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Soil fertility and root carbon exudation in *Tephrosia candida* (Roxb.) DC hedgerows under Sloping Agricultural Land Technology in Mizoram, northeast India

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Abstract
In Mizoram, northeast India, Sloping Agricultural Land Technology (SALT) has been a prominent form of agriculture after shifting cultivation, with *Tephrosia candida* (Roxb.) DC hedge row commonly used. The study was designed to assess the soil physicochemical properties and fine root biomass in bulk root zone (BRZ) and sparse root zone (SRZ), along with the rates of root exudation in *Tephrosia candida* (Roxb.) DC planted at Botanical garden of Mizoram University. The soil properties (soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, NH_4-N and NO_3-N) and fine root biomass were significantly higher in upper (0-15 cm) and lower soil depth (15-30 cm) of BRZ compared to SRZ. Total fine root biomass at upper and lower depths were 129 g m^{-2} and 48 g m^{-2}, respectively in BRZ which were six fold greater than the values in SRZ. The N-mineralization rate was also higher in BRZ. The annual C exudation rate in *T. candida* was 157 mg C g^{-1} yr^{-1} and the mean total annual C flux in BRZ and SRZ were 9 g C m^{-2} yr^{-1} and 1.7 g C m^{-2} yr^{-1} respectively, to a depth of 30 cm. Results indicated that the *T. candida* significantly enhanced soil nutrients in BRZ through greater exudation of C in the vicinity of roots, which fueled microbial growth. This indicates significant role of the species in maintaining the soil health in the region.

Key words: Bulk root zone, Fine root, Root exudation, Sparse root zone, *Tephrosia candida* (Roxb.) DC.

Introduction

Tephrosia candida (Roxb.) DC., a fast-growing nitrogen fixing shrub species belonging to family Leguminosae (sub-family: Papilionoideae), and commonly growing in tropical and sub-tropical regions, is native to the foothills of the Indian Himalayas. The species is occurring naturally and is also communally cultivated throughout South-East Asia (Nguyen and Thai, 1993) and is usually found at elevations up to 1650 m. The species grow well in areas having mean air temperatures of 20-30ºC and total annual rainfall of 1400-1800 mm. The species prefers acidic sandy soils. It is widely grown in hedgerows as well as alley cropping along with crops in the tropics due to its high biomass yield, dense vegetative cover, and deep root system with high nitrogen fixing ability (Lie et al., 2017).

The soils in northeast India are strongly acidic in nature and *Tephrosia candida*, has been widely grown in degraded land and shifting cultivation sites to enhance soil fertility and check soil erosion in Mizoram (Wapongnungsang et al., 2017). The species helps in restoring degraded lands, fixing atmospheric nitrogen, controlling soil erosion and increasing the level of soil nutrients. Understanding the root distribution and interaction with

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belowground environment is an essential aspect of soil productivity that critically affects ecosystem productivity. Fine and small roots (<5 mm), and coarse roots (>5 mm) are two major components of belowground biomass, and their vertical and horizontal distribution define the extent to which they modify soil physical and microbial properties (Buyanovsky et al., 1987; Singha and Tripathi, 2017).

Root exudates are well known to play an important role in mediating soil nutrient availability in ecosystems and stimulating microbial activity (Rohrbacher and Arnaud, 2016) through a semi-continuous input of labile carbon to soil in contrast to transient inputs of C resulting from leaf litter inputs (Kuzyakov and Cheng, 2001). The quality and quantity of root exudates are largely determined by plant species, age of individual plants and external factors like biotic and abiotic factors (e.g. soil structure, presence of microbes, soil fertility level) (Lesuffleur et al., 2007). Root exudates are one of the most poorly quantified constituents of belowground C cycles (Paterson et al., 2007) which have been estimated to represent 1% to 10% of net assimilated C (Jones et al., 2004). Earlier studies have shown numerous assessments of root exudation rates from trees (Phillips and Fahey, 2005; Phillips et al., 2011) as well as tree seedlings (Bengtson et al., 2012). Therefore, root exudation rates in *T. candida* (Roxb.) DC may profoundly affect the soil fertility levels in various land use systems as a result of shifting cultivation, forest degradation and various plantations.

