	7	8	11	0.0
(n=30)	Max.	746	1396	37	37	28	85	28	27	26	26	22	52.0
2014	Avg.	**535**	**769**	**24**	**22**	**16**	**47**	**16**	**16**	**15**	**15**	**15**	**8.2**
WHEAT	Min.	223	421	8	6	7	28	7	7	8	8	11	0.0
(n=23)	Max.	783	1144	39	36	26	82	29	29	27	27	23	74.2
2016	Avg.	**680**	**886**	**23**	**24**	**15**	**51**	**16**	**16**	**16**	**15**	**15**	**7.3**
WHEAT	Min.	364	335	6	7	1	26	5	6	7	7	10	0.0
(n=23)	Max.	992	1941	40	40	28	79	29	29	28	27	24	36.6
2016	Avg.	**687**	**914**	**12**	**14**	**27**	**33**	**29**	**29**	**28**	**28**	**27**	**1.8**
CORN	Min.	334	243	3	4	12	19	12	12	14	15	19	0.0
(n=22)	Max.	1690	2504	33	38	34	66	36	35	34	34	30	39.6
2017	Avg.	**696**	**952**	**22**	**26**	**15**	**48**	**16**	**16**	**16**	**16**	**15**	**6.2**
WHEAT	Min.	512	550	10	7	4	25	6	6	6	7	9	0.0
(n=24)	Max.	945	1327	31	37	30	73	32	31	30	29	25	60.8
2017	Avg.	**621**	**1056**	**12**	**31**	**21**	**43**	**23**	**23**	**23**	**23**	**24**	**2.9**
CORN	Min.	396	548	5	4	6	22	7	8	10	10	14	0.0
(n=25)	Max.	911	1854	24	51	34	72	36	36	34	33	30	27.9
PLANTED &	Avg.	**524**	**792**	**19**	**21**	**20**	**45**	**21**	**21**	**20**	**20**	**20**	**7.1**
UNPLANTED	Min.	57	54	1	1	1	15	3	4	5	7	9	0.0
(n=509)	Max.	1690	2504	44	51	36	88	41	39	36	34	32	89.4
PLANTED	Avg.	**534**	**850**	**23**	**26**	**17**	**49**	**19**	**18**	**18**	**18**	**18**	**8.5**
(n=289)	Min.	68	54	3	4	1	15	3	4	5	7	9	0.0
	Max.	1690	2504	42	51	34	87	38	36	34	34	31	84.7

†The number of total weeks between planting and harvesting of with corresponding field crop

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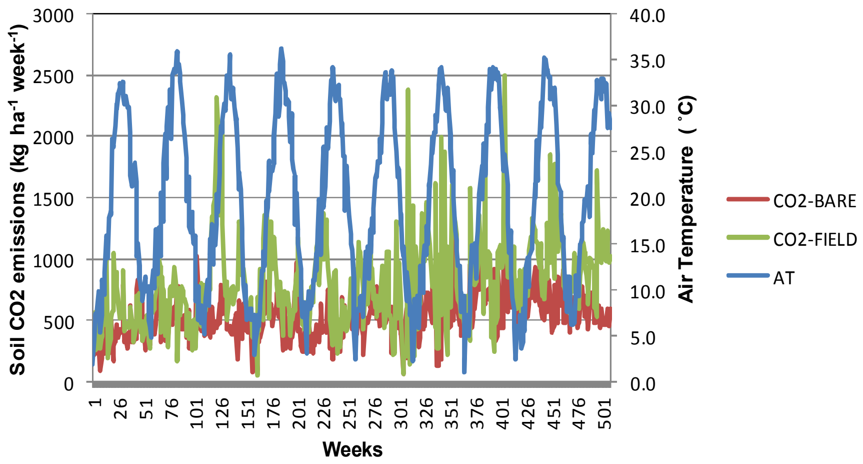

Figure 2. *The weekly fluctuations of field soil CO_2, bare soil CO_2 emissions and air temperature from 2009 to 2018 (509 weeks)*

