2 Review of Literature

The impact of climatic conditions would be different in different types of soil. Tropical soil, for example, stores more organic carbon (7.1 kg C m\(^{-2}\)) with a residence time of 10 years or less than temperate soil having organic carbon 5.2 kg C m\(^{-2}\) with a residence time of 10, 100 and 1000 years (Trumbore 1993). Hence tropical soil emits more soil CO\(_2\) annually which is in the range of 1.9-5.5 kg C m\(^{-2}\) yr\(^{-1}\) than temperate land (0.22-0.45 kg C m\(^{-2}\) yr\(^{-1}\)) (Trumbore 1993). This could result into relatively low fertility of the tropical soil. However, little information is available about the soil resource of the tropics compared to that of the temperate region (Hartemink 2002). Evidently, more research is needed to explore the effect of changing climatic condition such as an increase in temperature and variability in precipitation regime on tropical soils. In this chapter, work on *Hyptis suaveolens*, and that on soil properties and processes as related to change in climatic condition especially precipitation reviewed.

2.1 *Hyptis suaveolens* (L) Poit.

*Hyptis suaveolens* (L.) Poit, which is commonly known as Bushmint or pignut, is an important invader of the tropical and sub-tropical regions of the world (Wulff and Medina 1971, Sarmiento 1984, Afolayan 1993). Its invasion has been reported from different parts of India (Wealth of India 1959, Yoganarasimhan 2000, Sharma et al. 2009). The species prefers wet and warm areas for growth and spread (Padalia et al. 2014). The aboveground parts dry up and wither away in the summer season but plants vigorously resprout at the beginning of the subsequent rainy season. The growth of *Hyptis* is intense and it rapidly covers extensive areas after the rains. The small seed size and seed dimorphism (Schwarzkopf et al. 2009) support its growth in different microsites.
and in different temperature conditions, respectively (Maia 2008). *Hyptis* possesses several characteristics common to other invasive species, such as lack of natural enemies (Julien, 2002) and the presence of allelochemicals (Kapoor 2011, Chatiyanon et al. 2012, Islam and Kato-Noguchi 2013, Joseph and Jeeva 2016), that help in its survival and spread. Raizada (2006) has argued that this species has wide ecological amplitude, high plasticity and reproductive capacity because of which it is able to grow on a variety of soil types, land uses and land cover type, as also suggested by Padalia et al. (2013). *Hyptis* possesses attributes such as faster growth rate than native species, massive seed production (>2000 m$^{-2}$), high proliferation rate, dual mode of reproduction (from perennating root-stocks as well as seed) and higher resistance against pathogens due to allelo-chemicals and essential oil (Raizada 2006).

**Figure 2.1:** *Hyptis suaveolens* in (A) open plot (B) after senescence (C) flowering and (D) invaded grassland.
2.2 Soil carbon

Carbon is one of the vital non-mineral nutrients utilised by the ecosystem. Soils are one of the largest reservoirs of carbon and hence play a major role in governing the climate regime (Post et al. 1982, Swift 2001) by acting as a source or sink of CO₂, a major greenhouse gas. Soil carbon pool may act as a source or sink of atmospheric carbon depending upon the land use and climatic condition (Houghton et al. 1987, Don et al. 2011, Zatta et al. 2013).

Precipitation has a greater influence on ecosystem processes in the tropics than in temperature region. Precipitation affects soil organic carbon in several ways, for instance by altering available soil nutrient pool, microbial activity and fine root and litter chemistry (Schimel et al. 1994, Hutsch et al. 2002, Sardans et al. 2008, Posada and Schuur 2011). Zhang et al. (2015) showed that soil organic matter decomposition rate increases significantly with increasing mean annual temperature and precipitation. In a review, Wei et al. (2014 a, b) found that the increase in mean annual precipitation increases the soil organic carbon turnover rate globally. In the tropics where there is a seasonal climate, soil carbon pool including the microbial biomass carbon was higher in the drier season than in wetter season (Singh et al. 1989). Campo and Merino (2016) found the negative relationship between mean annual precipitation and soil carbon sequestration in the tropical dry forest in Mexico.

2.3 Soil nitrogen

The tropical soil is nutrient limited. Among all the essential nutrients, nitrogen is the most crucial. The rate at which nitrogen is made available to the plant defines the functioning of the ecosystem, soil nitrogen dynamics is governed by the immobilisation and release of nitrogen (Roy and Singh 1994, 1995). Precipitation affects nutrient
availability through soil wet-dry cycle (Austin et al. 2004). Soil carbon, nitrogen concentrations and organic matter decrease with the increasing rainfall (Cuevas et al. 2013). Campo and Marino (2016) found increase in the concentration of soil inorganic nitrogen in the driest site on a precipitation gradient. Singh et al. (1989) also reported nitrogen accumulation in the dry season. High concentration of nutrients on the driest site or dry season may be due to reduced leaching and release of nutrients immobilized in soil (Singh et al. 1989, Campo et al. 1998).