This study aims to (i) estimate the fine roots and coarse roots biomass in the bulk root zone (BRZ) and sparse root zone (SRZ); (ii) analyze the soil nutrient distribution in BRZ and SRZ and (iii) determine the magnitude of root exudation in *T. candida* (Roxb.) DC and assess the amount of C released per unit area in the stand through the process of exudation.

Material and Methods

Study Site

The study was conducted in 4-5 years old SALT trial farm established with *T. candida* hedgerows within Mizoram University campus, Northeast India. The geographic location of the study site is at 23º48.060' N latitude and 92º37.084' E longitude with an elevation of 685 m above mean sea level. The climate of the area is humid and tropical, which is characterized by short winter, and long summer which receives heavy rainfall during monsoon period, mainly the south-west monsoon. The mean annual temperature ranged from 21ºC to 32ºC (in summer) and 11ºC to 23ºC (in winter) and total annual rainfall varied from 2000 to 2500 mm.

Experimental design and sample collection

The experiment was carried out in *T. candida* (Roxb.) DC hedgerow plantations raised in ~1 ha area. The plant to plant distance was ~10 cm and row to row distance was 2 m. A total of five random sample plots of ~100 m^2 were demarcated for intensive soil sampling. The soil within a radial distance of 50 cm from the plant base of the hedgerow was considered as Bulk Root Zone (BRZ) and the soil portion after 50 cm from the plant base as Sparse Root Zone (SRZ). After removing plant litter, soil samples were excavated at two different soil depths (i.e., 0-15 cm and 15-30 cm) with a stainless-steel corer from five sample plots following simple random sampling. The soil samples collected from each plot were thoroughly mixed as composite soil and divided into five replicates. Soil samples were sieved through a 2-mm mesh. Large roots, stones and debris were removed from the samples. The samples were analyzed for physicochemical characteristics in the laboratory. Fine (< 2 mm) and coarse roots (2-5 mm) of *T. candida* were sampled using soil monolith (10 cm x 10 cm x 15 cm deep) method. The roots belonging to *T. candida* were identified morphologically for further estimation.

Analyses of soil samples

Soil moisture content (SMC) was determined gravimetrically by drying the soil samples at 105°C in a hot air oven to constant weight and the water content was expressed as a percentage of the dry weight. Bulk density was measured by collecting a known volume of soil and determining the weight after drying (McKenzie et al., 2004) and porosity was calculated using dry bulk density assuming a particle density of 2.65 g cm^{-3} (Danielson and Sutherland, 1986). Soil texture was determined using the hydrometer method (Bouyoucos, 1926). The textural classification according to the United States Department of Agriculture (USDA) was followed to give the textural class. Soil pH was measured in a soil-water suspension (1:2.5 soil-water ratios) with pH analyzer. Soil organic carbon (SOC) was determined by Walkley and Black method (Walkley and Black, 1934), available phosphorus (P) by ammonium molybdo-blue color method (Allen et al., 1974), total nitrogen (TN) by Kjheldhal method (Chapmann and Pratt, 1961) and exchangeable potassium (K) by Flame Photometer (Jackson, 1967). NO_3-N was estimated by phenol disulphonic acid method (Harper, 1924) and NH_4-N by Indophenol-blue method (Rowland, 1983). The N mineralization rate was estimated by the method proposed by Eno (1960).

Analysis of root samples

The root samples were washed over a jet of water using twin sieves (i.e., 2 mm upper, 0.5 mm lower) assembly. The root biomass was separated into three diameter classes (≤ 0.5 mm, 0.5-2 mm, 2-5 mm). After the separation, the roots were dried in the oven at 60°C to constant weight to obtain the dry mass. Root biomass of *T. candida* was represented as dry mass in g m^{-2}.