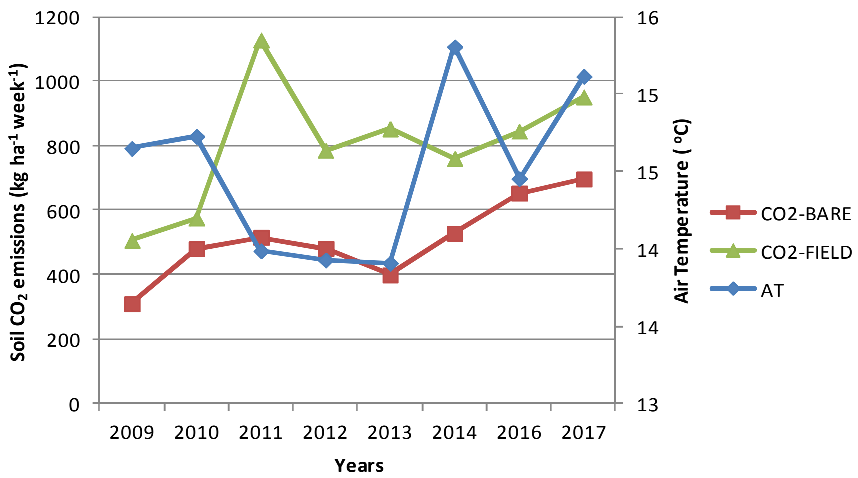

Figure 3. *Changes in yearly mean soil CO_2 emissions from two different sites and air temperature*

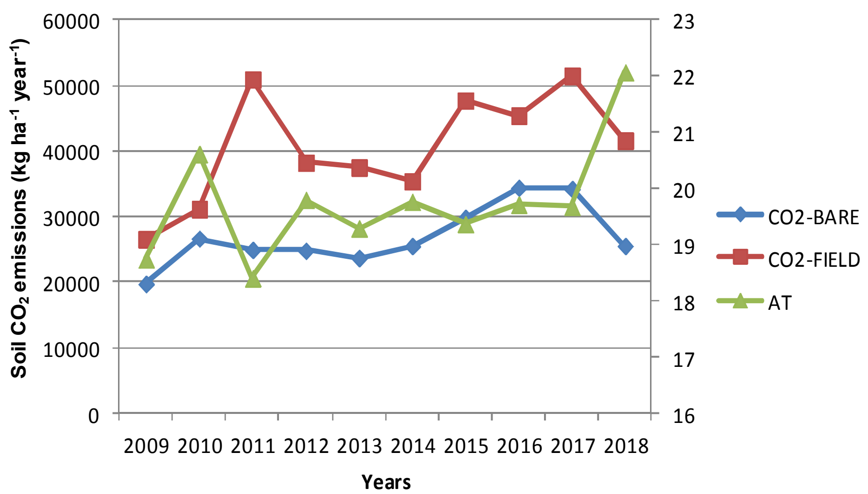

Figure 4. *Variations in cumulative yearly soil CO_2 emissions*

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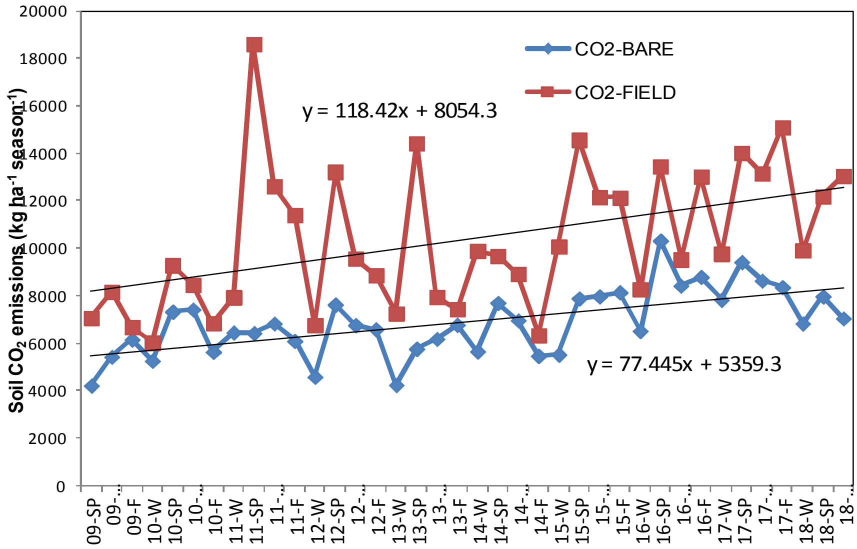

Figure 5. *Seasonal (each points corresponding to seasons starting from spring and followed by summer-fall-winter seasons) variations in soil CO_2 emissions from 2009 to 2018*

Correlations between the soil CO_2 emissions from the bare soils and wheat and corn plantations for each year separately and combined are given in *Table 3*. When all years were considered together, weekly CO_2-field values were significantly correlated ($p < 0.05$) with all meteorological parameters except rainfall, soil temperature at 100 cm and soil moisture data. While weekly CO_2-bare soil values were significantly correlated ($p < 0.05$) with all meteorological and soil moisture parameters (*Table 3*).

