Impacts of Woody Invader *Dillenia suffruticosa (Griff.) Martelli* on Physio-chemical Properties of Soil and, Below and Above Ground Flora

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Abstract

Dillenia suffruticosa (Griffith) Martelli, that spreads fast in low-lying areas in wet zone of Sri Lanka is currently listed as a nationally important Invasive Alien Species that deserves attention in ecological studies. Thus, impact of this woody invader on physical, chemical properties of soil and below and above ground flora was investigated. Five sampling sites were identified along a distance of 46km from Avissawella to Ratnapura. At each site, two adjacent plots [1m x10m each for *D. suffruticosa* present (D^{+}) and absent (D^{-})] were outlined. Physical and chemical soil parameters, microbial biomass and number of bacterial colonies in soil were determined using standard procedures and compared between D^+ and D^- by ANOVA using SPSS. Rate of decomposition of *D. suffruticosa* leaves was also determined using the litter bag technique at 35% and 50% moisture levels. Above ground plant species richness in sample stands was compared using Jaccard and Sorenson diversity indices. Decomposition of *D. suffruticosa* leaves was slow, but occurred at a more or less similar rate irrespective of moisture content of soil. Particle size distribution in D^+ soil showed a much higher percentage of large soil particles. Higher % porosity in D^+ sites was a clear indication that the soil was aerated. The pH was significantly lower for D^+ than D^- thus developing acidic soils whereas conductivity has been significantly high making soil further stressed. The significant drop in Cation Exchange Capacity (CEC) in D^+ soil was a remarkable finding to be concerned with as it correlated with fertility of soil. Significantly higher values of phosphates reported in D^+ soil support the idea that plant invaders are capable to increase phosphates in soil.

Higher biomass values recorded for D^+ sites together with higher number of bacterial colonies could be related to the unexpectedly recorded higher Organic Carbon. Both the Jaccard and Sorenson indices indicated that D^+ and D^- sites were dissimilar with respect to above ground plant species richness. Thus, changes in above ground vegetation and soil properties due to the invasion were identified and further studies are needed for determining the degree of soil deterioration due to the invasive behavior of *D. suffruticosa*.

Key words: *Dillenia suffruticosa, soil properties, Sri Lanka, invasive species, microbial biomass*

1. Introduction

Invasive alien Species (IAS) cause tangible ecological and economic damages by altering goods and services provided by the environment (Charles and Dukes, 2007, Parker, 1999, Primental et al., 2000). One major reason for these irreparable and irreversible impacts of IAS has been related to their ability to modify

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physical resources of the environment in ways that differ from resident plant associations (Ehrenfeld, 2004, Weidenhamer and Callaway, 2010). Many invasive plant species have high specific leaf areas, faster growth rates and increased leaf nutrient concentrations relative to the resident species of the same sites, and these traits change soil properties via modifying rates of decomposition and nutrient cycling in the soil environment (Allison and Vitousek, 2004). Additionally, allelopathic, defensive, or antimicrobial chemicals of plant invaders act as novel weapons and play a vital role in uniquely affecting the biogeochemistry of the soil to maintain the dominance of plant invaders (Callaway and Ridenour, 2004, Laio et al., 2008). There is much evidence that invasive plant species can modify physical or chemical attributes of soil, including inputs and cycling of nitrogen and other elements (Laio et al., 2008, Nicholas et al., 2008, Parker et. al., 1999, Walker and Smith, 1997).

For many years knowledge on impacts of IAS in Sri Lanka was mostly based on anecdotal observations, but in recent years empirical evidences on many aspects of IAS have been multiplied. Although studies on the impacts of plantation crops and many agricultural crops on Sri Lankan soils have been studied (Weerasinghe, 2012, Weerasinghe and Weerasinghe, 2007), impacts of many IAS, both on soil and native species remain understudied (Jayaratne and Ranwala, 2010). Para, (Dillenia suffruticosa (Griffith) Martelli., Family - Dilleniaceae) is one such example.

