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Dependency of rate of soil respiration on soil parameters and climatic factors in different tree plantations at Kurukshetra, India

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Abstract: Soil respiration is a key component of the terrestrial ecosystem carbon cycle which plays an important role in regulating soil carbon dynamics and its possible feedbacks to global warming. The major factors influencing the rate of soil respiration are climatic and edaphic, however, the effects of these factors on soil respiration of different plantation under similar climatic conditions has not been studied extensively in the dry tropical region. Hence, the objective of the present study was to determine the dependency of rate of soil respiration on soil parameters and climatic factors in different tree plantations. Carbon-dioxide (CO_2) efflux of soil (soil respiration: Mg CO_2-C ha^{-1} day^{-1}) was measured at monthly intervals in tree plantations of *Acacia nilotica + Dalbergia sissoo, Syzygium cumini, Tectona grandis, Populus deltoides* and *Eucalyptus tereticornis.* The soil respiration was highest in rainy season in all plantations. Among different plantations, the higher respiration rate was observed in *P. deltoides* (13.02 Mg C ha^{-1}) plantation followed by *T. grandis*. The least values of soil respiration were observed in *A. nilotica + D. sissoo* (9.99 Mg CO_2-C ha^{-1}). The CO_2 efflux from the soil surface was found to be positively correlated with soil moisture, soil temperature, rainfall and atmospheric temperature. The soil respiration rate was significantly correlated with soil moisture in all the plantations. However, significant correlation between soil respiration rate and soil temperature were observed only in *A. nilotica + D. sissoo* and *E. tereticornis.* The correlations were also significant between soil respiration rate and rainfall for *S. cumini*, *T. grandis, P. deltoides* and *E. tereticornis* plantations. Significant correlation between soil respiration rate and mean monthly atmospheric temperature was observed for the plantations of *A. nilotica + D. sissoo* and *P. deltoides.* The soil respiration in all plantations was found to be greatly influenced by soil moisture. The microclimatic factors such as soil moisture and soil temperature influence the activity of microbes positively which leads to increased rate of soil organic matter decomposition and results in more CO_2 efflux from the soil. Anthropogenic disturbances such as forest fire and LULC change may alter the soil moisture and temperature conditions and thereby soil respiration rate.

Key words: Carbon emissions, climate change, climatic variables, soil respiration, soil parameters, tree plantations.

Introduction

The soil is the major pool of organic carbon which remains bound in the soil organic matter in the terrestrial ecosystems. Globally, soil carbon pools are estimated to contain approximately three times more carbon than the atmosphere (Lal 2004) and twice of the vegetative and atmospheric carbon pools combined (Davidson & Janssens 2006). Therefore, the soil C sink is being viewed as one that could potentially have a significant impact on sequestering carbon-dioxide (CO_2) emissions (Bell & Lawrence 2009). The carbon balance of terrestrial ecosystems is the result of the balance between carbon uptake by plants and carbon loss by plant and soil respiration (Beer *et al.* 2010; Le Quéré *et al.* 2009, 2014).

Efflux of CO_2 from soil respiration is a major contributor to net carbon exchange in terrestrial ecosystems, second only in magnitude to

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Table 1. Physico-chemical properties of soil of different tree plantations.

Parameter	*A. nilotica* + *D. sissoo*	*S. cumini*	*T. grandis*	*P. deltoides*	*E. tereticornis*
Soil pH	6.56 ± 0.02	7.19 ± 0.02	6.93 ± 0.02	7.36 ± 0.02	7.24 ± 0.02
Electrical Conductivity (µS)	207.67 ± 2.18	246.93 ± 3.67	203.27 ± 5.21	134.04 ± 3.58	129.73 ± 3.82
Bulk Density (g cm^{-3})	1.06 ± 0.05	1.07 ± 0.02	1.14 ± 0.05	1.09 ± 0.03	1.12 ± 0.04
Organic Carbon (%)	1.75 ± 0.01	1.04 ± 0.01	0.83 ± 0.01	0.99 ± 0.01	0.91 ± 0.01