Root exudation measurements

Exudates were collected four times during a year (i.e., February, April, June, and August 2016) from intact fine roots using a modified culture-based cuvette system developed specifically for field-based exudate collections (Phillips et al., 2008). Terminal fine roots of six plants of *T. candida* were freed from soil while remaining attached to the tree from the upper 15 cm of soil mineral horizon by hand. In order to ensure that roots were from *T. candida*, all the fine roots were traced back to its base by removing the attached soil. Soil particles adhering to fine roots were removed by gentle washing, and forceps were used to dislodge soil organic matter aggregates. After a short equilibration period, the intact root system (i.e., roots still attached to the tree) of all six plants was placed into a 30 ml glass cuvette, and the remaining volume of the cuvette was filled with sterile glass beads. A carbon free nutrient solution (0.1 mM KH_2PO_4, 0.2 mM K_2SO_4, 0.2 mM $MgSO_4$, 0.3 mM $CaCl_2$) was added to the cuvette to buffer the roots, and the entire root cuvette system was sealed with parafilm. After 24 hrs, exudates were collected by flushing the cuvette three times by adding fresh solution which were then filtered through a sterile 0.22 mm syringe filter within 2-5 hrs after collection and stored at -20^{0}C until analysis. Total non-particulate organic C accumulated in the trapped solutions in each cuvette was analyzed with TOC analyzer (TOC-VCPH, Shimadzu, Japan).

Exudation rates were calculated as the mass of C (mg) flushed from each cuvette by considering roots <2 mm diameter class over 24 hrs incubation period. Mass-specific rates of root exudation (mg C g^{-1} day^{-1}) were calculated by dividing the total amount of C flushed by the total fine root biomass (<2 mm diameter) within each cuvette (Yin et al., 2014). Annual C exudation rate (mg C g^{-1} yr^{-1}) was estimated by multiplying daily exudation rates (average of four months) with the total number of days in a year (i.e., 365). The annual C flux (g C m^{-2} yr^{-1}) was calculated by multiplying the average mass-specific exudation of C and the total fine root biomass per m^2.

Statistical analysis

Data were reported as mean ± standard error (1SE). Paired sample *t*-test was conducted to analyze the difference in soil chemical properties between BRZ

and SRZ as well as differences in 0-15 cm and 15-30 cm soil depth. Two-way analysis of variance was performed to test the influence of soil depth and root zone on soil chemical properties. One-way ANOVA was performed to test seasonal variation in root exudates. All data were analyzed using SPSS software package (SPSS Inc., Chicago, IL, USA).

Results and Discussion

Spatial variations in soil physicochemical properties

The variations in soil physicochemical properties in two root zones and soil depth are shown in Table 1. Values of soil moisture, SOC, TN, exchangeable K and NH_4-N in upper and lower depths varied significantly ($p < 0.05$). The soil properties like soil moisture, pH, TN, exchangeable K and NH_4-N differed significantly ($p < 0.05$) between the two root zones, whereas, SOC, available P and NO_3^--N did not vary significantly. Soil moisture content ranged from 19.48% - 22.5% with higher values in BRZ (Table 1). The bulk density ranged from 1.14 – 1.36 g cm^{-3} with a high value in lower soil depth. The soil was sandy loam in texture. The proportions of sand, silt and clay contents varied from 59.6 – 65.7 %, 17.7 – 26.7 % and 9.6 – 21.6 %, respectively in two depths and zones.