In the 2012, 2013, 2016 and 2017 years, weekly soil CO_2 emission values obtained had a statistically significant positive correlations ($p < 0.05$) with air and soil temperatures at different depths while significant negative correlations ($p < 0.05$) with relative humidity. They had statistically significant negative correlation with soil moisture values in 2012 and 2013 and insignificant negative correlations in 2016 and 2017.

In the 2009 and 2011 years, only weekly soil CO_2 emission values obtained from the soils under wheat cultivation had statistically significant negative and positive correlations ($p < 0.05$) with the same variables. The same situation was valid for only weekly soil CO_2 emission values obtained from the bare soils in 2014 (*Table 3*). Rainfall values had statistically ($p < 0.05$) significant negative correlations with weekly soil CO_2 emission values obtained from the soils under wheat cultivation in 2010, 2012 and 2016 years (*Table 3*).

Correlations between the soil CO_2 emissions under corn plantation both in 2016 and 2018 and environmental parameters were mostly insignificant ($p > 0.05$) (*Table 3*). As opposed to bare land and soils under wheat cultivation, the soil CO_2 emissions measured during corn plantation in 2016 had negative correlations with air and soil temperatures but positive correlations with rainfall, relative humidity and soil moisture.

Modeling of soil CO_2 emissions

Multiple Linear Regression models were constructed between the soil CO_2 emissions at different locations (bare land and field crops) and available climate parameters; air

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temperature, soil temperature, relative humidity, precipitation and field soil moisture data. For different land managements the models were constructed for all weeks in whole years (from 2009 to 2018), for only weeks when the field is planted with wheat or corn (from 2009 and 2018) and for weeks during crop season in each year, separately. Coefficient of Determination (R^2) values showing the per cent variations in soil CO_2 emissions at different time and locations explained by each models and significance of independent variables in terms of contribution to the model are given in *Table 4*. Model R^2 values for complete years considering both planted and also unplanted weeks and considering only planted weeks were 0.16 and 0.22, respectively. They were 0.1 and 0.23 respectively for bare land. For the models constructed separately for each crop season in different years, R^2 values ranged from 0.47 to 0.77 for wheat plantation, between 0.19 and 0.55 for corn plantation and 0.12 to 0.66 for bare land (*Table 4*).

Table 3. *Correlations between soil CO_2 emissions and climatic variables and soil moisture field data*