photosynthesis by plants (Rustad *et al.* 2000). Predicted effects of climate change need to include the effects of changes in temperature and moisture conditions on release of CO_2 from terrestrial carbon pools, particularly soils. On a global scale, soil respiration produces 80.4 Pg CO_2–C annually (Raich *et al.* 2002) with a range of 79.3–81.8 Pg C yr^{-1} accounting for 60–90% of total respiration of global terrestrial ecosystems and it is approximately 11-fold greater than that from fossil fuel combustion and deforestation sources combined (Peng *et al.* 2009). Therefore, even a small shift or change in the soil CO_2 efflux can thus represent a large change in carbon flux from the land (Keith & Wong 2006). These fluxes from humid tropical forests are already very large. It has been suggested that a 3% increase in a tropical soil respiration of 1500 g C m^{-2} per year is greater than a 20% increase in a tundra soil-respiration rate of 200 g C m^{-2} per year (Raich 2017). Moreover, conservation of carbon stocks and flux monitoring and management are a part of climate change mitigation strategy (Sahu *et al.* 2015).

It has also been suggested that the efflux of CO_2 from soil contributes between 30 and 80% of the total forest ecosystem respiration depending on the localized site and climatic conditions (Davidson & Janssens 2006; Janssens *et al.* 2001). It consists of autotrophic root respiration and heterotrophic respiration which is associated with decomposition of litter, roots and soil organic matter (Bernhardt *et al.* 2006). There are many factors that influence soil respiration. Land use change (LUC) may detrimentally affect the soil organic carbon (SOC) directly supplemented by significant contribution to soil CO_2 efflux (Srivastava *et al.* 2016a). Further, soil moisture and macro-aggregate water stability have been found to be important drivers of SOC dynamics in dry tropical ecosystems (Srivastava *et al.* 2016b). However, soil moisture and soil temperature are among the major determinants affecting the rate of soil respiration in majority of the ecosystems. The relationships between soil respiration and these two environmental parameters vary in different ecosystems (Bao *et al.* 2016; Buchmann 2000; Moiser 1998; Rustad *et al.* 2000; Wood *et al.* 2013). Soil respiration increases quickly following rain events in dry climates. In incubation experiments also, the increase in soil respiration was reported primarily due to rapid microbial response to water availability (Kelliher *et al.* 2004). Also, temperature sensitivity of soil respiration helps in describing that how the flux of CO_2 from soils will respond to a change in temperature. Normally soil microbial and plant root processes are treated together because they are not readily distinguished from one another (Latimer & Risk 2015). Therefore, seasonal changes in soil microclimate play an important role in defining seasonal differences in soil CO_2 emissions within sites.

Effects of individual tree species on both soil autotrophic and heterotrophic respiration are difficult to predict due to strong interactions between abiotic and biotic factors (Binkley & Giardina 1998). Phenological differences among tree species have also been reported to influence the magnitudes of aboveground and belowground C fluxes (Newstrom *et al.* 1994). The type of vegetation alters the rate of soil respiration by influencing the quantity and quality of litter input into the soil which in turn brings about the variations in soil metabolism (Dias *et al.* 2010; Lee *et al.* 2010). The quantity and quality of fine roots and litterfall added by different tree species can impact not only the soil respiration rate but also the seasonal variation model of forest soil respiration (Huang *et al.* 2014).

Therefore, the present study aims to identify how rate of soil respiration is affected by different climatic and edaphic parameters. To understand these relationships the following objectives were undertaken to determine the dependency of rates of soil respiration on (i) soil parameters viz. soil moisture and soil temperature and (ii) climatic factors viz., atmospheric temperature and precipitation in different tree plantations in Kurukshetra District of Haryana.

