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Introspection of chemical transformations in soil through some natural drivers

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Abstract

Soil is regarded as reservoir of essential elements. Living world could not sustain their existence without direct or indirect assistance of soil elements. But the elements of the soil do not always remain in the desired form; instead these elements convert into unwanted irrespective of our consent. Intensive research work on soil revealed some indication that chemical transformation in soil may play some crucial role for changing our environment. The present article focuses on some natural drivers for altering some chemical constituents of soil.

Keywords: *Soil emissions, Green House Gases, Humidity, Temperature, Soil PH, Nutrients*

1. Introduction

Soil is considered to be skin of the earth and is a complex mixture of natural bodies. Since the dawn of civilization it has been serving to ensure the food, energy and handloom supply to human societies. Physical, chemical and biological functions of soil greatly depend on the component present in the soil and organic matter in soil and contribute a lot to soil including nutrient retention, soil structure, and moisture retention, degradation of pollutants, carbon sequestration and soil resilience.

The noticeable report of the Intergovernmental Panel on Climate Change (IPCC) gives a hint that the average elevation of global temperature will increase between 1.1 and 6.4 °C by 2090–2099 as compared to temperature range of 1980–1999 (Solomon *et. al*., 2007). This climate change will greatly influence in environment many locations. The change in climate will not only effects on the environment but also has the potential to threaten many matters including the soil (Brevik., 2012). This threaten will automatically stresses on food security through its influence on soil properties (Brevik and Burgess, 2013). On the other hand, alteration of soil by the various chemical transformations within the soil elements through the emission of greenhouse gases will greatly impact on the environment. For understanding these effects on both soil and environment by their own influence, climate-soils interaction and how changes in soil will lead to corresponding changes in environmental factors now and again is a great concern. Therefore, this paper will focus on the changes in soil through the chemical transformation of soil constituents by the various natural driving agents including humidity, Temperature, soil PH and availability of nutrients with a particular focus on the soil organic carbon and soil N changes into their oxide and hydrides. The article also highlights the fact that how the change of chemical constituents in soil may alter soil properties and consequent indication of future critical environment.

2. Drivers affecting Chemical transformation in soil:

Soil can be altered by some drivers and it can produce some greenhouse gases (GHG). The most critical factors reported to impact soil GHG generation rates include microbial activity, chemical decay processes, root respiration as well as heterotrophic respiration of soil fauna and fungi influence in production of GHGs in soils (Chapuis-Lardy *et. al.*, 2007)., In addition to these factors, soil moisture content (humidity), nutrient availability in soil, soil temperature, soil organic matter and soil aeration, porosity and water, net primary productivity, vegetation type and pH-values are also dominant factors for related emission flux rates (Ludwig *et. al*., 2001, Schlesinger and Andrews, 2000). Some important parameters like Land-cover-related parameters can also be considered as responsible determinant for soil emission. Drivers can be separated into proximal drivers that influence soil emissions in the direct environment (e.g.local climate, soil type) and distal drivers that effect soil emissions on larger scales (e.g. temperature, humidity); (Robertson,1989).

2.1. Humidity:

Soil humidity is one of the most significant soil parameter for Soil chemical transformation by emitting GHGs gas from soil because of its controlling power on microbial activity and all associated processes in soil. Nitrifying bacteria reside in soil pores and oxygen is needful for their living. Ludwig *et. al*., 2001 reported that emissions by nitrification even with a maximum at 20% WFPS have been observed by Soils with less water-filled pore space (WFPS) (Ludwig *et. al*., 2001). It was observed that because of inhibited nutrient supply in soil having below 10% WFPS, emissions of Nitric oxide (NO) decrease to some extent (Brümmer et al., 2008). In comparison of Nitrification, yields for NO production found to higher potential than that for N_2O production (Fowler *et. al*., 2009). On the other hand, anaerobic conditions are important requirement for CH_4- and N_2O-producing bacteria. Around 60% WFPS, N_2O production is optimal and found to be lowest when WFPS is below 30% (Gao *et. al*., 2014). It was further investigated the increase of N_2O emissions with an increase of WFPS above 80% (Keller and Reiners, 1994). Soil humidity is directly correlated with CH_4 production for which strictly anaerobic conditions are required (Gao et al., 2014; Smith *et al*., 2003). Therefore it can be said that under aerobic conditions soils are supposed to be CH_4 sinks (Fiedler *et. al*., 2005). Recently, Wetlands and rice paddies have been identified as strong sources of CH_4 (Dutaur and Verchot, 2007). Due to flooding of rice field, anaerobic fermentation of soil organic matter occurred because of stopping oxygen supply from the atmosphere to the soil. Methane possesses a great power beyond carbon di oxide to influence atmospheric warming. Aridity for Long periods can significantly minimize soil emissions. Then Soils may switch into a sink of N_2O (Goldberg and Gebauer, 2009). Soil moisture also depends on Grain-size distribution. Aerobic condition encourages the emission of gases because Soils having large pores retain less water. (van der Weerden *et. al*., 2010). Soils with unpolished texture give highest NO emission (McTaggart *et. al*., 2002). under anaerobic conditions, production of CH_4 and N_2O observed in soils with dominant fine pores (Dutaur and Verchot, 2007; Gu *et. al*., 2013). During the warm and dry periods, greater amount of CO_2 emissions observed with fine textured soils in comparison with sandy soils (Dilustro *et. al.*, 2005). Due to less availability of C and N for soil microbes, Stable soil aggregates (concretions, crusts) conduct to lower soil emissions (Kögel-Knabner *et. al*., 1998). The pulsing or Birch effect is caused by Precipitation after extended dry periods. (Birch, 1958). Enhancement of emissions within few minutes or hours after the onset of precipitation and come-back to background levels within a small number of days (Sponseller, 2007). The driving factor for the fact is the renewed mineralization and the presence of available easily decomposable material (Borken and Matzner, 2009) for the metabolism of reactivated microbes (Ludwig *et. al*., 2001). The extent of Birch effect diminutions with increase in frequencies of wet–dry cycles (Borken and Matzner, 2009).