The enhanced accumulation of organic matter and soil nutrients in upper soil depth of BRZ was as a result of greater input of litter through leaf fall and root mortality in association with C released via rhizodeposition due to greater microbial activity in this zone (Anikwe et al., 2016; Hauchhum and Tripathi, 2017; Lalnunzira and Tripathi, 2018; Singha and Tripathi, 2017, Wapongnungsang and Tripathi, 2019; Hauchhum and Tripathi, 2019). On the other hand, decreased soil fertility in lower soil depth was probably due to reduced rates of organic matter deposition through leaf litter fall and exudation. In the present study, significant increase (2-3 fold) in the rates of nitrification and N-mineralization in BRZ (radial distance of 50 cm from the plant base) compared to SRZ (50 cm away from plant base) could be related to enhanced organic matter deposition and rhizosphere priming effects (Phillips and Fahey, 2006). This could be because of a strong linkage of organic matter accumulation with the rates of organic matter deposition (via leaf fall and root mortality and rhizodeposition), decomposition and soil microbes (Wapongnungsang and Tripathi 2019; Hauchhum and Tripathi, 2019; Manpoong et al., 2020). Organic matter inputs act as a source of energy for microbes (Jackson et al., 2008) that govern the process of litter decomposition and ultimately accumulation of C and nutrients in the soil. Negative rate of ammonification in both zones was possibly due to rapid conversion of NH_4-N to NO_3-N and

Table 1. Variations in soil physicochemical properties in bulk root zone (BRZ) and sparse root zone (SRZ) for *T. candida* at Mizoram University campus, Northeast India.

Soil variables	0-15 cm		15-30 cm	
	BRZ	SRZ	BRZ	SRZ
Soil moisture (%)	22.15 ±0.2[a]	20.8 ±0.3[b]	20.15 ±0.1[a]	19.48 ±0.3[a]
Bulk density (g cm^{-3})	1.14 ±0.1[a]	1.18 ±0.2[b]	1.29 ±0.08[a]	1.36 ±0.1[b]
Sand (%)	63.7 ± 0.2[a]	65.7 ±0.9[b]	59.6 ± 1.5[a]	60.7 ± 1.1[a]
Silt (%)	26.7 ±0.5[a]	23.7 ±0.8[b]	19.8 ±1.6[a]	17.7 ±0.9[b]
Clay (%)	9.6 ±1.1[a]	10.6 ±1.5[a]	20.6 ±0.6[a]	21.6 ±1.3[a]
Soil pH	4.28 ±0.01[b]	4.45 ±0.06[a]	4.36 ±0.03[b]	4.47 ±0.05[a]
Soil organic carbon (%)	2.89 ±0.06[a]	2.43 ±0.04[b]	2.25 ±0.06[a]	1.87 ±0.01[b]
Total nitrogen (%)	0.33 ±0.04[a]	0.28 ±0.05[b]	0.22 ±0.04[a]	0.17 ±0.03[b]
Available P (mg g^{-1})	0.21 ±0.01[a]	0.18 ±0.002[b]	0.19 ±0.03[a]	0.14 ±0.002[b]
Exchangeable K (mg g^{-1})	0.08 ±0.003[a]	0.06 ±0.002[b]	0.06 ±0.004[a]	0.04 ±0.002[b]
Ammonium (mg g^{-1})	0.29 ±0.002[a]	0.25 ±0.002[b]	0.16 ±0.001[a]	0.12 ±0.007[b]
Nitrate (mg g^{-1})	0.39 ±0.01[a]	0.30 ±0.01[a]	0.27 ±0.002[a]	0.16 ±0.001[b]

Different small case letters in superscripts along the row indicate significant difference ($p < 0.05$) between BRZ and SRZ. Values are mean ±1 Standard error.

immobilization of ammonium N by microbial communities.