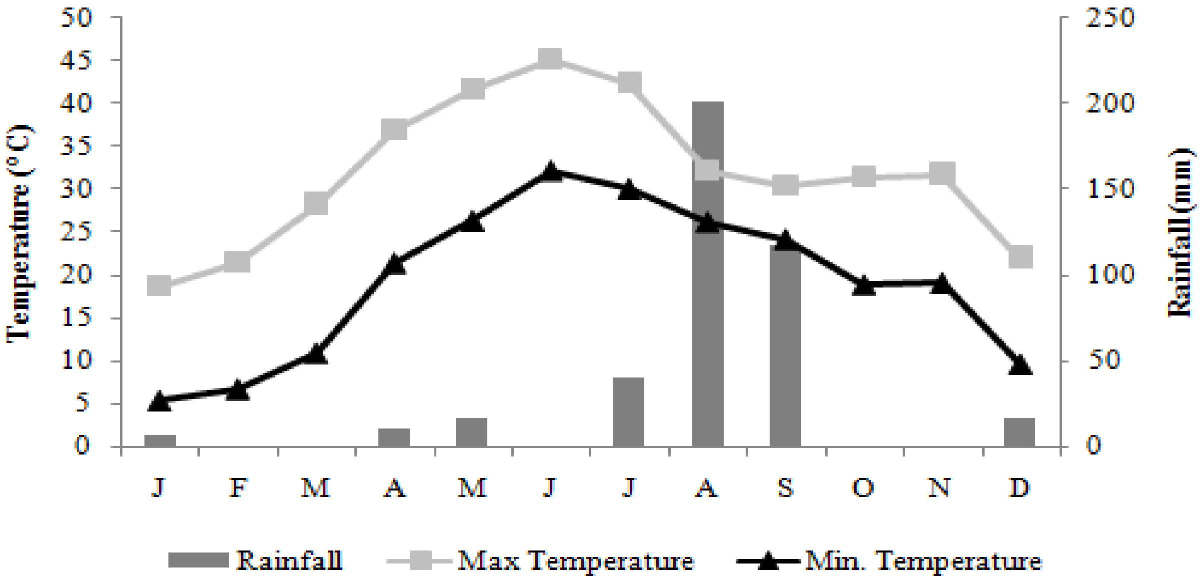

Fig. 1. Climatograph of the study area from January, 2012 to December, 2012.

Study Site

The study sites with plantations of *Acacia nilotica* + *Dalbergia sissoo, Syzygium cumini, Tectona grandis, Populus deltoides* and *Eucalyptus tereticornis* were located in the campus of Kurukshetra University, Kurukshetra. The district of Kurukshetra (area: 1682.53 km^2) lies between latitude 29°52' to 30°12' and longitude 76°26' to 77°04' in the North-Eastern part of Haryana State. The climate of the District is of very pronounced character i.e. very hot in summer (up to 45 °C) and very cold in winter (about 3 °C). The plantations were done in year 2001 by Forest Department of Haryana, under Social Forestry Scheme. The study was conducted in the year 2012. Climatic data for the year 2012 was recorded in the weather station (Eco Sense) installed in the Institute of Environmental Studies (KUK) and some data was also retrieved from the website of Indian Meteorological Department on day to day basis. During the study period, the maximum and minimum temperature ranged from 18.77 (January) to 45.15 °C (June) and 5.37 (January) to 32.15 °C (June), respectively, from January 2012 to December 2012. The average maximum and minimum temperature and rainfall is given in Fig. 1.

Materials and Methods

Soil moisture was determined using Moisture meter (IR 60, Denver Instruments), bulk density by soil core method (Blake & Hartage 1986). Soil temperature was measured in field by soil thermometer at the location where soil respiration was measured. Soil pH was measured in 1:2 ratios with distilled water using Systronics µpH System 361. Electrical Conductivity of the same suspension was measured using conductivity meter (Digital conductivity meter-611). Soil organic carbon was measured by dichromate oxidation method (Walkley & Black 1934). CO_2 efflux from soil (soil respiration: Mg CO_2-C ha^{-1} day^{-1}) of different plantations was measured *in situ* by Alkali Absorption Method (Gupta & Singh 1981) using 10 cm dia × 25 cm tall cylinders inserted 10 cm deep into the ground at monthly intervals from January 2012 to December, 2012. All green vegetation above the ground was cleared one day before fixing the chambers. Carbon dioxide efflux was collected in a beaker for reaction with 20 ml 2M NaOH for 24 h to avoid diurnal changes. Sodium hydroxide solution was then, precipitated by saturated $BaCl_2$ solution. Blanks consisted of a sealed chamber of the same volume enclosing a beaker of 2M NaOH were also run. The amount of CO_2 absorbed in 2M NaOH was determined titrametrically with 0.5 M HCl solution using phenolphthalein indicator. After titrating, CO_2 efflux rates were calculated as CO_2–C (mg) = (B – V) NE (Alef 1995), where B is the volume of HCl needed to titrate the NaOH solution from the control (Blank), V is the volume of HCl needed to titrate the NaOH solution in the beakers exposed to the soil atmosphere, N = 1.0 (molarity of HCl) and E the equivalent weight (6 for C; 22 for CO_2) CO_2 efflux was calculated as g CO_2–C m^{-2} day^{-1} and

Table 2. Nonlinear best fit regression equations w.r.t. value of coefficient of determination (R^2) of soil respiration as a function of soil moisture and soil temperature.