To fulfill the demand of food security for growing global population, irrigation is very much important to achieve the goal of sufficient crop production, it incite soil CO_2 emissions in indirect way. (Raich and Schlesinger, 1992) Increase of microbial activities for the rewetted dry soil is associated by the release of air trapped in the soil pores, which is also responsible for increase of CO_2 emission in soil (Rastogi *et. al*., 2002, Sparling, G.P. and Ross, 1988). the main reason for Rewetting of dry soils are irrigation or rainfall which increases CO_2 emission by increasing microbial activity, carbon mineralization and respiration (Sparling, G.P. and Ross, 1988, Calderon and Jackson, 2002) Soil moisture content greatly affects soil respiration and as the result of soil CO_2 emission (Sainju *et. al*., 2012). According to the observation of Ding et. al. , finding of peak soil CO_2 emission is at 70% soil moisture level (Ding *et. al*., 2007); whereas above 70% soil moisture level, CO_2 emission declined sharply. Rochette et al noticed that the rise in soil CO_2 emissions with increasing soil moisture content was accompanied with rising of microbial population and activity (Rochette *et. al*, 1991).

It is ultimate from the observation that Increased in soil moisture is known to responsible to elevated soil emissions of N_2O (Castellano *et. al*., 2010, Bateman and Baggs, 2005).

2.2. Temperature:

Soil temperature can be considered as one of the main abiotic driving factors of soil chemical transformation and soil emission. Soil temperature is also known to explain the variations of GHG emissions from soils (Fang, and Moncrieff, 2001, Toth *et. al*., 2018 , Franzluebbers *et. al*., 1995, Hu *et. al*., 2018). Schindlbacher *et. al*., observed that combination of soil temperature and soil moisture may explain a significant part of variations in NO (up to 74%) and N_2O (up to 86%) emissions for particular soils (Schindlbacher *et. al*., 2004). Horel *et.al*. 2018 found the significant differences between CO_2 emission values and influence of seasonal effects on soil respiration, and their reducing effect after plant and fruit maturity. Their study also explained the couple effects of soil moisture and temperature on soil GHG emissions, rather than

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these individual environmental factors (Horel *et. al*., 2018).

Soil temperature is one of the major factor prevailing microbial activities. Because nitrification and denitrification both processes have been exhibited as being directed by nitrification and denitrification bacteria, soil temperature could affect both transformation processes through its effects on bacterial activities. Various studies revealed that nitrification process preferred temperature ranging from 25 - 35°C, whereas, it will be suppressed when soil temperature decreased below 5°C or increased above 50°C (Well and Brady, 2017). Furthermore, for denitrification the favourable temperature range falls within 30-67°C (Huang *et. al*., 2000).

It has been observed increasing rate of soil emissions and soil respiration rates occurred significantly due to increase of soil temperature. As a result of which, response of microbial metabolism increased. With Increase in temperature, soil respiration rate increases and additional force of Methane and N_2O emissions leads to diminution of O_2 concentrations in the soil (Butterbach-Bahl *et. al*., 2013). As water is essential as a transport medium for nutrients required by microbes, the positive temperature effect may be overlain by soil water stress, (Fowler *et. al*., 2009). NO and N_2O emissions manifested a positive exponential rapport with soil temperature. (Fangand Moncrieff, 2001; Ludwig et al., 2001; Tang *et. al*., 2003, Schindlbacher *et. al*., 2004, Mazzetto *et. al*., 2014). Brooks *et. al*. observed that soil respiration from bacteria down to soil temperatures of −7◦C (Brooks *et. al*., 1997). The obedience of gas emissions from soils on temperature can be expressed with the temperature sensitivity factor (Q_{10}). Basically it is the measure of the rate of change in a biological or chemical system according to increase in temperature by 10^0C (Berglund *et. al*., 2010) and it also increases with soil depth (Tang *et. al*., 2003). It has been observed that with the help of this factor soil respiration can also be expressed. This is the factor by which soil respiration enhances by a 10°C increase in temperature (e.g., Kirschbaum, 1995; Van't Hoff, 1898). The said approach is implemented in the case of several models, which generally employ a fixed value of 1.5 (e.g., in the Community Land Model, CLM, (Foereid *et. al*., 2014)) or 2 (e.g., in CASA and TEM (Potter *et. al*., 1993; Raich *et. al*., 1991)), which is employed for all soils and soil moisture levels. Nevertheless, various studies indicate that Q_{10} is variable, with a range of 1 -12 (Gritsch *et. al*., 2015; Hamdi *et. al*., 2013). From the work of Zhou *et. al*. (2009a) it has been explored that on a global scale, those small inaccuracies may result in large errors with regard to Q_{10} in the estimation of carbon dynamics. it has been observed from the data of review by Raich and Schlesinger (1992) that Q_{10} is 2.4 with values ranging from 1.3 to larger than 3.3 for soil respiration; The average values are authenticated by recent studies of Hu *et. al*. (2015) with the values ranged from 1.7–2.5 and Jiang et al. (2015) with an average value of 2.2. The fluxes of CH_4 emission to temperature enhances with a Q_{10}-value of ∼ 4 (Dalal and Allen, 2008). Increase in N_2O emissions with temperature up to about 37^0C; according to that denitrification and mitigate N_2O emissions. From the compiled report it has been observed that reported Q_{10}-values for N_2O ranging from 1.7- 9.3 (Abdalla *et. al*., 2009a).The extensive studies revealed some overlapping in moisture and temperature effects, as the result observation of clear correlation in this regard become very difficult (Fangand Moncrieff, 2001). Temperature is prominent factor for the regulation of freeze–thaw events, driving gas emissions from soils (Holst *et. al*., 2008), and may be attributed for up to 50% of the grand annual N_2O emissions (Groffman *et. al*., 2009). On the other hand, CO_2 emissions in winter are considered insignificant for the annual emission budget due to lesser root respiration in temperate or hgh polar environments (Groffman *et. al*., 2006). Hence, soil water content has to be intimate to saturation to knock off the O_2 content (Groffman *et. al*., 2009). During freeze–thaw cycles, extra nutrients are liberated for microbial metabolism through the soil particles disaggregation (Christensen and Christensen, 1991). After decomposition, dead organic material (e.g., dead plant roots) oppresses increased microbial soil respiration and emissions of N_2O (Mørkved *et. al*., 2006). It is clear from many observations that winter emissions are most pertinent for the temperate climate zone. Independently, maximum soil emissions result in spring. The Changes of environmental factors like the soil wetting before and after rainfall with elevated air temperature, may also result an increase in emission of N_2O (Davidson, 1992, Adviento-Borbe, *et. al*., 2007). Blackmer *et. al.* 1982 observed that soil water and temperature are also instigating factor for diurnal variability in N_2O emissions can affect the measurement outcomes, e.g., measurements in mid-day can comprehensively vary from late afternoon or early morning measurements. Apart from that, authors also found site dependent diurnal patterns having strong patterns one study site and no clear diurnal patterns in another site (Blackmer, *et. al*., 1982). From the several studies, it is believed that the static chamber method may overestimate N_2O fluxes in the early afternoon. Hence, early morning or late afternoon assumed to be the preferred measurement time interval (Blackmer, *et. al*., 1982, Alves *et. al*., 2012, Ryden *et. al*.,1978). However, shaded areas might be less impressible for diurnal patterns (Blackmer, *et. al*., 1982) and during collecting sample it should be taken into consideration.