Nitrogen losses occur due to nitrate leaching and denitrification, particularly in the form of gases, and are strongly related to the soil moisture availability (Austin et al. 2004). But the extent of the effect of precipitation on organic matter, nitrogen and inorganic - N pool relies heavily on the soil organisms and resource availability (Austin et al. 2004).

Overall the biological processes appear to be more vigorous in moist soil resulting in a rapid cycling of the organic matter (Cuevas et al. 2013).

### 2.4 Nutrient cycling

Nutrient cycling refers to the use and reuse of nutrients and involves movement or flow of nutrients from the physical environment to the biological system i.e. living organisms and then back into the physical environment. The efficiency of the nutrient cycling of an ecosystem defines its productivity and nutrient loss through leaching and fluxes. Nutrient cycling involves important processes such as decomposition, mineralization and immobilization, which are important for regenerating ecosystem fertility by releasing nutrients for plants, all of which are affected by precipitation, temperature and the plants. Moist and dry tropical ecosystems differ in several aspects of nutrient cycling (Fig 2.2).
Such features as low range of mean annual precipitation (MAP), annual ratio of precipitation to potential evapotranspiration of less than 1.0, and 4 to 7 dry months in a year (Dirzo et al., 2011) control the biogeochemical cycles (Campo et al. 2001, Gei and Powers 2014, Verduzco et al. 2015) in the tropical dry forests. However, the potential effect of rainfall variability on biogeochemical processes in these water-stressed ecosystems has not been studied as extensively as for tropical wet forest. This lack of information limits our understanding of the potential effects of predicted increases in the frequency and duration of droughts and long-term reduction in mean annual precipitation (Meir and Pennington 2011).

Leaf nutrient resorption from senescing leaves and its efficiency is an important aspect of nutrient cycling. Foliar resorption can provide a substantial percentage of the nitrogen and phosphorus used annually by forests (Ryan and Bormann 1982). The study of Lal et al. (2001) indicated that resorbed nutrients, particularly N, P and K, could be a significant source of plant nutrient supply, and are likely to meet a significant proportion of the nutrient demand of the developing leaves in the majority of species studied. As an example, the nutrients retranslocated from senescing leaves support 50-100% of leaf area development and 46-80% of leaf mass development in tropical deciduous species. This internal cycling, by supporting pre-monsoon leaf initiation and expansion, enables the trees to take full advantage of the rainy season when water and soil nutrients become abundant and support a high forest productivity.
Negative effect of Rainfall, Inefficient nutrient cycling (3, 4, 5, 6, 8)

Positive effect of Rainfall, Efficient nutrient cycling (3, 4, 5, 6, 8)

Figure 2.2: Nutrient cycling in tropical moist and dry ecosystems. N, P NO₃ and CO₂ represents the nitrogen phosphorus, nitrate and carbon dioxide respectively. Numbers in each boxes represent the source: 1 = Campo et al. 1998, 2 = Harper et al. 2005, 3 = Heisler-white et al. 2008, 4 = Knapp et al. 2008a, 5 = Heisler-white et al. 2009, 6 = Thomay et al. 2011, 7 = Bejarano et al. 2014, 8 = Sala et al. 2015, 9 = Campo 2016, 10 = Campo and Merino 2016.
Resorption proficiency is a parameter describing the minimum level to which a nutrient is reduced during senescence, and has also been used to quantify nutrient resorption (Killingbeck 1996). Higher proficiencies correspond to lower final nutrient concentrations in senesced leaves. Resorption proficiency and resorption efficiency continue to receive widespread attention in attempts to establish their relationship with soil fertility, plant nutritional status, plant functional groups, and climate (Lal et al. 2001, Wright and Westoby 2003, Kobe et al. 2005, Rentería et al. 2005, Drenovsky and Richards 2006, Ratnam et al. 2008, Yuan and Chen 2009a,b).

The resorption efficiency of P, but not N, increased in years with low rainfall, suggesting that the costs of nutrient resorption relative to acquisition from soil differ between N and P and that P conservation increases when rainfall decreases (Rentería and Jaramillo 2011) indicating that water availability controls P dynamics in the Chamela Dry Tropical Forest. Earlier, Rentería et al. (2005), working with six dry-deciduous tree species reported that the levels of green and senesced-leaf P, but not N, change in response to topographic-related changes in nutrient and water availability due to changes in annual rainfall. These authors suggested that water more than soil nutrient availability controls nutrient resorption.