Study Site	Parameter	Soil Moisture (%)	Soil Temperature (°C)
A. nilotica + D. sissoo	Equation	$y = 0.012x^2 - 0.147x + 2.518$	$y = 0.523e^{0.067x}$
	R^2	0.730	0.519
	P	0.001	0.05
S. cumini	Equation	$y = 0.037x^2 - 0.554x + 3.911$	$y = 1.056e^{0.042x}$
	R^2	0.993	0.197
	P	0.001	ns
T. grandis	Equation	$y = 1.729e^{0.103x}$	$y = 1.018e^{0.045x}$
	R^2	0.765	0.344
	P	0.001	ns
P. deltoides	Equation	$y = 0.065x^2 - 0.726x + 4.380$	$y = 0.649e^{0.066x}$
	R^2	0.353	0.377
	P	0.01	ns
E. tereticornis	Equation	$y = 0.061x^2 - 0.701x + 3.792$	$y = 0.471e^{0.069x}$
	R^2	0.796	0.558
	P	0.01	0.05
Across all species (pooled average data of 12 months)	Equation	$y = 0.004x^2 + 0.146x + 1.668$	$y = 0.711e^{0.057x}$
	R^2	0.465	0.367
	P	0.05	ns

then to Mg ha^{-1}. Daily respiration was then multiplied by the number of days in the month to calculate monthly soil respiration. Annual soil respiration was computed as the sum of monthly rates (Jha & Mohapatra 2011). The experimental data was statistically analysed using data analysis tool pack of MS Excel spreadsheet 2007.

Results and Discussion

Physico-chemical properties of soil

Some of the physico-chemical properties of soils of different plantations are given in Table 1. The pH of all soil samples was estimated to be neutral or near neutral. The maximum value of soil pH was of *P. deltoides* while the minimum was found in the soil of mixed plantation of *A. nilotica* + *D. sissoo.* The electrical conductivity of soil sample of *S. cumini* was maximum followed by that of *A. nilotica* + *D. sissoo* and *T. grandis.* The electrical conductivity of soil was minimum in the tree plantation of *E. tereticornis.* Soil bulk density was found maximum in *T. grandis* plantation. Mixed plantation of *A. nilotica* + *D. sissoo* accounted for maximum soil organic carbon followed by *S. cumini* and *P. deltoides*, while the plantation of *T. grandis* had minimum soil organic carbon. Soil moisture was found to be maximum in mixed plantation of *A. nilotica* + *D. sissoo* and minimum in plantation of *T. grandis.* In case of soil temperature, the trend was vice-versa with soil of plantation of *T. grandis* accounting for maximum values and that of plantation of *A. nilotica* + *D. sissoo* accounting for minimum values.

Monthly variations in soil CO_2 efflux from different plantations

The variations in soil respiration among the study sites were found to be significant between different species and between different months (ANOVA, $P < 0.01, 0.05$). The mean daily respiration (g CO_2–C m^{-2} d^{-1}) was 2.73 (*A. nilotica* + *D. sissoo*), 3.39 (*S. cumini*), 3.51 (*T. grandis*), 3.55 (*P. deltoides*) and 2.77 (*E. tereticornis*). The respiration rates increased rapidly with the onset of rainy season following lower rates of dry month of summer and further followed by lower rates of dry months of winter season. The higher rates of soil respiration in the month of August in rainy season were further found to be higher in *S. cumini* plantation followed by *T. grandis* and *P. deltoides* plantation. Some fluctuations were observed among