Horel *et. al.* observed the clear seasonal effects between temperature and soil CO_2 emissions. During

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summer, daily soil temperature range (measured at 15 cm depth) reached 4.8 ^{0}C (averaging a 3.0 ^{0}C difference), On the Contrary, during spring and fall, the maximum daily changes were 5.1 and 4.2 ^{0}C (averaging 2.9 and 1.7 ^{0}C), respectively (Horel *et. al*., 2018). Whereas, Aforesaid changes are more traced in air temperature values, the emission of main soil N_2O drivers are soil temperature together with soil moisture values changes, instead of air temperature (Dobbie *et. al*., 1999). In contrast, intensive correlations between soil CO_2 emissions and temperature are more likely as longer daylight periods and higher temperatures influence plant growth, and as a result, plant root, heterotrophic, and mycorrhizal respiration, which are the premier biogenic sources of soil CO_2 efflux (Fenn, *et. al*., 2010, Kuzyakov, 2006).

Fidel *et. al*. analyzed the impact of biochar on soil CO_2 and N_2O emissions from Midwestern agricultural soil in a controlled laboratory incubation and in a field under four cropping systems. They hypothesized that biochar's impact on CO_2 and N_2O emissions will significantly depend on soil moisture, temperature and cropping system. In addition to that biochar may suppress the N_2O emissions by reducing the moisture sensitivity of soil nitrous oxide production and not only that but also biochar amendment will show the similar effect on soil N_2O emissions at the laboratory and field vice versa under specific condition but not all condition (Fidel *et. al*., 2019). Joseph *et. al*., 2018 showed a correlation among the soil moisture and soil temperatures with soil respiration (Joseph *et. al*., 2018). They observed effective and positive correlation of soil respiration with soil temperature in all systems. Their studies showed that the rate of soil respiration altered among various systems and was found to be higher during summer season with respect to winter season. The highest rate of soil respiration among the studied was recorded in system of cardamom and coffee and lowest in rubber. Continuous emission of nitrous oxide (N_2O) and methane (CH_4) gases was not observed in different agroforestry systems.

2.3. Soil pH-values

Soil PH is the key factor for influencing microbial activity. There is a direct impact of pH not only on the microbe or physico-chemical environment of soil. According to the different pH optima of different microbial groups, soil has a great diversification in their population balance, biodiversity and related regards from neutral to alkaline soils. While the biodiversity of soils now a day has become an environmental concern, biochemical processes arbitrated by the populations are of most relevant to crop productivity. Nitrification is one of such process which is obstructed at low pH, but this obstruction can be overcome by humic acids. With increasing pH, Nitrification increases, since the equilibrium between NH_3 and NO_3^-shifts to ammonia (Nugroho *et. al*., 2007). However, no important correlations between NO and N_2O emissions and pH-value were found (Pilegaard *et. al*., 2006). Denitrification results NO emissions under acidic soil conditions, whereas alkaline conditions nourish NO emissions caused by nitrification (Remde and Conrad, 1991). It has been observed that acidic soil conditions drive lower soil emissions. The pH optima form methanogenesis (CH_4 production) lies between pH 4 -7 (Dalal and Allen, 2008). Emission of CO_2 was observed to be maximum at neutral pH-values (Cuhel *et. al*., 2010). Under acidic conditions of soil, N_2O emissions decrease. The mitigation of soil N_2O emission is vital concern for sustainable development in agricultural field considering the effect of N_2O in environment various processes have been developed to be useful in controlling soil N_2O emissions. Use of nitrification inhibitors established itself as one of the significant controlling factor.