		CO_2-F	SM-B	SM-F	AT	RH	ST5	ST10	ST20	ST50	ST100	Rainfall
	kg ha^{-1} $week^{-1}$		%		°C	%	°C					mm
2009	CO2-B	0.48*	-0.36	-0.20	0.40*	-0.32	0.36	0.36	0.35	0.35	0.36	0.21
WHEAT	CO2-F	-	-0.37	-0.29	0.59**	-0.55**	0.59**	0.58**	0.58**	0.58**	0.56**	-0.09
2010	CO2-B	0.82**	-0.18	-0.24	0.14	-0.33	0.18	0.19	0.18	0.16	0.13	-0.28
WHEAT	CO2-F	-	-0.17	-0.28	0.22	-0.34*	0.26	0.27	0.26	0.22	0.16	-0.37*
2011	CO2-B	0.13	-0.10	-0.07	0.28	-0.17	0.26	0.27	0.28	0.30	0.42*	0.06
WHEAT	CO2-F	-	-0.01	0.20	0.81**	-0.52**	0.83**	0.82**	0.81**	0.80**	0.67**	-0.13
2012	CO2-B	0.75**	-0.43*	-0.38*	0.59**	-0.66**	0.55**	0.54**	0.53**	0.52**	0.46*	-0.37*
WHEAT	CO2-F	-	-0.46*	-0.47**	0.61**	-0.56**	0.59**	0.59**	0.58**	0.56**	0.47**	-0.40*
2013	CO2-B	0.49**	-0.75**	-0.69**	0.46*	-0.39**	0.52**	0.53**	0.52**	0.52**	0.44*	-0.26
WHEAT	CO2-F	-	-0.61**	-0.63**	0.76**	-0.59**	0.75**	0.76**	0.75**	0.74**	0.63**	-0.33
2014	CO2-B	0.34	-0.22	-0.38	0.55**	-0.37	0.51*	0.52*	0.52*	0.52*	0.50*	-0.13
WHEAT	CO2-F	-	0.40	0.52*	-0.36	0.36	-0.40	-0.40	-0.39	-0.39	-0.36	-0.15
2016	CO2-B	0.18	-0.31	-0.42*	0.51*	-0.58**	0.53**	0.53**	0.52*	0.52*	0.48*	-0.24
WHEAT	CO2-F	-	-0.34	-0.27	0.55**	-0.47*	0.55**	0.54**	0.54**	0.53**	0.48**	-0.45*
2017	CO2-B	0.69**	-0.38	-0.35	0.44*	-0.57**	0.41*	0.41*	0.41*	0.40	0.38	-0.22
WHEAT	CO2-F	-	-0.35	-0.32	0.57**	-0.29	0.56**	0.56**	0.56**	0.55**	0.53**	0.16
2016	CO2-B	0.70**	-0.03	0.02	-0.23	-0.04	-0.26	-0.26	-0.27	-0.28	-0.25	-0.07
CORN	CO2-F	-	-0.11	0.05	-0.34	0.10	-0.32	-0.31	-0.31	-0.31	-0.25	0.01
2017	CO2-B	0.36	-0.22	-0.51**	0.18	-0.21	0.19	0.20	0.20	0.21	0.24	-0.09
CORN	CO2-F	-	-0.63**	-0.25	0.58**	-0.48*	0.61**	0.62**	0.63**	0.64**	0.68**	-0.15
2018	CO2-B	0.36	0.02	0.07	-0.20	-0.01	-0.27	-0.28	-0.29	-0.30	-0.32	0.12
CORN	CO2-F	-	-0.58**	0.40*	0.29	-0.23	0.29	0.29	0.30	0.31	0.34	-0.12
PLANTED &	CO2-B	0.51**	-0.15**	-0.10*	0.17**	-0.21**	0.15**	0.15**	0.16**	0.15**	0.13**	-0.14**
UNPLANTED	CO2-F	-	0.01	0.14**	0.14**	-0.10*	0.12**	0.12**	0.12**	0.11*	0.06	-0.07
PLANTED	CO2-B	0.49**	-0.37**	-0.31**	0.31**	-0.40**	0.30**	0.30**	0.31**	0.31**	0.30**	-0.24**
	CO2-F	-	-0.30**	-0.07	0.40**	-0.36**	0.38**	0.38**	0.38**	0.38**	0.35**	-0.19**

AT: Air temperature (°C); ST5, ST10 and ST100 are soil temperature at 5, 10 and 100 cm, respectively; SM: Soil Moisture; RH: Relative; * significant at $p < 0.05$ level;** significant at $p < 0.01$ level

Both SM and ST at different depths were found significant ($p < 0.05$) in the models constructed for the soils under field crops (*Table 4*). For models constructed for soil CO_2 emissions in bare land, the ST20 and ST100 were significant when considering

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whole weeks (planted and unplanted), the SM, RH and ST5 were statistically significant when considering only weeks in crop seasons (planted) (*Table 4*).

Table 4. *MLR modeling results for soil CO_2 emissions under different land managements*

	2009 Wheat	2010 Wheat	2011 Wheat	2012 Wheat	2013 Wheat	2014 Wheat	2016 Wheat	2017 Wheat	2016 Corn	2017 Corn	2018 Corn	Planted & Unplanted	Planted
	CO_2-FIELD												
R2	0.54	0.47	0.77	0.53	0.60	0.66	0.60	0.48	0.19	0.55	0.27	0.16	0.22
SM-F	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	**	*
AT	ns	**	ns	ns	ns	**	*	ns	ns	ns	ns	ns	ns
RH	ns	ns	ns	ns	ns	*	*	ns	ns	ns	ns	ns	ns
ST5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
ST10	ns	ns	ns	ns	ns	s	ns	ns	ns	ns	ns	ns	ns
ST20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	*
ST50	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
ST100	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
Rainfall	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
	CO_2-BARE												
R2	0.55	0.48	0.43	0.54	0.62	0.50	0.66	0.47	0.28	0.12	0.34	0.07	0.23
SM-B	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	*	ns	**
AT	ns	**	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
RH	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**
ST5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**
ST10	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
ST20	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns
ST50	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
ST100	ns	ns	*	ns	ns	ns	*	ns	ns	ns	ns	**	ns
Rainfall	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns

R^2: coefficient of determination; AT: air temperature (°C); ST5, ST10 and ST100 are soil temperature at 5, 10 and 100 cm, respectively; SM: soil moisture; RH: relative humidity

For the models constructed for each crop seasons in different years separately, the significance of independent variables in the models changed based on different crop types and also years. Air temperature were found significant only in the models constructed for soils under wheat plantation in 2010, 2014 and 2016 years and for bare soils in 2010 and 2014 years. Relative humidity values were significant only for models constructed for soils under wheat plantation in 2014 and 2016 and bare soils in 2019. ST at different depths were not found significant in the models constructed for each cropping season year separately for field crops but found significant for bare soils in 2010 (ST10), 2011 (ST100) and 2016 (ST50 and ST100) years. Rainfall was found statistically significant for the models constructed for soils under wheat plantation in 2014 and for bare land in 2016 cropping season (*Table 4*).

Stepwise regression was used to select the most important variables in modeling the soil CO_2 emissions in different cropping seasons and managements. The most significant variables selected by stepwise regressions are shown in *Table 5*. Accordingly, when all weeks (planted and unplanted weeks) considered, the method selected SM and AT as the most important variables explaining the variations in the soil CO_2 emissions under field crops and RH in soil CO_2 emissions from bare land. When considering only planted weeks, the result did not change for soils under field crops but

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SM, ST5 and ST10 variables in addition to RH were also found as the most significant in modeling the soil CO_2 emissions from bare land.

Table 5. *Significant meteorological parameters in modeling soil CO_2 emissions determined by stepwise regression*

		VARIABLES	R^2	P
2009 WHEAT	CO_2-FIELD	AT	0.35	**
	CO_2-BARE	AT	0.16	*
2010 WHEAT	CO_2-FIELD	Rainfall	0.14	*
	CO_2-BARE	-	-	-
2011 WHEAT	CO_2-FIELD	ST5, SM-Field	0.75	**
	CO_2-BARE	ST100	0.18	*
2012 WHEAT	CO_2-FIELD	AT	0.38	**
	CO_2-BARE	RH	0.44	**
2013 WHEAT	CO_2-FIELD	AT	0.57	**
	CO_2-BARE	SM-Bare	0.57	**
2014 WHEAT	CO_2-FIELD	SM-Field	0.27	*
	CO_2-BARE	AT	0.31	**
2016 WHEAT	CO_2-FIELD	AT	0.31	**
	CO_2-BARE	RH	0.33	**
2017 WHEAT	CO_2-FIELD	AT	0.32	**
	CO_2-BARE	RH	0.32	**
2016 CORN	CO_2-FIELD	-	-	-
	CO_2-BARE	-	-	-
2017 CORN	CO_2-FIELD	ST100	0.46	**
	CO_2-BARE	-	-	-
2018 CORN	CO_2-FIELD	SM-Field	0.16	*
	CO_2-BARE	-	-	-
PLANTED	CO_2-FIELD	AT,SM-Field,	0.18	**
	CO_2-BARE	RH,SM-Bare,ST5,ST10	0.21	**
PLANTED &	CO_2-FIELD	SM-Field, AT,	0.10	**
UNPLANTED	CO_2-BARE	RH	0.04	**

R^2: coefficient of determination; *p significant at $p < 0.05$ level; **significant $p < 0.01$ level
Variables selected according to stepwise regression; AT: air temperature (°C); ST5, ST10 and ST100 are soil temperatures at 5, 10 and 100 cm, respectively; SM: soil moisture; RH: relative humidity

In other stepwise regression models performed for each crop season separately, the model selected AT as the most significant variable in 2009, 2012, 2013, 2016 and 2017 in explaining the variations in CO_2 emissions from the soils under wheat cultivation, in 2009 and 2014 years from bare land. Rainfall was only found as the most significant parameter in explaining the variations in CO_2 emissions from the soils under wheat cultivation in 2010, when stepwise regression is used. The RH was found the most significant parameter for the variations in soil CO_2 emissions from bare land. Soil temperatures at 5 cm and 100 cm were found the most significant variables for the variations in CO_2 emissions in 2011 from the soils under wheat cultivation and bare land. The ST100 was also found the most significant variable for the variations in soil

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CO_2 emissions from the corn field in 2017. Soil moisture was selected as the most significant variable by stepwise regression in explaining variations in the soil CO_2 emissions from wheat plantation in 2011 and 2014 years and from bare land in 2013 (*Table 5*).