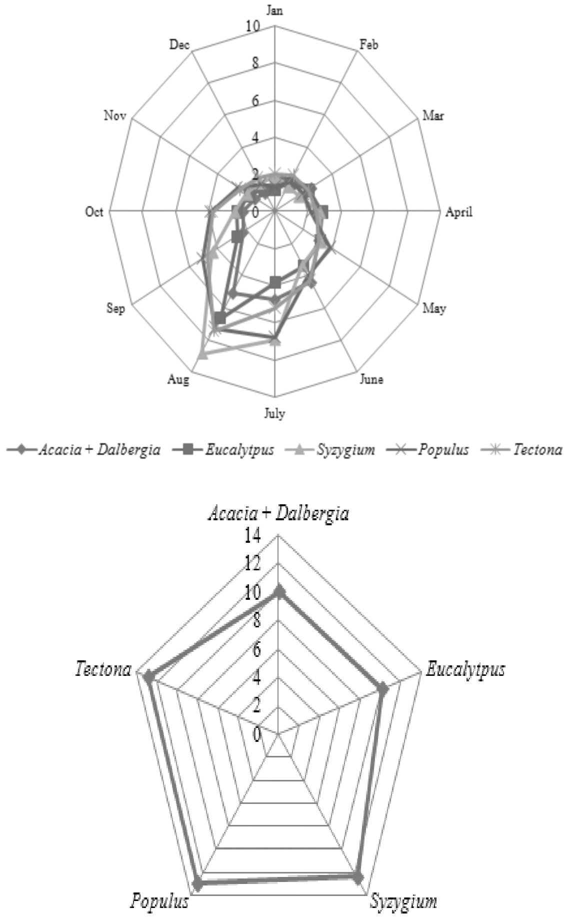

Fig. 2 (a) Monthly ($CO^{2-}C\ m^{-2}\ d^{-1}$) and (b) annual (Mg C ha^{-1}) variations in soil respiration (CO_2 evolution) among different study sites.

other months during the study period. Monthly CO_2 efflux from soils of various plantations are depicted in Fig. 2a, which indicate a narrowing of all site trends. The high rates of soil respiration during rainy season could be due to the displacement of air rich in CO_2 from within the soil and from microbial activity that oxidize the carbon dissolved in water. Also, the increase in organic matter decomposition coupled with rapid proliferation of soil microbial activity after a period of drying could be the main cause for increased rates of soil respiration in rainy months (Jha & Mohapatra 2011). The total or cumulative annual soil respiration of all study site plantations followed the order as *P. deltoides* (13.02 Mg C ha^{-1}) > *T. grandis* (12.88 Mg C ha^{-1}) > *S. cumini* (12.47 Mg C ha^{-1}) > *E. tereticornis* (10.16 Mg C ha^{-1}) > *A. nilotica* + *D. sissoo* (9.99 Mg C ha^{-1}) (Fig. 2b).

Soil CO_2 efflux relationship with soil moisture and soil temperature

In the present study, seasonal changes in soil respiration rates were estimated to be associated with variations in soil temperature and soil moisture (Fig. 3a-e). Significant positive correlations were observed between soil respiration and soil moisture for *A. nilotica* + *D. sissoo* plantation ($r^2 = 0.73$, $P < 0.001$), *E. tereticornis* ($r^2 = 0.80$, $P < 0.01$), *S. cumini* ($r^2 = 0.99$, $P < 0.001$), *P. deltoides* ($r^2 = 0.35$, < 0.01) and *T. grandis* ($r^2 = 0.77$, $P < 0.001$). Positive correlation was also observed between soil respiration and soil temperature but the significant values were obtained only for the plantations of *A. nilotica* + *D. sissoo* and *E. tereticornis*. Soil moisture as a single independent factor, therefore, explained the greater variability in soil respiration than soil temperatures in *S. cumini, P. deltoides* and *T. grandis* plantations as the correlation value between soil respiration and soil temperature were not significant for these study sites (Table 2). Soil moisture explained 35%, 73%, 76%, 79%, and 99% of the variation in soil respiration in *P. deltoides, A. nilotica* + *D. sissoo, T. grandis, E. tereticornis* and *S. cumini* plantations, respectively. Many other studies (A'Bear *et al.* 2014; Devi & Yadav 2008; Jangra *et al.* 2011; Londo *et al.* 1999; Morén & Lindroth 2000; Ohashi *et al.* 1999; Soe & Buchmann 2005; Steinweg *et al.* 2013; Sundrapandian & Dar 2013) have suggested that soil respiration is affected by temperature and soil moisture more strongly than by any other factor. Some studies have also reported that soil CO_2 fluxes increase even with changes in vegetation cover (Houghton *et al.* 2012; Raich & Tufekcioglu 2000) primarily as a function of the effects that LULC change can have on soil environmental conditions, such as soil temperature (Savva *et al.* 2010), soil moisture (Buytaert *et al.* 2006; Nosetto *et al.* 2005; Wang *et al.* 2012), and soil ecological properties, such as organic matter quality and quantity (Smith *et al.* 2014).