2.4. Availability of Nutrients

Availability of Nutrient is foremost to microbial and plant respiratory system. It is well known to us that soil microorganisms lead a major role in the deterioration and recycling of organic matter, leading the activities of mineralization, which results the release of inorganic nutrients owing to the benefit of plant roots. According to the knowledge on plant-microbe interactions, the microbes are living mediators which naturalize the oxidation of carbon and mineralization of organic forms of P and N to inorganic and bioavailable forms. Therefore, it is important to mention that natural content of C and N in soil, along with atmospheric deposition, manure or fertilizer applications also circulate an important role. The emissions of N_2O found to be negative correlation with the C/N-ratio (Pilegaard *et. al*., 2006), with N_2O emissions found lowest at C/N-ratios $\geqslant$ 30 (limited disintegration of organic material) and highest at a C/N-value of 11 (optimum disintegration and humus build-up); Gundersen *et. al*. (2012a,b). In combination with drought and low pH-values, emissions of N_2O can be suppressed significantly at C/N-ratios <20 (Gundersen et al., 2012a,b). CO_2 and CH_4 emissions correlate positively with the ratio of C/N value (Shi *et. al*., 2014; Weslien *et. al*., 2009). Nevertheless, CH4 production in soils may be suppressed due to the availability of other electron donors such as Mn4+, Fe^{3+}, NO^{3-} and SO_4^{2-} (Achtnich *et. al*., 1995; Dalal and Allen, 2008; Fumoto *et. al*., 2008; Kögel-Knabner *et. al*., 2010; Sahrawat, 2004), which is of individual relevance in many sub-tropical soils and specially in rice paddies. Considering carbon not limiting, with increasing of soil N content generally leads to soil respiration in higher scale and net ecosystem exchange (NEE) in greater extent (Niu *et. al*., 2010; Peng *et. al*., 2011). N fertilizer application with limited C availability has restricted influence on soil respiration (Micks *et. al*., 2004). The N fertilizers application leads to a lesser sensitivity of soil respiration against soil temperature and a greater sensitivity to soil moisture (Peng *et. al*., 2011). Micks *et. al*. , 2004 studied that application of NO^{3-} or NH_4^+ leads to diminish or to no change in the rate of soil respiration of forest soils (Micks *et. al*., 2004). During long-term experiments of N addition, soil respiration decreases (Bowden *et. al*., 2004). Under aerobic soil conditions, the application of liquid manure (urea) led to higher N_2O emissions, whereas, under saturated conditions NH_4^+fertilizers caused higher N_2O emissions (Tenuta and Beauchamp, 2003). For minimizing N_2O emissions from agricultural lands, application rates of fertilizer need to be adapted to plant needs due to the fact that all forms of nitrogen cannot be taken up by plants. Non plant-available N amounts may lead to enhancing emissions of N_2O (McSwiney and Robertson, 2005). CO_2 and N_2O fluxes may be increased by Cover crops after their incorporation and significantly impact on soil respiration during their lifetime (Sanz-Cobena *et. al*., 2014b). Increased level of N_2O emissions can be prevented using controlled-release fertilizers or denitrification inhibitors (Shoji *et. al*., 2001); yet, this effect can be oppressed by heavy precipitation events (Venterea *et. al*., 2012). One of the most important factors is Soil water content for selecting the fertilizer type to resist increased N_2O fluxes (Sanz-Cobena *et. al*., 2014a). Tillage system may also influence fertilizer applications. Under no-till and conservation tillage using urea, N_2O emissions found to be higher, while use of urea-ammoniumnitrate fertilizers could be observed no differences (Venterea *et. al*., 2005). But Different observations on the influence of the tillage system was also found where there are some finding of decrement of N_2O emissions with no-till practice happened (Omonode *et. al*., 2011) and explanation in this regard has been described by lower temperatures of soil (Six *et. al*., 2002), whereas, others established a positive effect of no-till on N_2O emissions and narrated this with higher microbial activities (Baggs *et. al*., 2003). N_2O emissions in greater extent occur due to the higher soil moisture during no-till practice. In this connection, it has been observed that under no-till system higher N_2O emissions cannot be balanced by CH_4-uptake rates and higher C sequestration (Li *et. al*., 2005; six *et. al*., 2002). However, no information was included about the beginning point of the no-till practice for said study. From the review by six *et. al*., 2004 regarding impact of no-till practices on emissions of N_2O, a long term studies has been recorded (six *et. al*., 2004). They found only higher N_2O emissions during the first ten years after switching from conventional tillage to conserving farming practice with no-till. Soil compaction resulted from the use of farming machines may lead to decrease soil emission (Mordhorstet *et. al*., 2014). At the forest sites, N deposition reduction led to reduce soil NO emissions. On the contrary, it has been found from other studies that by the reduction N_2O emissions were not affected (Eickenscheidt and Brumme, 2012). Abatenh *et. al*. reviewed on microbial function to mitigate GHG emission and role of microbes to fight climate change and GHG reduction through nutrient recycling. It acts as either generators or users of these gases (Abatenh *et. al*., 2018).

From the observation of Joseph *et. al*. it is clear that during summer months the relatively high soil temperature (30-32^{0}C) experienced availability of sufficient soil moisture (18.74 - 20.39 %) Due to which, the decomposition of plant litter might have enhanced in all systems by increasing activity of the micro flora and fauna present in soils, consequently, the rate of soil respiration increases (Joseph *et. al*., 2018). The soil moisture content less than 10 per cent greatly influence the activity of microorganisms in soil (Reshi *et. al*., 2007). Soil respiration rate was found to be minimum in both morning and noon hours of December. The reason behind the fact is lower soil temperature (18.6-24.34^{0}C) which minimizes the microbial activity and decomposition of soil organic matter thus driving to carbon dioxide emission in lesser extent. During summer month, the precipitation received in the study fields contributed to sufficient moisture in soil. Precipitation is considered to be a significant factor influencing soil respiration variability in soil and there was an effective increase of the soil respiration rate instantly after the rainfall in summer (Law *et. al*., 2001).

3. Conclusions

Soil acts not only a sink of reactive carbon, but it handles the global carbon cycle which is directly linked with atmospheric chemistry, ecosystem diversity and radioactive forcing. As per International energy outlook, (EIA 2017), rate of global CO_2 emissions will be increased by 16 per cent between 2015 and 2040. According to the biennial update report (BUR,2016), In 2010, India released 2,136.84 million tons of CO_2 equivalent GHGs and the major source identified in this regard agriculture sector which occupied as 3rd ranking among the emitter of GHGs in the world (Stirling *et. al*., 2017). The present article revealed the action of some natural drivers causing the subsequent release of soil constituents into their oxides or hydrides. Hence, thinking of soil management should be a desirable practice during the forthcoming decades, as the GHGs emitted from soils sinking the atmosphere should be reduced to minimize adverse effect on the environment. The present work will boost the new researcher to find out the new way, techniques, methodologies and process to control our environmental hazards and save the global environment.

References

[1] Abatenh E, Gizaw B, Tsegaye Z, and Tefera G Microbial Function on Climate Change - A Review. *Environ Pollut Climate Change* 2: 147, (2018).

[2] Abu-Hamdeh, N.H. and Reeder, R.C. Soil thermal conductivity effects of density, moisture, salt concentration, and organic matter. *Soil Sci. Soc. Am. J.*, 64, 1285–1290, (2000).

[3] Achtnich, C., Bak, F., and Conrad, R., Competition for electron donors among nitrate reducers, ferric iron reducers, sulfate reducers, and methanogens in anoxic paddy soil. *Biol. Fertil. Soil.* 19, 65–72. (1995).

[4] Adviento-Borbe, M.A.A., Haddix, M.L., Binder, D.L., Walters, D.T., and Dobermann, A. Soil greenhouse gas fluxes and global warming potential in four high-yielding maize systems. *Glob. Chang. Biol*. 13, 1972–1988, (2007).

[5] Alves, B.J.R.; Smith, K.A.; Flores, R.A.; Cardoso, A.S.; Oliveira, W.R.D.; Jantalia, C.P.; Urquiaga, S., and Boddey, R.M. Selection of the most suitable sampling time for static chambers for the estimation of daily mean N_2O flux from soils. *Soil Biol. Biochem*., 46, 129–135, (2012).

