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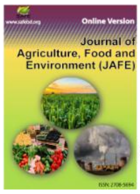

Original Article

Effects of forest encroachment on tree stock parameters and soil nutrient status in the Madhupur Sal (*Shorea robusta* C.F. Gaertn) forest of Bangladesh

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Encroachment, stand density, tree diameter, basal area, soil chemical properties

A B S T R A C T

Tree stock parameters and soil nutrient status were affected due to forest encroachment in the Madhupur Sal forest of Bangladesh from September 2015 to April 2016. The study was investigated through 120 sample plots of 10 m × 10 m in sizes taken randomly from three sites such as high, medium, and low encroached forest. Prior to objective, tree stock parameters were measured having a diameter at breast height (dbh) ≥ 10 cm and necessary soil samples were collected. The collected soil samples were analyzed in the laboratory to determine the organic matter, total N, available P, exchangeable K, available Ca, Mg, S, Fe, B and Zn. The results revealed that the tree stock parameters such as stand density, basal area and dbh were measured the highest (650 trees/ha, 30.17 m^2/ha and 26 cm) in the low encroached forest and the lowest (75 trees/ha, 4.47 m^2/ha and 21 cm) in the high encroached forest sites. Accordingly, the higher content of organic matter (1.60%), total N (0.18%), available P (12.97 ppm), exchangeable K (0.25 ppm), available Ca (3.38 ppm), Mg (1.47 ppm), S (20.34 ppm), Fe (234.06 ppm), B (0.68 ppm) and Zn (2.3 ppm) were found in soils from low encroached forest site and lower (0.65%), (0.09%), (8.09 ppm), (0.10 ppm), (1.09 ppm), (0.92 ppm), (10.60 ppm), (180.85 ppm), (0.28 ppm) and (1.22 ppm) in the high encroached forest site soils. Therefore, it can be concluded that tree stock parameters and soil nutrients status were remarkably affected due to the forest encroachment in the Madhupur Sal forest of Bangladesh.

Introduction

The Sal forests in 'Tropical Moist Deciduous Forest' are one of the major forest types in Bangladesh (Hasan *et al.*, 2018) covering an area of 120 thousand hectares which accounts for 0.81% of the total area of Bangladesh and about 32% of the total forest land (Banglapedia, 2015). Madhupur Tracts is representing of the major patches of Bangladesh Sal forests which consists of two National Parks: Madhupur and Bhawal National Park. In the past, both the parks were included within a continuous Sal (*Shorea robusta*) belt and consisted of the same species with rich flora and fauna diversity. But now a day this Sal forest facing severe deforestation problems due to various destructive anthropogenic activities such as encroachment of forest areas, illegal logging, over-exploitation, agricultural activities, grazing, and some other forms of human interference (Banglapedia, 2015; Rahman *et al.*, 2010). About 50,000 forest-dependent households including ethnic minorities are living in and around the 21 villages of the Madhupur forest area (Islam *et al.*, 2012; Islam *et al.*, 2013; Islam *et al.*, 2015). Moreover, two-third (49748 ha) of the Madhupur forest area was deforested and subsequently grabbed by the local people in order to practice commercial tree and/or crop cultivation (Islam *et al.*, 2015). Natural Sal forests are endangered due to the practices of agriculture and the introduction of exotic species (Pinaky Roy, 2009; Rahman, 2010). As a reaction to the conflicting land-use interests, agroforestry activities and the introduction of exotic species were initiated by the Government Forest Department in 1989 under the umbrella of the social forestry program in the Madhupur Sal forest of Bangladesh (Alam *et al.*, 2008).

As the land use patterns are changing in this forest it also has a significant effect on the soil nutrient quality e.g. growth of *Shorea robusta* is highly influenced by N, P, K, and soil pH. Several other nutrients like P, K, S, Ca, Mg, Fe, Zn and B also decreasing from the soil due to improper land use patterns (Li *et al.*, 2013). Another important effect of land-use changes in forest stock parameters by direct and indirect uses of the forest from human disturbance agents who induce the forest structure changes and all these contribute to changes in intra-specific variability, species diversity and ecosystem variety (McKinney, 2002). Most of the areas of Madhupur Sal forest have now been degraded and encroachment by local people. Some lands have been artificially planted to replace the natural forests of the region by high value indigenous medicinal species like *Azadirachta indica*, *Melia azedarach*, *Terminalia bellirica*, *Terminalia chebula*, etc. in the past, and recently by fast-growing and exotic tree species *Acacia* and *Eucalyptus* under social forestry and agroforestry programs (Bangladesh Forest Department, 2013). This plantation forestry and agroforestry or agricultural activities can bring change to the rural people, lifestyle, but it is not sure that it can sustain the soil fertility and increase the forest areas of natural forest. Therefore, it is necessary to examine the effects of land-use changes due to forest encroachment in the soil fertility status and forest parameters besides the plantation forestry for sustainable forest coverage.