In general, the soil chemical properties were significantly enhanced in BRZ compared to SRZ at both the soil depths (Table 1). The soil was strongly acidic in nature (4.28 – 4.47). SOC concentration was significantly greater (19-20%) in two depths of BRZ, which might have been due to the deposition of large quantities of litter through leaf fall and root mortality in this zone. Similarly, per cent TN was 18-29% greater in two soil depths of BRZ compared to SRZ. The values of available P and exchangeable K were also greater in both the soil depths of BRZ, which ranged from 0.14 – 0.21 mg g^{-1} in BRZ and 0.04 – 0.08 mg g^{-1} in SRZ. The greater amount of NH_4-N and NO_3-N in BRZ compared to SRZ was the result of higher nitrogen fixation in this zone due to greater concentration of roots. In BRZ, the level of NH_4-N was 16% higher in upper soil depths and 33% higher in lower depth, and similarly NO_3-N was 30% and 67% higher in these two depths. This indicated greater uptake of NH_4-N and NO_3-N by the plant from upper BRZ due to high concentration of roots than in the SRZ (Kunhamu et al., 2010). The rate of nitrification and net N-mineralization was significantly greater in BRZ compared to SRZ. The values of nitrification ranged from 0.07-0.16 mg g^{-1} day^{-1} and 0.04-0.12 mg g^{-1} day^{-1} in two depths (Table 3). The rate of ammonification was negative in both BRZ and SRZ. Higher acidity in the BRZ compared to SRZ indicated greater organic acid produced in this zone as a result of enhanced root exudation and microbial population (Paterson, 2003). This resulted in greater organic acid production through microbial metabolism and increased release of hydrogen ions around the root zone due to higher root absorption of cations (Ahmed et al., 2014; Hauchhum and Tripathi, 2017; Zaidey et al., 2010). Greater soil moisture content and soil nutrient concentrations in BRZ was related to higher organic matter content and the role of rhizosphere microbiome in improving the soil structure and fertility (Hossain and Sugiyama, 2011; Zhang et al., 2011).

Spatial changes in fine root biomass

The proportions of different fine root categories varied significantly between two root zones and depths. For instance, <0.5 mm diameter root category contributed to 25% of the total root biomass (i.e., <0.5 mm + 0.5– 2 + 2-5 mm diameter) in both the soil depth of BRZ, whereas, the same root category contributed 37-42% of the total root biomass in two depths of SRZ (Table 4). The other two categories (i.e., 0.5– 2 and 2-5 mm diameter) of roots contributed almost equally at two depths and zones except at BRZ in lower depth (0.5-2 mm

Table 2. Two-way analysis of variance on the effect of soil depth and root zones on different soil variables.

Soil variables	Soil Depth	Root zone	Depth × Root zone
Soil moisture content	**	**	NS
pH	NS	*	NS
Soil organic carbon	*	NS	NS
Total nitrogen	*	**	NS
Available Phosphorous (mg g^{-1})	NS	NS	NS
Exchangeable Potassium (mg g^{-1})	**	**	NS
NH_4 -N (mg g^{-1})	**	**	*
NO_3 -N (mg g^{-1})	NS	NS	NS

(* and ** indicate significant differences at $p < 0.05$ and $p < 0.01$ respectively and NS indicates non-significant difference).

Table 3. Ammonification, nitrification and net N-mineralization rates in two root zones.

Root zones	Ammonification (mg g^{-1} day^{-1})	Nitrification (mg g^{-1} day^{-1})	Net N-Mineralization(mg g^{-1} day^{-1})
Bulk root zone	-0.032 ±0.05[a]	0.16 ±0.02[a]	0.12 ±0.03[a]
Sparse root zone	-0.034 ±0.04[a]	0.07 ±0.005[b]	0.04 ±0.001[b]

Different letters indicate the significant difference ($p < 0.05$) between the root zones.

Table 4. Total root biomass of *T. candida* in each of the root size classes in bulk root zone (BRZ) and sparse root zone (SRZ) at two soil depths.