[6] Baggs, E.M., Stevenson, M., Pihlatie, M., Regar, A., Cook, H., Cadisch, G.,.Nitrous oxide emissions following application of residues and fertiliser underzero and conventional tillage. *Plant Soil*, 254, 361–370, (2003).

[7] Bateman, E.J. and Baggs, E.M. Contributions of Nitrification and Denitrification to N_2O Emissions from Soils at Different Water-Filled Pore Space. *Biol. Fertil. Soils*, 41, 379–388, (2005).

[8] Berglund, Ö., Berglund, K., and Klemedtsson, L.,. A lysimeter study on the effect of temperature on CO_2 emission from cultivated peat soils. *Geoderma*, 154, 211–218, (2010).

[9] Biennial Update Report, “First Biennial Update Report to UNFCCC”, Press Information Bureau Government of India Ministry of Environment, Forest and Climate Change. 2016

[10] Birch, H.F., The effect of soil drying on humus decomposition and nitrogen availability. *Plant Soil*, 10, 9–31, (1958).

[11] Blackmer, A.M., Robbins, S.G., and Bremner, J.M. Diurnal variability in rate of emission of nitrous oxide from soils. *Soil Sci. Soc. Am. J.*, 46, 937–942, (1982).

[12] Borken, W., and Matzner, E.,. Reappraisal of drying and wetting effects on C and Nmineralization and fluxes in soils. *Glob. Change Biol.* 15, 808–824, (2009)

[13] Bowden, R.D., Davidson, E., Savage, K., Arabia, C., and Steudler, P., Chronicnitrogen additions reduce total soil respiration and microbial respiration intemperate forest soils at the Harvard Forest. *Forest Ecol. Manage*., 196 (1), 43–56, (2004).

[14] Brevik, E.C. Soils and climate change: Gas fluxes and soil processes. *Soil Horiz*, 53, doi:10.2136/sh12-04-0012. (2012)

[15] Brevik, E.C., Burgess, L.C. Climate Change, Soils, and Human Health. In Soils and Human Health;Eds.; CRC Press: Boca Raton, FL, USA,; pp. 345–383 (2013)

[16] Brooks, P.D., Schmidt, S.K., and Williams, M.W.,. Winter production of CO_2 and N_2O from alpine tundra: environmental controls and relationship to inter-system C and N fluxes. *Oecologia*, 110, 403–413, (1997).

[17] Brümmer, C., Brüggemann, N., Butterbach-Bahl, K., Falk, U., Szarzynski, J.,Vielhauer, K., Wassmann, R., and Papen, H.,. Soil-atmosphere exchange of N_2O and NO in near-natural savanna and agricultural land in Burkina Faso (W.Africa). *Ecosystem*, 11, 582–600 (2008).

[18] Butterbach-Bahl, K., Baggs, E.M., Dannenmann, M., Kiese, R., and Zechmeister-Boltenstern, S., Nitrous oxide emissions from soils: how well do we understand the processes and their controls? *Philos. Trans. R. Soc.B: Biol. Sci.* 368, 20130122. doi: 10.1098/rstb.2013.0122, (2013).

[19] Calderon, F.J. and Jackson, L.E. Rototillage, Disking, and Subsequent Irrigation. *J. Environ. Qual*., 31, 752–758, (2002).

[20] Castellano, M.J., Schmidt, J.P., Kaye, J.P. Walker, C., Graham, C.B., Lin, H., and Dell, C.J. Hydrological and Biogeochemical Controls on the Timing and Magnitude of Nitrous Oxide Flux across an Agricultural Landscape. *Glob. Chang. Biol*. 16, 2711–2720, (2010).

[21] Chapuis-Lardy, L., Wrage, N., Metay, A., Chotte, J.L., Bernoux, M., Soils, a sink for N2O? A review. *Glob. Change Biol*. 13, 1–17 (2007).

[22] Cuhel, J., Simek, M., Laughlin, R.J., Bru, D., Chèneby, D., Watson, C.J., Philippot, L., Insights into the effect of soil pH on N_2O and N2emissions and denitrifiercommunity size and activity. *Appl. Environ. Microbiol*. 76, 1870–1878. (2010).

[23] Dalal, R.C., Allen, D.E., Greenhouse gas fluxes from natural ecosystems.Turner review no. 18, *Australian. J. Bot*. 56, 369–407, (2008).

[24] Davidson, E. Sources of nitric oxide and nitrous oxide following wetting of dry soil. *Soil Sci. Soc. Am. J.* 56, 95–102, (1992).

[25] Dilustro, J.J., Collins, B., Duncan, L., and Crawford, C., Moisture and soil texture effects on soil CO_2 efflux components in southeastern mixed pine forests. *For. Ecol. Manage*. 204, 87–97, (2005).

[26] Ding, W., Meng, L., Yin, Y., Cai, Z. and Zheng, X. CO_2 emission in an intensively cultivated loam as affected by long-term application of organic manure and nitrogen fertilizer. *Soil Biol. Biochem.*, 39, 669–679 (2007).

[27] Dobbie, K.E., McTaggart, I.P., and Smith, K.A. Nitrous oxide emissions from intensive agricultural systems: Variations between crops and seasons, key driving variables, and mean emission factors. *J. Geophys. Res. Atmos*., 104, 26891–26899.(1999).

[28] Dutaur, L., and Verchot, L.V., A global inventory of the soil CH_4 sink. *Glob.*

Biogeochem. Cycles, 21 (n/a), http://dx.doi.org/10.1029/2006GB002734., (2007).

[29] Eickenscheidt, N., and Brumme, R., NOx and N_2O fluxes in a nitrogen-enrichedEuropean spruce forest soil under experimental long-term reduction of nitrogen depositions. *Atmos. Environ*. 60, 51–58, (2012)

[30] Fang, C.; Moncrieff, J.B. The dependence of soil CO2 efflux on temperature. *Soil Biol. Biochem*. 33, 155–165, (2001).

[31] Fenn, K.M., Malhi, Y., and Morecroft, M.D. Soil CO_2 efflux in a temperate deciduous forest: Environmental drivers and component contributions. *Soil Biol. Biochem*., 42, 1685–1693, (2010).

[32] Fidel, R.B., Laird, D. A. and Parkin , T. B, Effect of Biochar on Soil Greenhouse Gas Emissions at the Laboratory and Field Scales, *Soil Syst*., 3, 8; (2019).