In Bangladesh the past research has focused on listing the available plant species (Malaker *et al.*, 2010), different stands of Sal (*Shorea robusta*) forest and their soil health (Hasan and Mamun, 2015), species diversity and anthropogenic activities and their effects on vegetation parameters and soil nutrient (Ahmed *et al.*, 2009, Hasan *et al.*, 2018). But the effects of forest encroachment due to land-use changes on forest stock parameters and soil nutrient status of Sal forests which have not been sufficiently investigated in the past. Keeping the above points into consideration the study was undertaken to evaluate the effects of forest encroachment on tree stock parameters and soil chemical properties in the Madhupur Sal forest of Bangladesh.

Materials and Methods

Study area

The Madhupur Sal forest is located in Madhupur Upazila under the district of Tangail which is popularly known as ‘‘Madhupur Garh” everywhere (Hossain *et al.*, 2013). It is located from 23°50′ to 24°50′ north latitude and 89°54′ to 90°50′ east longitudes (Figure 1) at a distance of about 96 km north from Dhaka. The total area of the Madhupur Sal forest is about 18447.44 ha comprising four ranges namely Madhupur National Park, Dokhla, Arunkhola, and Madhupur (Hossain *et al.*, 2013). The soil is reddish-brown clay with low organic matter and low fertility having a moderate to the strong acidic reaction. The annual rainfall ranges from 203-229 cm. The annual temperature and humidity range from 10-34°C and 60-86%.

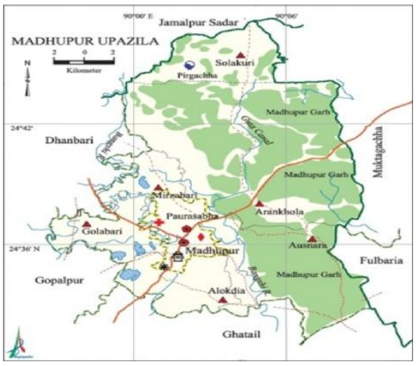

Figure 1. Map of Madhupur Upazila where green colouring showing the location of Madhupur Sal forest (Source: http://en.banglapedia.org/index.php?title=Madhupur_Upazila green).

Field methods

To investigate the effects of forest encroachment, necessary soil samples and tree parameters were done following the random sampling method from September 2015 to April 2016. A total of 120 sample plots of 10 m × 10 m quadrate size were laid out according to Williams (1991) from three sites such as high, medium, and low encroached forest lands in the Madhupur Sal forest (Table 1).

Table 1. Forest encroachment and land-use practices in the Madhupur Sal forest.

Types of forest encroachment	Land use practices
High encroached forest sites (HEFS)	Where the land belongs to the forest department but there is no control of forest authority on this zone. Highly disturbed and encroached by local people to the rice field, cropland, fallow land, banana garden, pineapple garden, and homestead.
Medium encroached forest sites (MEFS)	Where land also belongs to the forest department but local people have access to do agroforestry, fruit orchard, agriculture, social forestry in the deforested land.
Low encroached forest sites (LEFS)	Where the forest land is highly protected characterized by natural vegetation facing low human encroachment.

Soil sample collection and preparation

A total of 120 soil samples 40 from each of the stated sites were collected at 0 to 15 cm soil depth. From each quadrate plot, five soil cores were taken and mixed to make a composite sample. Then the soil samples were air-dried, processed, and sieved through 20 mesh sieves and packed with a specific tag for laboratory analysis.

Collection of tree stock parameters data

Tree stock data were recorded from the same plot (10 m × 10 m) in the time of soil sampling. From each quadrate plot, a number of trees species per plot was recorded which having the diameter at breast height (dbh) ≥ 10 cm for calculating the tree's stands density. Stand density was determined for each species using the estimated number of trees and basal areas of the species per hectare. The estimated number of trees of each species per hectare was obtained by extrapolating the total number of trees enumerated in the respective plots using the following formula (Etigale *et al.*, 2014).