Fine root categories	0-15 cm depth		15-30 cm depth	
(mm)	BRZ (g m^{-2})	SRZ (g m^{-2})	BRZ (g m^{-2})	SRZ (g m^{-2})
<0.5	32.22 ±4.7^{bA}	9.28 ±2.1^{aB}	12.04 ±1.5^{bA}	3.31 ±1.5^{aB}
0.5- 2	49.22 ±6.5^{aA}	6.44 ±2.3^{bB}	23.23 ±4.7^{aA}	3.22 ±1.2^{aB}
2-5	47.59 ±3.9^{aA}	6.15 ±1.9^{bB}	13.16 ±4.5^{bA}	2.23 ±0.8^{bB}

Small letters in column indicates significant difference ($p < 0.05$) among the root categories and capital letters indicate significant difference between root zones.

category) where it's contribution increased to 48%. However, the mean value of fine root biomass was significantly higher in BRZ than SRZ which decreased from upper soil depth to lower soil depth. Similary, Kunhamu et al. (2010) found higher root activity within a radial distance of 25 cm from the base of *Acacia mangium*, and the same decreased with increase in distance from the tree base. Total fine root biomass in upper (0-15 cm) and lower (15-30 cm) soil layer was 129 g m^{-2} and 48 g m^{-2}, respectively in BRZ, which were six fold greater than in SRZ.

The distribution of fine root biomass was more abundant in BRZ compared to SRZ suggesting that the species roots developed in concentric rings near the stem bases to acquire abundant nutrients and water. These roots proliferated in the soil distinctly away from the plant stem to exploit water and nutrients from the soil due to scarcity of these nutrients created near the bases to support plant growth (Tripathi et al., 1999). The fine root distribution varied with soil depth, and was more concentrated in upper soil depth than lower one. This indicated stimulated root growth by increased nutrient levels in the nutrient rich upper soil layer as a result of high fertility level. Similar trends have been reported by other workers (Lalnunzira and Tripathi, 2018; Tripathi and Singh, 1994). Roots constitute major components of belowground carbon and nutrient input to soil and their vertical distribution depends on the soil environments (Barbhuiya et al., 2012; Sahu et al., 2013). The conversion of part of very fine (<0.5 mm) roots to higher diameter class (0.5-2 mm) was likely and could contribute to the increase in proportion of higher diameter classes roots (Tripathi et al., 1999). However, at the same time fine roots continuously underwent mortality and high turnover due to short life span and thus majority of them might not have developed into larger diameter roots (Tripathi and Singh, 1995; Singha and Tripathi, 2017). This could be considered as a strategy of the plant to survive under unfavourable condition because of the higher life span of high diameter category. Further, higher stem densities distribution restricted the spread of absorbing roots (fine roots) which could facilitate competitive downward displacement of roots (Kunhamu et al., 2010). Substantial contribution of 0.5-2 mm diameter roots (34% in 3 year forest and 50% in old growth forest) to total fine root biomass was recently reported in this region (Singha and Tripathi, 2017).

Temporal variations in annual C exudation rates

Roots enclosed in the cuvettes were flushed thrice to ensure the collection of maximum amount of C released from these roots. The average mass-specific root exudation was highly seasonal with maximum exudation recorded in the month of August followed by June, April and February. Similar trends were reported by Hauchhum and Tripathi (2019) in three common weeds growing in shifting cultivation sites of Mizoram. The mass-specific exudation rate ranged from 0.168 – 0.768 mg C g^{-1} day^{-1}(Fig. 1). The amount of C exuded in first flush of the cuvette was significantly higher compared to second and third flushes (Fig. 2). Results showed that the amount of soluble C decreased with the increase in number of flushes. Phillips et al. (2008) reported