[33] Fiedler, S., Höll, B.S., and Jungkunst, H.F.,. Methane budget of a Black Forest spruceecosystem considering soil pattern. *Biogeochemistry*, 76, 1–20, (2005).

[34] Foereid, B., Ward, D. S., Mahowald, N., Paterson, E., and Lehmann, J. (2014). The sensitivity of carbon turnover in the community land model to modified assumptions about soil processes. *Earth System Dynamics*, 5(1), 211–221. (2014).

[35] Fowler, D., Pilegaard, K., Sutton, M.A., Ambus, P., Raivonen, M., Duyzer, J., Simpson,D., Fagerli, H., Fuzzi, S., Schjoerring, J.K., Granier, C., Neftel, A., Isaksen, I.S.A., Laj,P., Maione, M., Monks, P.S., Burkhardt, J., Daemmgen, U., Neirynck, J., Personne,E., Wichink-Kruit, R., Butterbach-Bahl, K., Flechard, C., Tuovinen, J.P., Coyle, M.,Gerosa, G., Loubet, B., Altimir, N., Gruenhage, L., Ammann, C., Cieslik, S.,Paoletti, E., Mikkelsen, T.N., Ro-Poulsen, H., Cellier, P., Cape, J.N., Horváth, L.,Loreto, F., Niinemets Ü, Palmer, P.I., Rinne, J., Misztal, P., Nemitz, E., Nilsson, D.,Pryor, S., Gallagher, M.W., Vesala, T., Skiba, U., Brüggemann, N.,Zechmeister-Boltenstern, S., Williams, J., O'Dowd, C., Facchini, M.C., Leeuw, G.,de, Flossman, A., Chaumerliac, N., and Erisman, J.W.,. Atmosphericcomposition change: ecosystems-Atmosphere interactions. *Atmos. Environ*. 43(33), 5193–5267, (2009)

[36] Franzluebbers, A.J., Hons, F.M., and Zuberer, D.A. Tillage and crop effects on seasonal dynamics of soil CO_2 evolution, water content, temperature, and bulk density. *Appl. Soil Ecol*. 2, 95–109, (1995).

[37] Fumoto, T., Kobayashi, K., Li, C., Yagi, K., and Hasegawa, T., Revising aprocess-based biogeochemistry model (DNDC) to simulate methane emissionfrom rice paddy fields under various residue management and fertilizerregimes. *Glob. Change Biol*. 14, 382–402, (2008).

[38] Gao, B., Ju, X., Su, F., Meng, Q., Oenema, O., Christie, P., Chen, X., and Zhang, F., Nitrous oxide and methane emissions from optimized and alternative cereal cropping systems on the North China Plain: a two-year field study. *Sci. Total Environ*. 472, 112–124, (2014).

[39] Goldberg, S.D., and Gebauer, G., N_2O and NO fluxes between a Norway spruceforest soil and atmosphere as affected by prolonged summer drought. *Soil Biol. Biochem*. 41, 1986–1995, (2009).

[40] Gritsch, C., Zimmermann, M., and Zechmeister-Boltenstern, S. Interdependencies between temperature and moisture sensitivities of CO_2 emissions in European land ecosystems. *Biogeosciences*, 12(20), 5981–5993. (2015).

[41] Gu, J., Nicoullaud, B., Rochette, P., Grossel, A., Hénault, C., Cellier, P., Richard, G., A regional experiment suggests that soil texture is a major control of N_2O emissions from tile-drained winter wheat fields during the fertilization period. *Soil Biol. Biochem*. 60, 134–141, (2013).

[42] Gundersen, P., Christiansen, J.R., Alberti, G., Brüggemann, N., Castaldi, S., Gasche, R.,Kitzler, B., Klemedtsson, L., Lobo-do-Vale, R., Moldan, F., Rütting, T., Schleppi, P.,Weslien, P., and Zechmeister-Boltenstern, S., The response of methane andnitrous oxide fluxes to forest change in Europe. *Biogeoscience*, 9, 3999–4012, (2012a).

[43] Gundersen, P., Christiansen, J.R., Frederiksen, P., Vesterdal, L., Influence ofhydromorphic soil conditions on greenhouse gas emissions and soil carbonstocks in a Danish temperate forest. *For. Ecol. Manage*. 284, 185–195, (2012b).

[44] Hamdi, S., Moyano, F., Sall, S., Bernoux, M., and Chevallier, T. Synthesis analysis of the temperature sensitivity of soil respiration from laboratory studies in relation to incubation methods and soil conditions. *Soil Biology and Biochemistry*, 58, 115–126, (2013).

[45] Horel, A., Tóth, E., Gelybó, G., Dencs ˝o , M. and Potyó, I., Soil CO_2 and N_2O Emission Drivers in a Vineyard (Vitis vinifera) under Different Soil Management Systems and Amendments, *Sustainability*, 10, 1811; doi:10.3390/su10061811 (2018)

[46] Hu, E., Sutitarnnontr, P., Tuller M., and Jones S. B., Modeling temperature and moisture dependent emissions of carbon dioxide and methane from drying dairy cow manure, *Front. Agr. Sci. Eng*. 5(2): 280–286, (2018).

[47] Huang Y. Z, Feng Z, and Fuzhu Z. Study on loss of nitrogen fertilizer from agricultural fields and countermeasure. Journal of Graduate School, *Academia Sinica*., 17(2), 49-58, (2000).

[48] International Energy Outlook,US Department of Energy, Energy Information Administration of Government of United States of America, 2017.

[49] Joseph, P. Jessy M.D., and Mohan, M., Soil Nutrient Status and Greenhouse Gas Emission in Major Agroforestry Systems of South India, Proceedings of 113 th IASTEM International Conference, Dubai, UAE, 1st -2 nd April 2018 ((2018).

[50] Kirschbaum, M. The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage. *Soil Biology and Biochemistry*, 27(6), 753–760, (1995).

[51] Kögel-Knabner, I., Amelung, W., Cao, Z., Fiedler, S., Frenzel, P., Jahn, R., Kalbitz, K.,Kölbl, A., and Schloter, M.,. Biogeochemistry of paddy soils. *Geoderma*, 157, 1–14. (2010),

[52] Kögel-Knabner, I., Matzner, E., Knickner, H., Kandeler, E., and Guggenberger, G., Structure and stability. *Mitt. Dtsch. Bodenkdl. Ges*. 87, 51–56, (1998).