Seasonal variations in the soil CO_2 emissions from both field and also bare land were also estimated using GLM model and available meteorological parameters and soil moisture data. For this purpose, the data was first split into two groups. 70% of the data was used for model construction and the rest 30% was estimated using constructed model. R^2 and RMSE values showing the accuracy of the estimations of soil CO_2 emissions of the samples in validation set (test set) were 0.15 and 0.05 and 253 and 178 kg ha^{-1} week^{-1} for field and bare area, respectively. *Figure 6* shows the consistency between actual and model predictions for the CO_2 values in both locations.

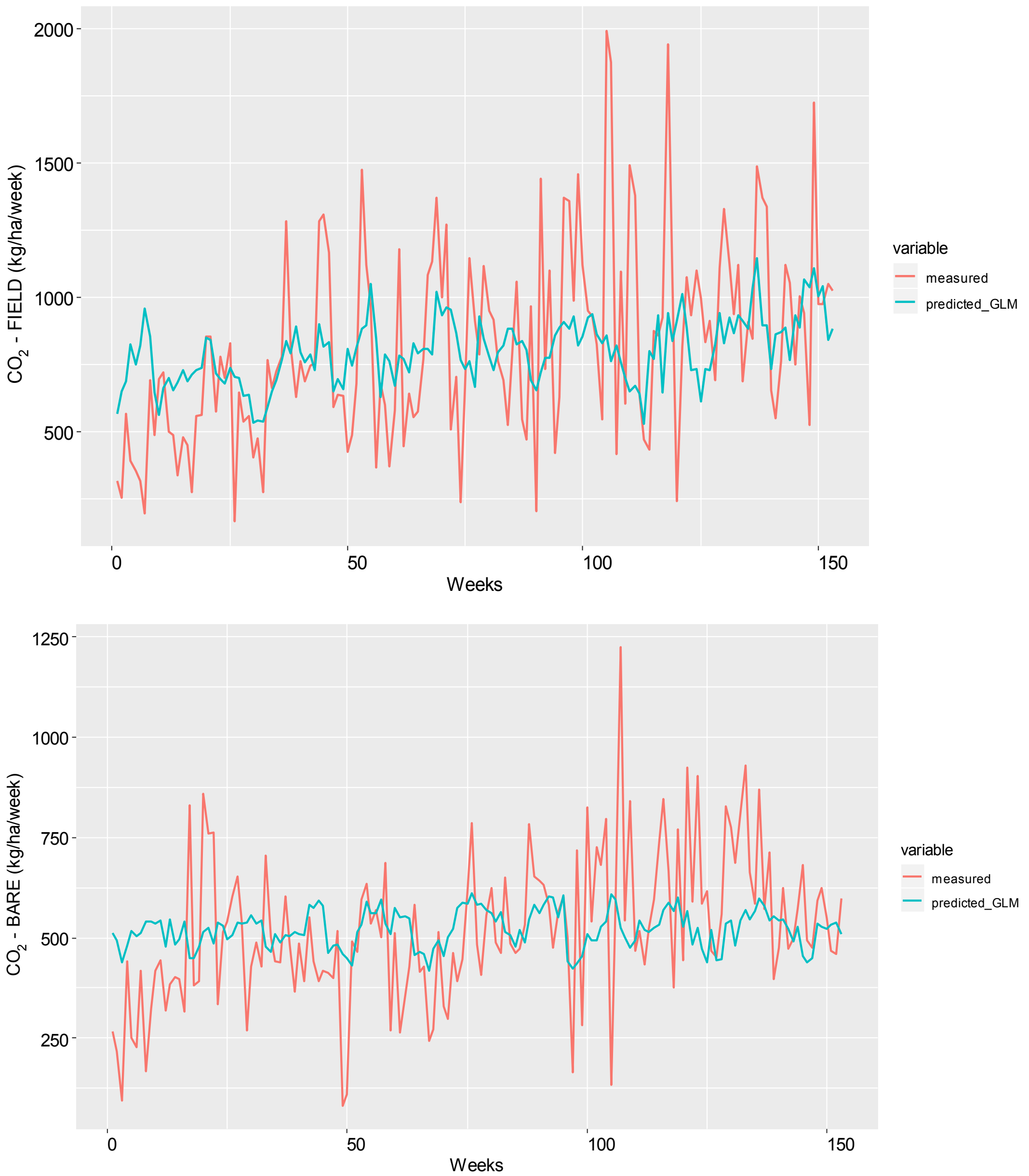

Figure 6. *Actual and GLM model predictions of soil CO_2 emissions in field (CO_2-FIELD; R^2: 0.148; RMSE: 253) and bare areas (CO_2-BARE; R^2: 0.05; RMSE: 178)*

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Discussion

Around 20% of atmospherically CO_2 is due to agricultural activities (Lal and Bruce, 1999) and grain crops such as wheat and corn are the most produced grain crops worldwide therefore the quantification of soil CO_2 emissions under these types of vegetation are important in terms of accuracy of carbon budgets and modeling.

Long term weekly soil CO_2 emission amounts from field crops and bare land had a distinct trend in seasonal fluctuation. Higher in summer and lower in winter seasons similar to air temperature (*Fig. 2*). Seasonal trends have been often reported for CO_2 emissions from soil under various other crops (Raich et al., 2002).

Soil CO_2 emissions under field crops showed a clearly higher release compare to bare soils. The relation between soil CO_2 emissions over the years and mean air temperature can be observed in *Figure 3*.

The soil CO_2 emissions showed an increase over time, as can be observed in *Figures 4* and *5*. The yearly cumulative soil CO_2 emissions could be explained with increased temperature over years. In addition, the plant residuals increased causes increase in soil organic matter. In some years the rates showed a decrease compared to previous year, however there was a general trend toward the higher cumulative emission.