The study of Singh and Singh (1991 a, b and 1993) revealed that the tropical deciduous forest is characterised by three levels of superimposed mineral cycling viz. internal (leaf to stem and stem to leaf, i.e. reuse of resorbed nutrients), short-term through short-lived components (i.e. through leaf litterfall, and fine roots to soil and then back to plant after release by decomposition) and long-term through long-lived components (through the fall of branch, bole and course root litter and their decomposition).
Campo (2016) found that nutrient use efficiency increased with reduced mean annual precipitation (MAP); N and P are cycled more efficiently with greater water deficit (N use efficiency increased from 56 at the sub-humid site to 71 at the semiarid site, and P use efficiency increased from 720 at the sub-humid site to 1205 at the semiarid site) Large increases in P use efficiency (an increase of 40%) than in N-use efficiency (an increase of 21%) with decrease in MAP, shows that the extent of the dry season and/or intensity of drought may have created P limitation in these ecosystems (Campo and Vázquez-Yanes 2004). In the TDF of the Yucatan Peninsula where soil pH is more than neutral, P may be chemically bound to calcium (Gamboa et al. 2010, Cuevas et al. 2013) and this condition would be pronounced in drier sites, where shallow soils and slow P release create bad P conditions.

2.5 Decomposition and Mineralisation

Decomposition and mineralisation are two essential processes by which organic substance such as leaf litter, plant debris, dead organisms, etc. are broken down into simpler organic and inorganic materials. Decomposition is mainly a biological process, and its speed is governed by three major factors, physical environment like soil temperature and moisture, soil organisms, and quality of soil organic matter (Brussaard 1994).

Temperature has been argued to influence the decomposition rate more in temperate climate and precipitation has a greater impact in tropical climate where it is considered a primary driver for decomposition (Power et al. 2009, Berg et al. 1993, Gholzet al. 2000, Trofymow et al. 2002). Soil temperature and soil moisture are predominantly governed by climatic conditions and seasonality. Decomposition rate is high in tropical than in temperate regions (Power et al. 2009). In determining the
decomposition rate, rainfall becomes crucial as it influences soil temperature as well soil moisture (Salamanca et al. 2003).

Studies have reported that timing and magnitude of precipitation events markedly affect the decomposition processes (Anaya et al. 2012), and annual decay rate consistently increases with the increase in precipitation in tropical ecosystems (Campo and Merino 2016). In a pan-tropical study, Power et al. (2009) found that average decomposition rate and the ratio of above and below ground decay increase linearly with the annual precipitation. A study on decay dynamics, reported inhibitory effect of excessive addition of water on the decomposition rate in mesic to wet climatic conditions (Schuur 2001). Probably, it might be due to the anaerobic condition created due to water abundance.

Precipitation affects decomposition rate both directly and indirectly. It affects directly by affecting microbial population and mesofauna and their activities and by leaching of the soluble compounds, and indirectly by changing litter chemistry and plant traits (Fragoso and Lavelle 1992, Cornejo et al. 1994, Austin and Vitousek 2000).

Although several studies on the influence of precipitation regime on ecosystem C cycling in tropical forests are available (e.g., Schuur 2003, Powers et al. 2009, Posada and Schuur 2011, Malhi et al. 2015), a full understanding of the impact remains incomplete (Powers et al. 2011, Marín-Spiotta and Sharma 2013). In TDFs most ecosystem processes are controlled by water availability (Campo et al. 1998, 2001), for example, slow decomposition of organic matter occurs in drought period causing high carbon storage in the forest and deposition of free light fraction of organic matter (Cuevas et al. 2013, Roa-Fuentes et al. 2013).
In a study by Pandey et al. (2013) mean weight loss of litter through decomposition showed positive relationship with soil surface temperature and soil moisture content. This study showed higher weight loss during rainy season as warm and humid condition in rainy season favour decomposition, and lower weight loss during winter season as cold and dry condition negatively affect litter weight loss in tropical forest (Arunachalam et al.1998, Maithani et al. 1996).

N and P mineralisation in tropical soil is closely related to the rainfall pattern (Allen et al. 2017). The study by Jha et al. (1996 a, b) in a tropical dry forest showed that the rate of N mineralisation increased in the rainy season as soil moisture content increased. Jha et al. (1996a) studied the N-mineralization rates and the size of the viable community of nitrifying bacteria in a dry forest site and an adjoining cropland site, and found a strong positive relationship between N-mineralization and soil moisture, which indicated that the mineralization process was moisture limited. In the study of Jha et al. (1996a), the most probable number (MPN) counts of ammonia- and nitrite-oxidizing bacteria were the largest in rainy season and smallest in the dry season, and were significantly and positively related to soil moisture. The size of the viable community of nitrifiers was positively related with nitrification as well as N-mineralization rates. The activity of nitrifiers is reported to be inhibited more than that of ammonifiers at soil moisture potentials below -1.5 MPa (Dommergues 1966). While substrate limitation was the major inhibiting factor for the activity of nitrifying bacteria at soil water potentials greater than -0.6 MPa, the adverse physiological effects associated with cell dehydration were more inhibiting at water potentials of less than -0.6 MPa (Stark and Firestone 1995). Thus soil moisture affects the activity of nitrifying bacteria through both dehydration as well as
substrate limitation. The sensitivity of nitrifiers to soil moisture is related to their high energy requirement, diverting energy sources which might otherwise be used to synthesize compatible solutes such as amine or polyols, which could help the organisms to withstand dry conditions (Sprent 1987).