Dillenia suffruticosa, native *to East Asia, was* introduced to Sri Lanka as an ornamental plant to Royal Botanical Gardens in 1882 from Boneo. It is a light demanding woody shrub that could grow up to 6m tall in open lands in moist soil, thus proliferated fast as dense stands in the wet-low country of Sri Lanka inhabiting many marshy/semi- marshy areas (including abandoned paddy fields) in Kalutara, Galle and Ratnapura districts, posing a threat to native biota. Shade provided by its large leaves hinder undergrowth and accumulation of litter created a favourable habitat for mosquitoes, thus raising human health issues in the surroundings. When growing in riparian habitats it influenced sedimentation rates (Ranwala, 2011). These impacts listed D. suffruticosa as a nationally important IAS over the last ten years (Wijesundara, 1999, 2010). It was also recognized as an alternate host for Oil palm nettle caterpillar Setoranitens in Malaysia (Lim et al., 2001). However, important uses of D. suffruticosa have also been documented. Ability to staunch bleeding (Ahmed and Holdsworth, 1995), anti-fungal (Johnny et al., 2011, Wiart et al., 2004) and phyto- remediation (Rahim et. al., 2011) properties, usage of live poles as an effective and economical means of slope stabilization in bio-engineering (Abdullah et al., 2012, Prasad et al., 2012, Sasan et al., 2009) are among them.

Control through utilization has been suggested as an eco- friendly approach in IAS management (Geesing et.al.,2004) but at the same time, concern on IAS as ecosystem engineers (Crooks, 2002, Walker and Smith, 1997) cannot be neglected. As IAS alter structure and function of invaded ecosystems by modifying physical, chemical and biological resources, impact analysis is considered very important. Despite the widespread global attention on IAS, studies on their qualitative and quantitative consequences on the environment have not been well documented in many countries (Callaway and Maron, 2006, Jayaratne and Ranwala, 2010, Richardson and Van-Wilgen, 2004). In this context, we describe some impacts of *D. suffruticosa* on its immediate neighborhood through this paper.

The present work examined changes in physical, chemical properties of soil and below and above ground flora *between stands with and without D. suffruticosa*. Hence the study was conducted with the following objectives. Firstly, to determine the decomposition time and rate of leaves of *D. suffruticosa*. Secondly to identify the effects of *D. suffruticosa* on physical parameters of soil such as particles-size distribution, bulk density, porosity percentage and chemical parameters such as pH, conductivity, cation exchange capacity and nutrients (mainly Nitrates and Phosphates) in soil. Thirdly, to recognize the effect of *D. suffruticosa* on below ground flora (microbial biomass and bacterial colonies of soil) and above ground vegetation in invaded sites.

2. Materials and Methods

2.1 Study sites

Sampling sites, S1-S5 were selected at a total distance of 46 km along the High Level Road between Awissawella and Ratnaputa based on visual observation of presence of D. suffruticosa. At each site, two 1m x10m size adjacent plots were randomly outlined to represent presence (D^+) and absence (D^-) of D. suffruticosa. The regional climate of the study sites was wet, humid and warm with an annual average rainfall > 2500mm, overall year round temperature approximately at 30^{o}C. The stands contained Red Yellow Podsolic soils.

2.2 Determination of time and rate of decomposition of D. suffruticosa leaves

Fifty Nylon mesh bags (8cm ×10cm, pore size 0.25mm^2) each containing 2g of leaf matter were prepared using air dried mature leaves of *D. suffruticosa*. Bags were sealed and kept buried (3 per pot) approximately 5cm beneath in 16 pots containing soil obtained from natural habitat of *D. suffruticosa*. Two bags were kept out of water at room temperature (30^{o}C). To simulate natural moisture contents of soil, two equal sets of pots were maintained at 35% and 50% moisture levels under greenhouse conditions (30^{o}C). At 14 day intervals, 3 litter bags were removed from each set of pots and separately washed several times followed by air drying for seven days. Residues were carefully taken out, oven dried at 70^{0}C until a constant weight was obtained. The mean mass loss of residues was calculated and plotted against decomposition time. Time taken for 50% loss of the initial mass (t_{50}) was obtained for each moisture level. Decomposition rate was calculated by $\log_n (W_t/W_0) = \log_n W_0 - Kt_{50}$,where W_t= Weight of residue remaining at time $t_{50,}$ W_0 = Initial weight of residues, t_{50} = Time taken for 50% loss of the initial mass, K = decomposition rate, according to Anderson and Ingram (1993).