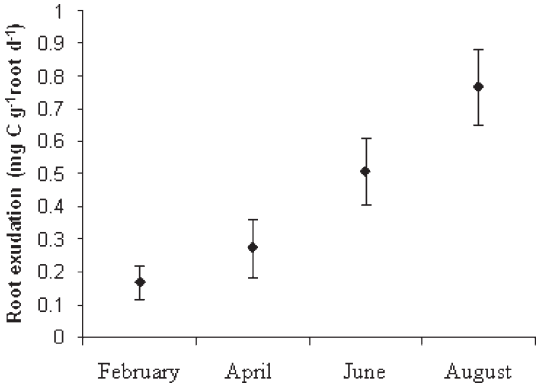

Figure 1. Monthly variation in total root exudates (addition of all the flushes) of *T. candida* stand

that three flushes were sufficient to remove over 90% of the soluble C in each cuvette. The annual C exudation rate in *T. candida* was 157 mg C g^{-1} yr^{-1}, which was equivalent to an annual C flux of 13 g C m^{-2} yr^{-1} at 0 – 15 cm soil depth and 6 g C m^{-2} yr^{-1} at 15 – 30 cm soil depth in BRZ. Subsequently, the annual C flux in SRZ was 2 g C m^{-2} yr^{-1} at 0 – 15 cm soil depth and 1 g C m^{-2} yr^{-1} at 15 – 30 cm soil depth. The mean total annual C flux in BRZ and SRZ was 9 g C m^{-2} yr^{-1} and 1.7 g C m^{-2} yr^{-1} respectively to a depth of 30 cm (Fig. 3).

Variation in exudation rates was driven by site-specific factors such as nutrient availability, soil