[53] Kuzyakov, Y. Sources of CO_2 efflux from soil and review of partitioning methods. *Soil Biol. Biochem.* , 38, 425–448, (2006).

[54] Law, B.E,. Kelliher, F.M., Baldocchi, D.D., Anthoni, P. M., Irvine, J. and Moore, D. and Vantaul, S. Spatial and temporal variation in respiration in a young ponderosa pine forest during a summer drought. *Agriculture and Forest Meteorology*, 110, 27-43, (2001).

[55] Li, C., Frolking, S. and Butterbach-Bahl, K., Carbon sequestration in arable soils islikely to increase nitrous oxide emissions, offsetting reductions in climateradiative forcing. *Clim. Change*, 72, 321–338, (2005).

[56] Ludwig, J., Meixner, F.X., Vogel, B., and Förstner, J.,. Soil-air exchange of nitricoxide: an overview of processes, environmental factors, and modeling studies. *Biogeochemistry*, 52, 225–257, (2001).

[57] Ludwig, J., Meixner, F.X., Vogel, B., Förstner, J., 2001. Soil-air exchange of nitricoxide: an overview of processes, environmental factors, and modeling studies. *Biogeochemistry*, 52, 225–257.

[58] Mazzetto A M, Barneze A S, Feigl B J, Van Groenigen J W, Oenema O, and Cerri C C. Temperature and moisture affect methane and nitrous oxide emission from bovine manure patches in tropical conditions. *Soil Biology & Biochemistry*, 76, 242–248, (2014).

[59] McSwiney, C.P., and Robertson, G.P., Nonlinear response of N_2O flux toincremental fertilizer addition in a continuous maize (Zea mays L.) croppingsystem. *Glob. Change Biol*. 11, 1712–1719, (2005).

[60] McTaggart, I.P., Akiyama, A., Tsuruta, H., and Ball, B.C.F.,. Influence of soil physicalproperties, fertiliser type and moisture tension on N_2O and NO emissions fromnearly saturated Japanese upland soils. *Nutr. Cycl. Agroecosyst*. 63, 207–217, (2002).

[61] Micks, P., Aber, J.D., Boone, R.D., Davidson, E.A.,. Short-term soil respirationand nitrogen immobilization response to nitrogen applications in control andnitrogen-enriched temperate forests. *For. Ecol. Manage*. 196, 57–70, (2004).

[62] Mordhorst, A., Peth, S., Horn, R., Influence of mechanical loading on staticand dynamic CO_2 efflux on differently textured and managed luvisols, *Geoderma*, 219–220, 1–13, (2014).

[63] Niu, S., Wu, M., Han, Y.I., Xia, J., Zhang, Z.H., Yang, H., and Wan, S., Nitrogen effectson net ecosystem carbon exchange in a temperate steppe. *Glob. Change Biol*.16, 144–155, (2010).

[64] Nugroho, R.A., Röling, W.F.M., Laverman, A.M., and Verhoef, H.A., Low nitrification rates in acid Scots pine forest soils are due to pH-related factors. *Microbiol. Ecol*. 53, 89–97, (2007).

[65] Omonode, R.A., Smith, D.R., Gál, A., and Vyn, T.J., Soil nitrous oxide emissions incorn following three decades of tillage and rotation treatments. *Soil Sci. Soc. Am. J*. 75 (1), 152–163, (2011).

[66] Peng, Q., Dong, Y., Qi, Y., Xiao, S., He, Y., and Ma, T., Effects of nitrogen fertilization on soil respiration in temperate grassland in Inner Mongolia, China. *Environ.Earth Sci*. 62, 1163–1171, (2011).

[67] Pilegaard, K., Skiba, U., Ambus, P., Beier, C., Brüggemann, N., Butterbach-Bahl, K.,Dick, J., Dorsey, J., Duyzer, J., Gallagher, M., Gasche, R., Horvath, L., Kitzler, B.,Leip, A., Pihlatie, M.K., Rosenkranz, P., Seufert, G., Vesala, T., Westrate, H.,Zechmeister-Boltenstern, S., Factors controlling regional differences in forest soil emission of nitrogen oxides (NO and N_2O). *Biogeoscience*, 3, 651–661, (2006).

[68] Potter, C. S., Randerson, J. T., Field, C. B., Maston, P. A., Vitousek, P. M., Mooney, H. A., & Klooster, S. A. Terrestrial ecosystem production: A process model based on global satellite and surface data. *Global Biogeochemical Cycles*, 7(4), 811–841,(1993).

[69] Raich, J. W., Rastetter, E. B., Melillo, J. M., Kicklighter, D. W., Steudler, P. A., and Peterson, B. J., Potential net primary productivity in South America: Application of a global model. *Ecological Applications*, 1(4), 399–429, (1991).

[70] Raich, J.W., and Schlesinger, W.H. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus*. 1992, 44B, 81–99.

[71] Rastogi, M., Singh, S., and Pathak, H. Emission of carbon dioxide from soil. *Curr. Sci.*, 82, 510–517 (2002)

[72] Remde, A., and Conrad, R., Role of nitrification and denitrification for NO metabolism in soil. *Biogeochemistry*, 12, 189–205, (1991).

[73] Reshi, Z., and Tyub S., Detritus and Decomposition in Ecosystems. New India Publishing Agency, New Delhi.123 -125, (2007).

[74] Robertson, G.P., 1989. Nitrification and denitrification in humid tropical ecosystems: potential controls on nitrogen retention. In: Mineral Nutrients in Tropical Forest and Savanna Ecosystems. Blackwell Scientific, Cambridge ,Massachusetts, USA, pp. 55–69.

[75] Rochette, P., Desjardins, R.L. and Pattey, E. Spatial and temporal variability of soil respiration in agricultural fields. *Can. J. Soil Sci*., 71, 189–196, (1991).

[76] Ryden, J.C., Lund, L.J., and Focht, D.D. Direct in-field measurement of nitrous oxide flux from soils. *Soil Sci. Soc. Am. J*., 42, 731–737, (1978).

[77] Sahrawat, K.L., Terminal electron acceptors for controlling methane emissions from submerged rice soils. *Commun. Soil Sci. Plant Anal*. 35, 1401–1413, (2004).