2.3 Determination of physical and chemical properties of soil

A composite soil sample was obtained from each of the plots twice a year (6 month intervals). Physical parameters of soil such as particles-size distribution, water retention capacity, bulk density, porosity % and chemical parameters such as pH, conductivity, cation exchange capacity and nutrient levels (mainly Nitrates and Phosphates) were tested in D^+ and D^- according to Hess, (1971). Data analyses for each parameter were done by two way Analysis of Variance using SPSS software (Version 16) to assess the significant (P= 0.05) impacts occurred due to the presence of *D. suffruticosa* during sampling times.

2.4 Determination of the changes in below and above ground flora due to the presence of D. suffruticosa.

Soil samples obtained for above physical and chemical analyses were also used to compare below ground flora such as microbial biomass and number of different bacterial colonies between D^+ and D^- soil. Microbial biomass was measured using fumigation incubation technique as per Jenkinson and Powlson (1976) while number of bacterial colonies was enumerated according to Robert *et. al*., (1957).

To identify the effect on above ground flora, height and crown cover percentage of *D. suffruticosa* and number of undergrowth plant species was recorded in D^+ and D^- plots at each site. Similarity of above ground vegetation between D^+ and D^- plots was compared for each site by Jaccard [IS_J = c/(a+ b+ c)*100] and Sorenson [ISs = c /½(a+ b)*100] similarity coefficients (Muleller Dombois and Ellenburg, 1974) where a and b were species richness in D+ and D- plots respectively and c = number of species common to both D^+ and D^-.

3. Results

3.1 Time and rate of decomposition of D. suffruticosa leaves

Dillenia suffruticosa leaves decomposed at a rate of 0.014g/day and 0.011g/day respectively at 35% and 50% moisture levels taking 98 and 126 days for a 50% weight loss (Figure 1).