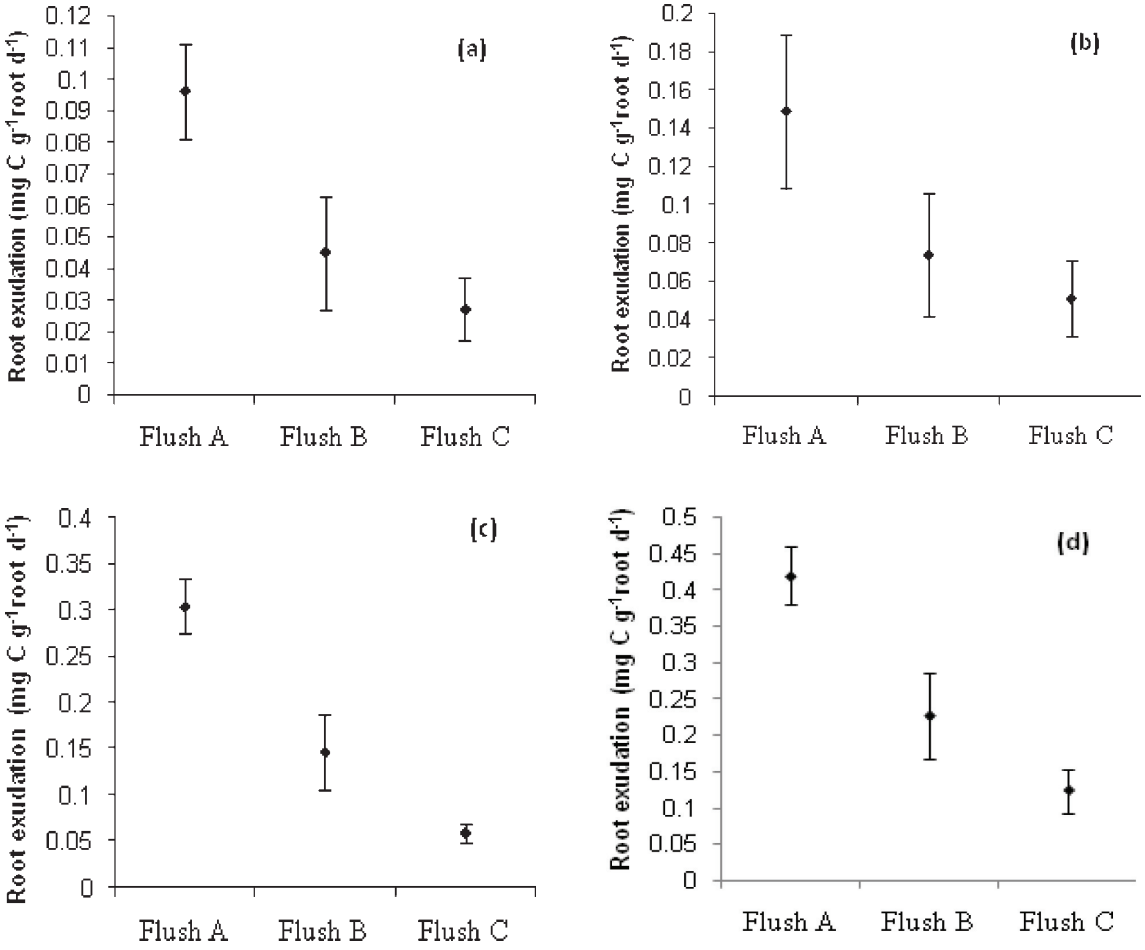

Figure 2. Monthly variation in the recovery of soluble carbon (3 flushes) from bead-filled cuvettes (a) February (b) April (c) June and (d) August

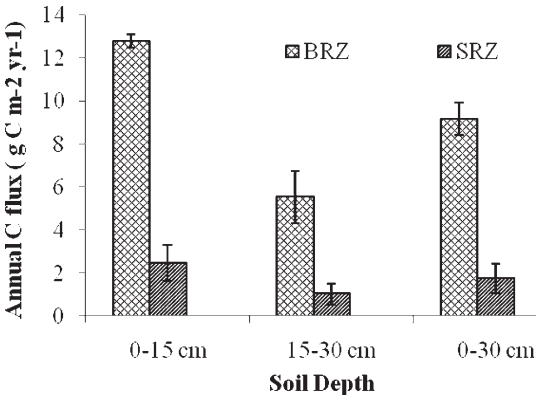

Figure 3. Total annual C fluxes in bulk root zone (BRZ) and sparse root zone (SRZ) at 0 – 15 cm and 15 – 30 cm soil depths.

structure and root characteristics (Hauchhum and Tripathi, 2019). Higher mass-specific root exudation rate during the wet months (June and August) compared to dry months (i.e., February and April) suggested a significant role of environmental condition on the process of exudation. The present result was in conformity with previous results reported in tulip, maple, oak and beech (Phillips et al., 2013; Yin et al., 2014) and in three common weeds (*Crassocephalum crepidioides*, *Ageratum conyzoides* and *Bidens pilosa*) of Mizoram (Hauchhum and Tripathi, 2019). Annual C flux from *T. candida* in the present investigation occured towards the lower range reported from studies published in European beech forest in temperate region (Tuckmantel et al., 2017). Higher total C exudation in BRZ compared to SRZ was probably due to the differences in fine root biomasses in two zones. The rate of exudation was measured in BRZ and therefore, the variation in root biomass could also affect the exudation rates in SRZ. Root exudates are well known for determining the composition and diversity of the microbial community in the rhizosphere and thus, play a significant role in regulating the nutrient dynamics along the root zone (Paterson et al., 2007).

This study concluded that *T. candida* growing in the hedgerows under sub-tropical environment added carbon and nutrients near the roots (BRZ) which spread further to enrich the sparse root zones (SRZ) and improve soil fertility level. The addition of carbon and nutrients near the root zone of the species strategically included increased root exudation, addition of litter and thus microbial dominance that stimulated the process of soil fertility improvement. Therefore, the species could be recommended for extensive trial under shifting cultivation sites in Mizoram to boost crop productivity and maintain soil fertility in the region. Further, the species could be recommended even for the promotion of agroforestry practices in the region as a process of weaning away from Jhuming (shifting cultivation). Since the present study was based on the bulk and sparse root zone at single age site and the root exudation was limited to the bulk root zone only, further extensive study is recommended to explore site age chronosequence at different places including a control with replicated plots for wider application.

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