Soil CO_2 emissions measured varied highly based on time of measurement (seasonal-climate), management (field crop vs. bare land) and cropping season (type of crop). Guo et al. (2013) also showed that the quantity of the soil CO_2 emissions under field cropping (wheat) can change depending on different growing stage of the crop in addition to environmental parameters such as soil temperature and rainfall.

The soil CO_2 emissions obtained from field crop plantation of our study were in a similar range with other ecosystems. Meng-yang et al. (2014) reported soil CO_2 emissions as 829, 629 and 474 g CO_2 m^{-2} from July 1 to September 30 (921, 698 and 526 kg ha^{-1} $week^{-1}$, respectively) for fields under 20- year continuous maize, wheat and soybean cultivation in a similar semi arid area located in northeast China. Gu et al. (2016) reported the soil CO_2 emissions under wheat plantation ranging from 372 to 418 mg m^{-2} h^{-1} (equals to 625-702 kg ha^{-1} $week^{-1}$). Chen et al. (2004) indicated soil CO_2 emissions in wheat field ranging from 10 to 606 mg m^{-2} h^{-1} (equals to 17-1019 kg ha^{-1} $week^{-1}$). The average soil CO_2 emissions from under semi-arid continuous wheat was 2.34 μ mol m^{-2} s^{-1} (equals to 622 kg ha^{-1} $week^{-1}$) by Zhang et al. (2011).

The CO_2 emissions obtained in our study were relatively lower than other ecosystems such as orchards, forests or pastures. In arid region in China for grassland in the Black Chinese soils, Li et al. (2009) measured average weekly soil CO_2 emissions during growing season as 1680 kg ha^{-1} $week^{-1}$. Lessard et al. (1994) measured the soil CO_2 emissions under forest vegetation and found a range between 158 and 1037 kg ha^{-1} $week^{-1}$ and also compared with nearby cultivated fields, which provided soil CO_2 emissions between 18 and 495 ha^{-1} $week^{-1}$. This is three times lower than emissions in the soils under forest. As opposed to these researchers, Iqbal et al. (2009) comparing the soil CO_2 fluxes under different land management, such as vegetables, forest, uplands and orchard stated that the soils under forest and orchard management provided relatively lower CO_2 emissions compare to other agricultural land uses.