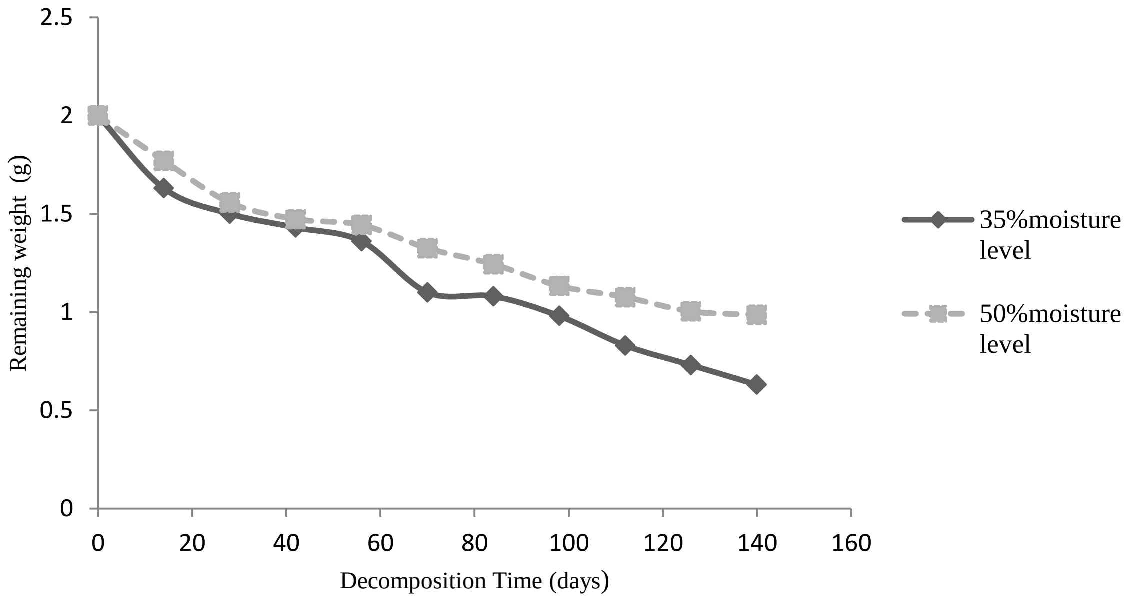
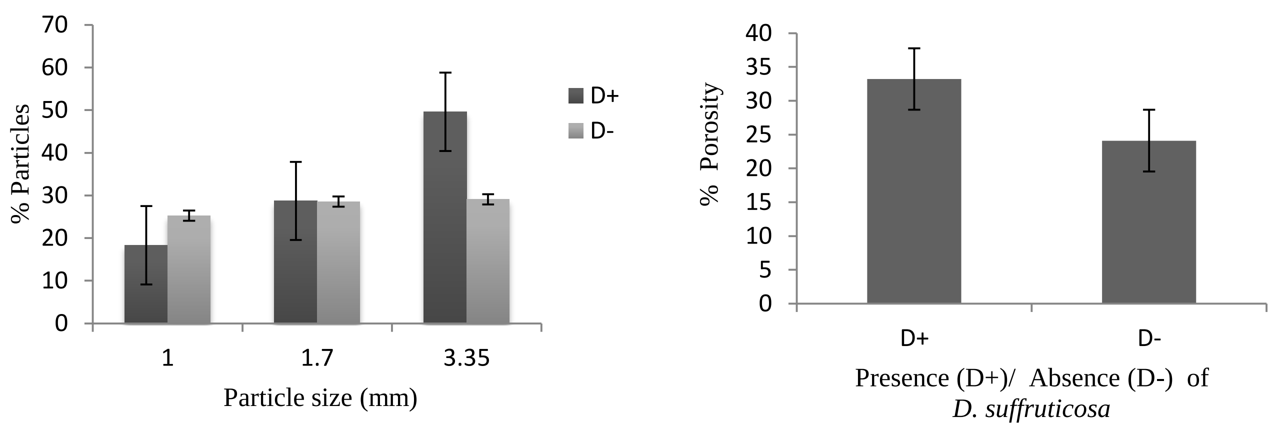


Figure 1: Remaining weight of dried D. suffruticosa leaves during decomposition at 35% and 50% moisture levels

3.2 Change in physical and chemical properties of soil

Our results indicated that *D. suffruticosa* tend to increase the percentage of large particles in soil (Figure 2a) simultaneously and significantly increasing the porosity of soil (Figure 2b). However, bulk density and water retention capacity did not vary significantly between D+ and D- soil. It was also found that there was no influence of the time of data collection on soil parameters investigated above.