2.6 Soil CO$_2$ flux

Soil respiration or soil CO$_2$ flux is the production of carbon dioxide by the respiration of soil microorganisms and plant roots. Soil CO$_2$ flux is the largest carbon flux to the atmosphere by the earth (Vicca et al. 2014). Soil respiration includes autotrophic respiration (respiration by plant root) as well as heterotrophic respiration (respiration by microbes and soil fauna) hence; it indicates the below ground productivity and metabolic activity (Cleveland et al. 2010). Soil CO$_2$ flux is regulated by various factors including root biomass and its activity. Soil CO$_2$ flux increases with an increase in root biomass (Schlesinger and Andrew 2000). Root biomass and its activity contribute 20% - 90% to the total CO$_2$ flux globally from the soil (Boone et al. 1998). Apart from root biomass, soil CO$_2$ flux is also strongly regulated by substrate availability to the microbes, soil temperature and soil moisture (Linn and Doran 1984, Craine et al. 1999, Zak et al. 1999).

Altered precipitation pattern would lead to variation in soil moisture availability and hence will affect both plant and microbial processes and alter the soil CO$_2$ flux (Harper et al. 2005). General predictions indicate that increased water stress would decrease soil CO$_2$ flux (Harper et al. 2005). Studies conducted across the globe indicated that soil CO$_2$ flux is more susceptible, in the twenty-first century, to a decrease in mean annual precipitation in tropics in the near future (Neelin et al. 2006, IPCC 2013). The
change in climatic conditions alters hydrological cycle and apparently results in an enormous and nonlinear effect on the soil CO$_2$ flux (Vicca et al. 2014).

As indicated earlier, soil organic matter decomposition rate also varies with the change in temperature and precipitation (Zhang et al. 2015). Thus soil CO$_2$ flux would change as substrate availability fluctuates with changes in temperature and precipitation. A hump-shaped curve describes the relationship between soil CO$_2$ flux and soil moisture as well as between soil organic carbon and soil moisture (Orchard and Cook 1983, Wood and Silver 2012, Vicca et al. 2014), indicating that carbon mineralization decreases in both dry and inundated condition due to lack of water in the former and lack of oxygen in the latter (Allen et al. 2017). Studies have indicated that the lack of rain in the dry period and drought conditions decrease soil CO$_2$ flux in dry tropical forests (Adachi et al. 2009, Wood and Silver 2012). In a rainfall manipulation meta-analysis experiment, Wu et al. (2011) proved that decreasing precipitation reduced soil CO$_2$ flux by 12% and increased precipitation increased the soil CO$_2$ flux by 30%.

Waring and Powers (2016) observed that soil CO$_2$ fluxes are linked to seasonal and short-term variation in water availability, as also indicated by other studies (Birch 1958, Cook and Orchard 2008, Moyano et al. 2012). In the field manipulation, rewetting of dry soils produced an immediate pulse of CO$_2$, accompanied by rapid immobilization of N into the microbial biomass. Strong CO$_2$ pulses were also observed in previously moistened soil, suggesting that observed respiratory responses were biological in origin, and did not simply represent flushing of pent up CO$_2$ out of soil pore space. Instead, CO$_2$ pulses likely represent rapid microbial metabolism of organic substrate that was previously unavailable due to occlusion in soil aggregates or limitations on diffusion (Manzoni et al. 2014).
2.7 Microbial biomass

Microbial biomass measures the size, diversity and activity of microbial population in soil, and is related to soil organic matter decomposition and nutrient mineralisation. It is a biological soil property and is an important indicator of soil fertility (Dominati et al. 2010). In the tropical soil, microbial population constitutes considerable number (~ $10^{11}$-$10^{12}$ per g soil) (Dubinsky et al. 2010), preserving thus a huge reservoir of functional and physiological plasticity that allows them to adapt to different environmental conditions (Bouskill et al. 2013).

Soil moisture and organic carbon are the two major governing factors for the microbial biomass. Low precipitation or drought generates a significant metabolic response in microbes (Bouskill et al. 2016), hence affecting the activities and composition of the microbial communities. In a study by Bouskill et al. (2013), microbial community structure got reduced under drought condition, showing the change in precipitation regime.