According to average weekly emissions, the soils in continuous wheat and corn emitted 38% more CO_2 than the bare soils. The CO_2 emission from soil is the combination of root and soil microbial activities (Kuzyakov and Larionova, 2006). The root contributions to soil emissions are known as 48% (Raich and Tufekcioglu, 2000).

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Soils under plantation can provide 2 to 3 fold higher CO_2 emissions compared to bare soil.

When considering the years for both corn and wheat; the mean soil CO_2 emissions measured during corn production was higher than wheat production in both 2016 and 2017. This may be due to differences in time of growing wheat and corn. Wheat grows in winter and spring seasons, corn is grown in summer season, mostly when the air and soil temperatures are higher. The researcher who compared the soil CO_2 emissions from wheat and corn cultivation in a field experiment specifically designed for comparison purpose reported that emissions were higher in corn than both wheat and also soybean cultivations. The researcher attributed the increase to that of higher residues incorporated into the soil in corn cultivation. Our study was completely under farmer conditions with regular field cares. Relatively higher emissions from the soil under corn crops have been attributed to higher residue incorporation under corn vegetation compare to other crops compared such as wheat and soybean.

We found statistically significant correlations between the soil CO_2 emissions and meteorological variables available and field soil moisture data. Except a few cases, the soil CO_2 emissions had mostly significant positive correlations with AT and ST while significant negative correlations found with RH, rainfall and soil moisture. Significance of variables such as the soil temperature and moisture in modeling the soil CO_2 emissions have been mostly emphasized by earlier researchers. The negative correlations between soil the CO_2 emissions and soil moisture content and rainfall could be due to optimum moisture conditions during the study period which was provided by irrigation. Earlier researchers reported that as long as soil moisture are at optimum level, its impact may be insignificant in the soil CO_2 emissions (Morell et al., 2010; Mancinelli et al., 2010).

Modeling of soil CO_2 emissions

Although the models used to estimate the soil CO_2 emissions at different locations, crop managements and seasons were found statistically significant ($p < 0.05$). The R^2 values showing capability of MLR models for explaining variations in the long terms soil CO_2 emissions were relatively lower, indicating that there are other factors that may involve in overall variations in the emissions. Zhang et al. (2011) emphasized that soil management practices such as tillage had high control over the quantity of soil CO_2 emissions under field conditions in addition to environmental factors such as soil temperature and moisture.

Lower R^2 values have been also found by earlier researchers. Mapanda et al. (2010) obtained R^2 values between the soil CO_2 emissions and various environmental parameters were between 0.12 and 0.48 from the models. Mancinelli et al. (2010) received R^2 values between 0.25 and 0.28 using the soil temperature and moisture as controlling parameter.

According to the MLR and stepwise regression models, the significant and most significant parameters selected in modeling relationships between long terms fluctuations in soil CO_2 emissions from different crop management and climatic parameters along with field soil moisture data were not same for the models constructed for different seasons and cropping managements. All variables included into the models were once selected as the most significant variables in modeling, however in most cases, AT was selected as the most significant variable in modeling the soil CO_2

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emissions, which was followed by soil moisture, soil temperatures at different depth, RH and rainfall data.

Overall the accuracies of the soil CO_2 estimations using GLM models and available meteorological data were low. However the model estimations closely followed the actual observations (*Fig. 6*). Low estimation accuracies were mostly due to the higher emission values within the data sets which were not being able to be captured by the model and were underestimated. In addition to climate variables, agricultural practices such as plowing which are not included in the model may impact magnitude of the distribution of soil CO_2 emissions and cause occurrence of extreme values.

Conclusions

This study evaluated the long term (from 2009 to 2018) seasonal fluctuations in the soil CO_2 emissions under wheat and corn plantation and compared their results with ones obtained from bare soils located nearby. The CO_2 emissions from the soils under field crops were always about 38% higher than bare soils. The soil CO_2 emissions showed an increasing trend over the years which can be explained by increases in air temperature and accumulations of plant residues in the soil. Up to 77% of variations in the soil CO_2 emissions were explained with combined use of MLR model and available meteorological parameters and soil moisture data. Air temperature, soil temperatures at different depth and soil moisture were found the most significant parameters impacting the overall variations in long terms fluctuations in the soil CO_2 emissions under different cropping and bare soils. Overall the results indicated that per cent of variations explained by modeling could be improved by incorporating the soil management factors into models.

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