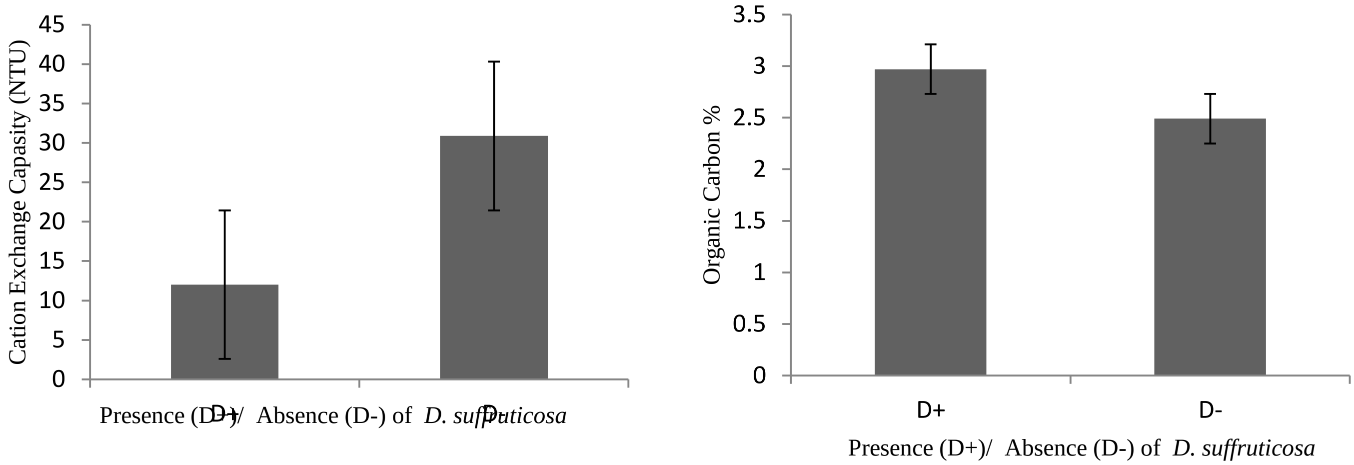


(a) (b)

Figure 2: Change of a) particle size distribution >1mm, and, b) Percentage porosity in D^+ and D^- soils.

The pH of the soil was significantly reduced (6.00 vs 6.40, P=0.05) and conductivity of soil was significantly increased (25.64 vs 18.24, P=0.05) by the presence of *D. suffruticosa*. Further, the Cation Exchange Capacity was significantly affected (Figure 3a) while an increase in % Organic Carbon in D^+ plots also observed (Figure 3b).

Invasion of *D. suffruticosa* significantly increased the Phosphate content of soil. There was no significant change in the Nitrate content due to the presence of the woody invader (Figure 4).



(a) (b)

Figure 3: Change in a) Cation Exchange Capacity b) Percentage Organic carbon in soil between *D. suffruticosa* present and absent stands

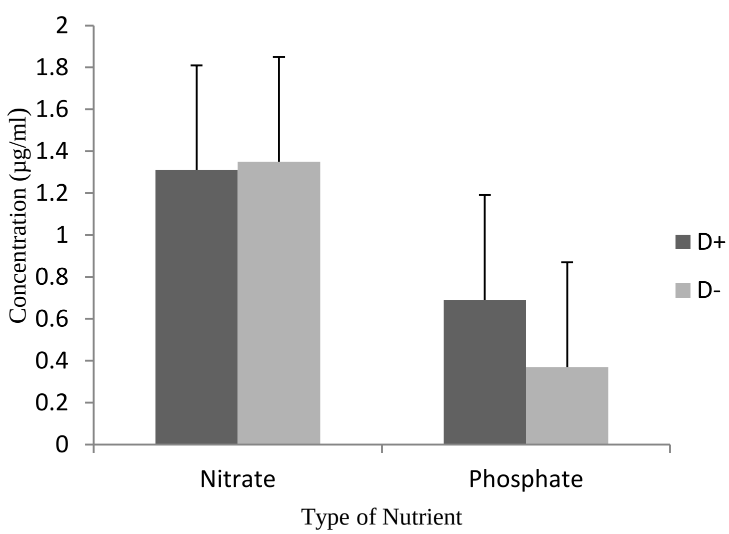


Figure 4: Change in Nitrate and Phosphate contents in soil by *D. suffruticosa*

3.3 Changes in below and above ground flora due to presence of D. suffruticosa

The microbial biomass (Figure 5) and the number of bacterial colonies reported from soil was relatively high in D^+ plots (166 x10^5 vs 97x 10^5 g^{1-}soil, P=0.05) indicating that the invader promoted the existence of diverse micro flora in soil.

Observations revealed that presence of *D. suffruticosa* had significantly changed the composition and richness of undergrowth plant species under its stands. Further, it was noticed that species richness of undergrowth vegetation was inversely related to crown cover of *D. suffruticosa* which was about 2-3m tall in fully grown shrubs. At 100% crown cover no undergrowth was found. Both the Jaccard and Sorenson indices confirmed that D^+ and D^- sites were dissimilar with regard to plant species richness (Table 1).