Relationship between soil respiration and climatic variables

The monthly rates of soil respiration were found to be positively correlated with mean monthly atmospheric temperature and rainfall. The significant values between mean monthly temperature and soil respiration rates were however, obtained for *A. nilotica* + *D. sissoo* (r =

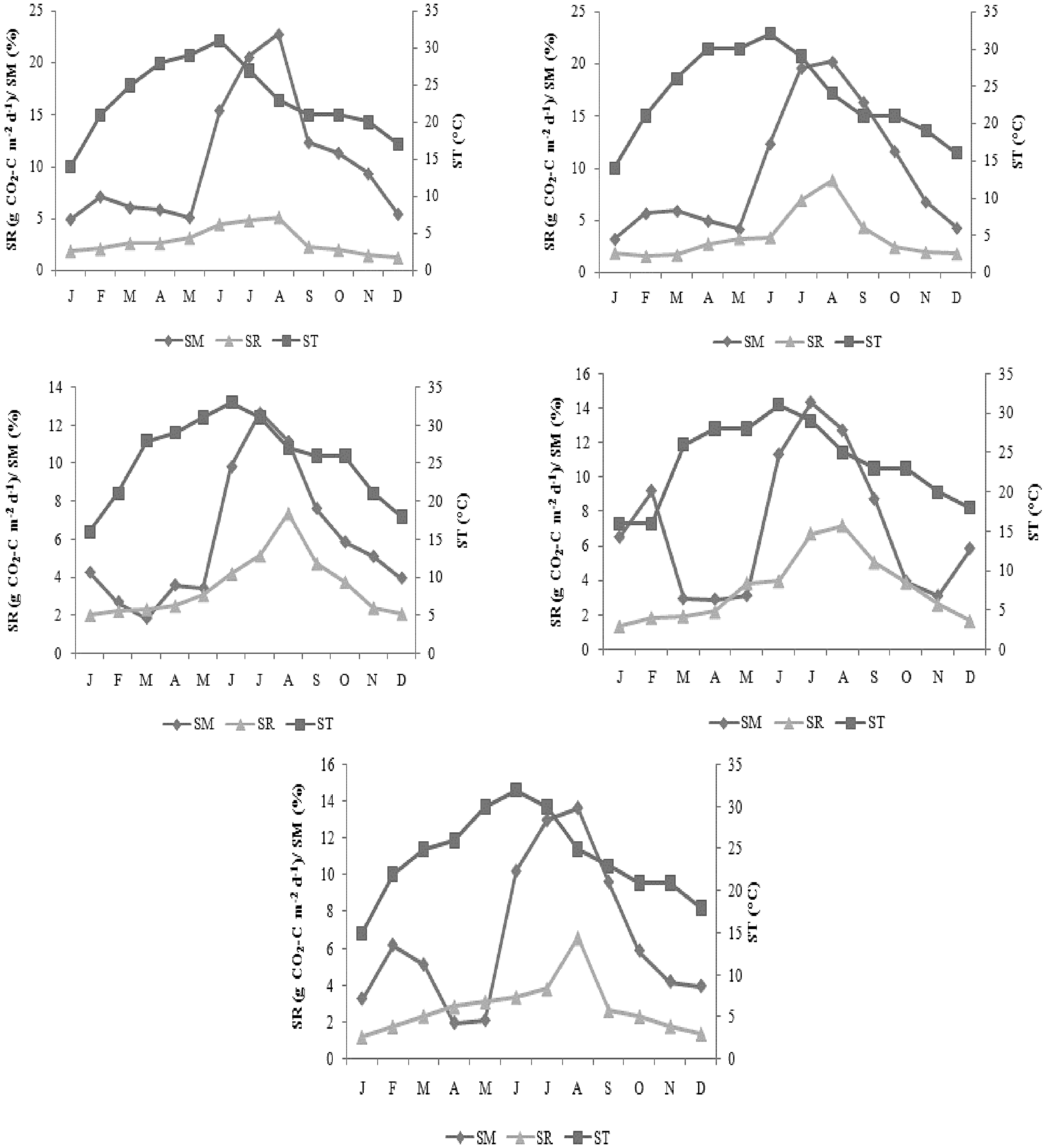

Fig. 3. Monthly variations in soil respiration (SR), soil moisture (SM) and soil temperature (ST) in (a) *A. nilotica* + *D. sissoo*; (b) *S. sumini*, (c) *T. grandis*, (d) P. *deltoids* and (e) *E. tereticornis*.