[78] Sainju, U.M., Stevens, W.B., Caesar-TonThat, T. and Liebig, M.A. Soil greenhouse gas emissions affected by irrigation, tillage, crop rotation, and

nitrogen fertilization. *J. Environ. Qual*., 41, 1774 (2012)

[79] Sanz-Cobena, A., Abalos, D., Meijide, A., Sanchez-Martin, L., and Vallejo, A., Soil moisture determines the effectiveness of two urease inhibitors to decreaseN2O emission. Mitig. Adapt. Strateg. *Glob. Change*, http://dx.doi.org/10.1007/s11027-014-9548-5, (2014a).

[80] Sanz-Cobena, A., García-Marco, S., Quemada, M., Gabriel, J.L., Almendros, P.,Vallejo, A.,. Do cover crops enhance N2O, CO2 or CH4 emissions from soil in Mediterranean arable systems? *Sci. Total Environ*. 466–467, 164–174, (2014b).

[81] Schindlbacher, A. and Zechmeister-Boltenstern, S., and Butterbach-Bahl K., Effects of soil moisture and temperature on NO, NO2, and N2O emissions from European forest soils, *Journal Of Geophysical Research*, 109, D17302, doi:10.1029/2004JD004590, (2004).

[82] Schlesinger, W. H. and Andrews, J. A., “Soil respiration and the global carbon cycle,” *Biogeochemistry*, 48(1), 7–20, (2000).

[83] Shi, W.Y., Yan, M.J., Zhang, J.G., Guan, J.H., and Du, S., Soil CO_2 emissions from fivedifferent types of land use on the semiarid Loess Plateau of China, withemphasis on the contribution of winter soil respiration. *Atmos. Environ*. 88, 74–82, (2014).

[84] Shoji, S., Delgado, J., Mosier, A., and Miura, Y., Use of controlled release fertilizers and nitrification inhibitors to increase nitrogen use efficiency and to conserve air and water quality. *Commun. Soil Sci. Plant Anal*. 32, 1051–1070, (2001).

[85] Six, J., Feller, C., Denef, K., Ogle, S.M., Moraes Sa, J.C., and Albrecht, de, Soil organic matter, biota and aggregation in temperate and tropical soils—effects of no-tillage. *Agronomy*, 22, 755–775, (2002).

[86] Six, J., Ogle, S.M., Jay Breidt, F., Conant, R.T., Mosier, A.R., and Paustian, K.,. The potential to mitigate global warming with no-tillage management is only realized when practised in the long term. *Glob. Change Biol*. 10, 155–160, (2004).

[87] Smith, K.A., Ball, T., Conen, F., Dobbie, K.E., Massheder, J., and Rey, A., Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes. *Eur. J. Soil Sci*. 54, 779–791, (2003).

[88] Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. IPCC. Summary for Policymakers. In Climate Change 2007: The Physical Science Basis; Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change;, Eds.; Cambridge University Press: Cambridge, UK, 2007; pp. 1–18. . (2007)

[89] Sparling, G.P. and Ross, D.J. Microbial contributions to the increased nitrogen mineralization after air-drying of soils. *Plant Soil*., 105, 163–167 (1988).

[90] Sponseller, R.A., Precipitation pulses and soil CO2flux in a Sonoran Desert ecosystem. *Glob. Change Biol*. 13, 426–436, (2007).

[91] Stirling, C., White, J., Kaur, K., Sapkota, T. Study reveals new opportunities to cut greenhouse gas emissions in India, 2017. Retrieved from https://www.cimmyt.org/study-reveals-new-opportunities-to-cut-greenhouse-gas-emissions-in-india. on dated .02.2019.

[92] Tang, J., Baldocchi, D.D., Qi, Y., and Xu, L., Assessing soil CO_2 efflux using continuous measurements of CO_2 profiles in soils with small solid-state sensors. *Agric. For. Meteorol*. 118, 207–220, (2003).

[93] Tenuta, M., Beauchamp, E.G., Nitrous oxide production from granular nitrogen fertilizers applied to a silt loam soil. *Can. J. Soil Sci.* 83, 521–532, (2003).

[94] Tóth, E., Gelybó, G.; Dencs˝o, M., Kása, I., Birkás, M., Horel, Á. Chapter 19—Soil CO2 emissions in a long-term tillage treatment experiment A2—Muñoz, María Ángeles. In Soil Management and Climate Change; Zornoza, R., Ed.; Academic Press: Cambridge, MA, USA,; pp. 293–307, (2018).

[95] van der Weerden, T.J., Kelliher, F.M., and de Klein, C.A.M.,. Influence of pore sizedistribution and soil water content on nitrous oxide emissions. *Soil Res*. 50 (2), 125–135 (2010).

[96] Van’t Hoff, J. H. Lectures on theoretical and physical chemistry. In Chemical Dynamics Part I (pp. 224–229). London: Edward Arnold. (1898).

[97] Venterea, R.T., Burger, M., and Spokas, K.A., Nitrogen oxide and methane emissions under varying tillage and fertilizer management. *J. Environ. Qual.* 34, 1467–1477, (2005).

[98] Venterea, R.T., Halvorson, A.D., Kitchen, N., Liebig, M.A., Cavigelli, M.A., Del Grosso,Stephen J., Motavalli, P.P., Nelson, K.A., Spokas, K.A., Singh, B.P., Stewart, C.E.,Ranaivoson, A., Strock, J., and Collins, H., Challenges and opportunities fo rmitigating nitrous oxide emissions from fertilized cropping systems. *Front. Ecol. Environ*. 10 (10), 562–570, (2012).

[99] Weil RR, Brady NC. Nitrogen and sulfur economy of soils. In: Brady RWaN, editor.The Nature and Properties of Soils. Cambridge: Pearson, pp. 584-642, (2017).

[100] Weslien, P., Kasimir Klemedtsson, Å., Börjesson, G., and Klemedtsson, L., Strong pH influence on N_2O and CH_4 fluxes from forested organic soils. *Eur. J. Soil Sci*. 60, 311–320, (2009).

[101] Zhou, T., Shi, P., Hui, D., and Luo, Y. Global pattern of temperature sensitivity of soil heterotrophic respiration (Q_{10}) and its implications for carbon-climate feedback. *Journal of Geophysical Research*, 114, G02016, (2009a).