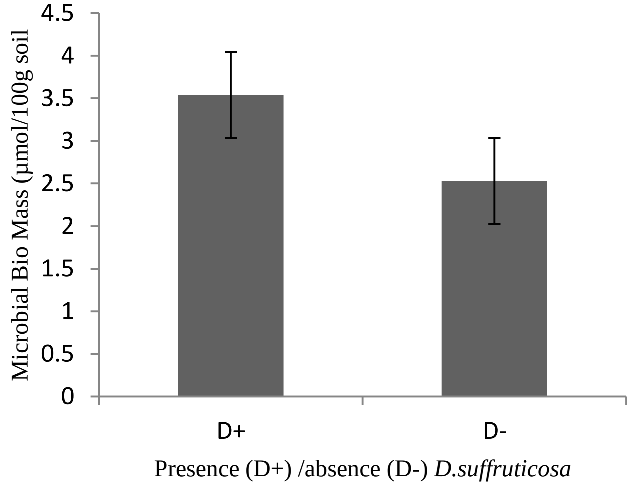


Figure 5: Change in microbial biomass in soil between *D. suffruticosa* present and absent stands

Table 1 .Similarity coefficients obtained for D+ and D- plots at five sampling sites. **IS_J**= Jaccard Similarity coefficient and **IS_S**= Sorenson Similarity coefficient

Sampling site	GPS coordinates	Cover of *D. suffruticosa* in D+	**IS_J**	**IS_S**
(S1) Getaheththa	Lat 6;54;39.866, Lon 80;13;29.8219	100%	4.76	4.76
(S2) Eheliyagoda	Lat 6;50;294059 Lon 80;16;18.5459	50%	5.26	5.55
(S3) Parakaduwa	Lat 6;49;28.272 Lon 80;18;16.776	50%	0.00	0.00
(S4) Kuruwita	Lat 6;47;30.221 Lon 80;20;33.532	100%	0.00	0.00
(S5) Ratnapura	Lat 6;42;50.062 Lon 80;22;50.432	100%	0.00	0.00

4. Discussion

Invasive Alien plant species impose multitude of impacts on structure and function of the ecosystem through direct or indirect effects on abiotic and biotic components of the environment (Charles and Dukes, 2007, Parker et. al., 1999, Walker and Smith, 1997) and our results are also in favor of this idea to a certain extend.

Plant invaders, mainly through their litter and root exudates change soil structure and nutrient cycles, mobilize and/or chelate nutrients, modify soil nutrient pools and diversity of soil biota. These effects on soil biogeochemistry are not only closely linked to the nutrient stoichiometry and secondary metabolites of leaf tissues but also the rate of decomposition of plant litter which play a pivotal role in releasing nutrients and chemicals into soil (Ehrenfeld, 2003, 2004, Weidenhamer and Callaway, 2010). Single species litter dynamics have shown that rate of litter decomposition and nutrient cycling are closely correlated with site environmental conditions (particularly climate), litter chemistry, composition of soil biota and the moisture content of soil (Swift et.al., 1979). As proven by our results, ability of *D. suffruticosa* to decompose its litter in a more or less same rate at high and low moisture levels (under the same environmental conditions) could be attributed to its broad tolerance limits (Allison and Vitousek, 2004) to withstand commonly prevailing moisture fluctuations of the soil. In such instances the invader is said to pose a threat to native species by delaying decomposition of their litter as many native species require substantial amount of water to efficiently decompose leaf litter in wet and warm environments (Facelli and Picket, 1999).