0.68, $P < 0.05$) and *P. deltoides* plantation (r = 0.57, $P < 0.05$). The correlation between rates of soil respiration and monthly rainfall was significant for the plantations of *S. cumini* (r = 0.75, $P < 0.01$), *T. grandis* (r = 0.81, $P < 0.001$), *P. deltoides* (r = 0.66, $P < 0.05$) and *E. tereticornis* (r = 0.76, $P < 0.01$) showing the significance of climatic factors in controlling rates of soil respiration. Rain exerts control during dry periods either by controlling soil moisture content fluctuations in surface layers where most of the biological activity occurs (Lee *et al.* 2002) or by strongly stimulating soil CO_2

emissions through “drying and rewetting effect” (Lee *et al.* 2002; Rey *et al.* 2002).

Biological processes such as the amount of organic matter input and the rate of decay of these residues are affected by soil temperature, oxygen and soil moisture levels (Baldock 2007). Provided that sufficient water is available, higher temperatures lead to faster decomposition of soil organic matter, less storage of carbon in the slow and passive pools, and greater loss of carbon through respiration (Canadell *et al.* 2007). The amount and quality of organic carbon inputs into the soil are a function of the vegetation present (Baldock & Skjemstad 1999). Increasing plant biomass production would likely increase soil organic carbon, while adding plant residues with higher carbon: nitrogen (C:N); and lower nitrogen: lignin ratios would reduce residue decomposition rates and potentially maintain or increase soil organic carbon. In the present study also, the mixed plantation of *Acacia nilotica* and *Dalbergia sissoo* was observed to be having higher percentage of organic carbon. However, the rate of soil respiration was lowest as compared to other plantations. The results were confirmed by negative correlation values between CO_2 efflux and soil organic carbon ($r = -0.59$). The other soil factors such as soil pH, soil EC and soil bulk density did not seem to affect the rate significantly.

Soil respiration is often considered as a measure of soil total microbial activity which reflects the rate of decomposition of soil organic matter (Zak *et al.* 2008). Several studies have also reported significant correlation between soil respiration and labile fractions of soil organic carbon especially microbial biomass carbon pool (Dube *et al.* 2009; Iqbal *et al.* 2010; Wang *et al.* 2013).

Conclusion

In the present study, the cumulative CO_2 efflux in different plantations exposed to similar climatic conditions varied from 9.99 Mg CO_2-C ha^{-1} to 13.02 Mg C ha^{-1}. The sole plantation of *P. deltoides* accounted for maximum emission of carbon dioxide in the atmosphere as soil CO_2 efflux. The mixed plantation of native tree species of *A. nilotica* + *D. sissoo* with minimum anthropogenic disturbances and more soil carbon had the lowest emission of carbon as CO_2 efflux. Various factors such as soil temperature, moisture, site productivity, soil physico-chemical properties and soil microbial communities greatly influence the rates of soil respiration in the form of CO_2 loss. Although, CO_2 efflux from the soil surface in the present study were found to be positively correlated with soil moisture, soil temperature, rainfall and atmospheric temperature, the soil respiration under all plantations was largely governed by soil moisture since the soil respiration rate was significantly correlated with soil moisture and rainfall in all the plantations. The inference is completely opposite to the temperate ecosystem, where soil respiration is controlled by soil temperature. Thus, changes in rainfall pattern and hence soil moisture rather than temperature will have a maximum effect on the process of soil respiration. Since, soil respiration is considered to be the sum of heterotrophic and autotrophic respiration, the combined effect of microclimatic factors and anthropogenic activities can be modeled to advance the understanding of the concept. The merits of these estimations will be helpful in reflecting the important soil-to-atmosphere CO_2 efflux.

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