Presence of a large proportion of easily decomposable substances in plant tissues is reflected by higher decomposition rates of litter and this characteristic serves as a trait of invasiveness. However, according to our results *D. suffruticosa* exhibited a slow decomposition rate (average of 12.5mg/day and (t_{50}) 105 days) compared to *Lantana camara* (rate 126 mg/day and t_{50}- 11 days) and *Croton lacciferus* (average rate 154 mg/day and t_{50}- 09 days) under more or less similar climatic and soil conditions (Ranwala, unpublished data). Although litter quality was not investigated in this work, according to Hirobi et al., (2004), low nutrients (N= 8.7, P= 0.19, K= 1.83, Ca= 7.09, Mg=2.16 mg g^{-1}) and high amount of acid insoluble residue (368.2 mg g^{-1}) in *D. suffruticosa* leaves were responsible for slow decomposition rates.

Our results proved that the presence of *D. suffruticosa* structurally alter soil by creating larger soil particles and many air pores, thus making the soil much aerated. Acidity and high conductivity of soil under *D. suffruticosa* stands further indicated that the soil chemistry was affected probably be due to the accumulation of more H+ ions, minerals released from litter, inputs of CO_2 into substrate and or release of secondary metabolites/exudates by the invader (Kelly et. al., 1998). However, further work is required to comment on the mechanism. As proven by our results, Cation Exchange Capacity (CEC), which plays a major role in deciding the fertility status of soil, was also affected by the presence of *D. suffruticosa*. Significantly decreased CEC of soil in *D. suffruticosa* stands was a major evidence to show that mobility of nutrients has been affected by the invasive plant. Reduced CEC in the present study is an important finding to be concerned with as this could directly interfere with the absorbance and exchange of nutrients of any native species in the neighborhood. Increased organic carbon content exhibited by the plots with *D. suffruticosa* in our results served as an indication of the species potential of increasing soil organic carbon stock and hence soil fertility in invaded sites. However, addition of carbon stimulates soil microbial growth, which in turn accumulates soil nitrogen in their biomass limiting the availability of nitrogen to plants in many instances (Vitousek, 1982). The study was not able to identify any difference in nitrate content between D^+ and D^- soils but in available phosphates. This finding correlates with Martin et. al., (2009) which states that higher content of soil phosphates was common in many terrestrial invasions. However, further research is needed to ascertain whether this elevated phosphorus was brought through the invasive plant (Weidenhamer and Callaway, 2010) or activated by soil microbial biomass. This increase could also be attributed to the increased acidity which may assist to convert non soluble phosphate to soluble phosphates in the soil environment (Hedley et. al., 1983).

Movement of nutrients in soil is biologically mediated, thus changes in soil microbiota could be linked to changes in nutrient cycling of soil (Katherine et.al., 2006). At the same time, the abundance, composition and activity of the decomposing community is directly influenced by the plant and its litter resource (Couteaux et al., 1995, El-Shatnawi and Mukhadmeh, 2001, Kourtev et al., 2002). Higher microbial biomass observed in D^+ soils in this study may have also contributed to alter soil chemical properties under *D. suffruticosa* stands, but, further investigations on microbial composition are required to comment on this change. As soil is degraded with the increase of unfavorable microorganisms in soil (Katherine et.al., 2006), it would be worthy to investigate on the changes in populations of favourable or unfavourable microorganisms between D^+ and D^- soil.

In general diversity, density of plants is expected to be high in places where ample sunlight is supplied (Bazzaz and Picket, 1980). It was clearly understood that *D. suffruticosa* suppress undergrowth plant species richness/composition by physically shading the floor and probably suppressing establishment and growth of seedlings of the resident species. Many IAS alter species assemblages in communities; reduce abundance and richness of the neighborhood by increasing above and below ground competition for resources such as light and nutrients and by exuding secondary metabolites through roots and plant litter (Meier and Bowman, 2008, Vilà and Weiner, 2004, Yurkonis et. al., 2005, Xiong and Nilsson, 1999). These prevent seedling establishment, inhibit growth and development of resident plant species thereby creating feedbacks for continued invasion in many ecosystems.

Our work also confirmed that the woody invader, *D. suffruticosa* modify its neighborhood by altering soil properties and above ground community composition.

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