$N = h/a \times c$

Where, h= one hectare, a= area of the plot in a hectare, c= number of trees counted in the plot and N= estimated the number of trees per hectare.

The basal area of each tree was calculated with the basal area function as stated by (Avery and Burkhart, 2002). The formula is:

$BA = \pi D^2/4(100)$

Where, BA= Basal area (m^2), π= Constant (3.142) and D= Diameter at breast height (cm).

The total basal area of each species was obtained by calculating together the basal areas of the individuals of the species. Basal area of each species per hectare was anticipated by extrapolating the total basal area of the species using the formula:

$BA = h/a \times d$

Where, BA= Basal area per hectare, h= one hectare, a= area of the plot in a hectare and d= basal area in each plot.

Laboratory analysis of collected soil samples

The prepared soil samples were analyzed in Humboldt Soil Testing Laboratory, Soil Science Department, Bangladesh Agricultural University, Mymensingh. Organic carbon was determined by the wet oxidation method (Walkley and Black, 1934). Total nitrogen was determined by the micro-Kjeldahl method (Jackson, 1958). Available P was extracted by the Molybdenum blue method of Bray and Kurtz using a spectrophotometer (Jackson, 1958). Exchangeable K was determined by the 1N NH4OAc extract method using a flame photometer (Page *et al.,* 1989). Available Ca and Mg were extracted with 1N NH4OAc using an atomic absorption spectrophotometer method (Petersen, 2002). Sulfur (S) was determined by a Turbidimetric method using a spectrophotometer (Page *et al.,* 1989). Available Fe and Zn were determined by a diethylenetriaminepentaacetic acid (DTPA) extraction method using an Atomic Absorption Spectrophotometer (AAS) (Petersen, 2002). Boron (B) was determined by the spectrophotometer technique using a colorimetric reaction with Azomethine-H (Ogner, 1980).

Data analysis

The data were calculated for each plot and then made an average for each encroachment site which was representing the value of the whole forest. Then the data were tabulated and analyzed through a standard computer package statistical procedure MSTAT-C, MS Excel, and SPSS software (Gomez and Gomez, 1984).

Results and Discussion

Effects of forest encroachment on tree stock parameters in the Madhupur Sal forest

Trees stand density

The result revealed that the average stand density (trees/ha) of natural trees was significantly affected due to forest encroachment (Table 2). The highest (650 trees/ha) stand density was found in the low encroached forest sites while the lowest (75 trees/ha) stand density was obtained from the high encroached forest sites in the Madhupur Sal forest (Table 2). The stand density of the Madhupur Sal forest is fitted within the limits reported for other Sal forests of India and Nepal (Pandey and Shukla, 2003; Webb and Sah, 2003). Similar results found that the highest (795.4 trees/ha) total density was measured in the peripheral zone and the lowest (155.5 trees/ha) in the buffer zone in the Gachabari Sal forest area of Bangladesh (Rahman *et al.,* 2007; Rahman *et al.,* 2009).

Basal area (BA)

The result indicated that the basal area of natural trees in the Madhupur Sal forest ranged from 4.77 to 30.17 m^2/ha that was significantly affected due to forest encroachment in the Madhupur Sal forest (Table 2). The low encroached forest sites in the Madhupur Sal forest had the highest (30.17 m^2/ha) basal area followed by the medium encroached forest sites with 8.80 m^2/ha while the lowest (4.47 m^2/ha) basal area was measured in the high encroached forest sites (Table 2). The basal area of mature trees was decreased with an increase in human disturbance intensity in the Gachabari Sal forest area of Bangladesh which was very much supportive of the present study result (Rahman *et al.*, 2007; Rahman *et al.,* 2009). The average basal area (30.17 m^2/ha) of the low encroached forest obtained in the present study was very close to the Sal and moist deciduous forests reported by (Pandey and Shukla, 2003; Webb and Sah, 2003).

Diameter at breast height (dbh)

The result showed that with an increase of the forest land encroachment the average diameter at breast height (dbh) of the natural trees in the high to low encroached forest sites were ranged from 21-26 cm which was not statistically significant (Table 2). The average highest (26 cm) diameter at breast height of the natural tree was obtained from the low encroached forest sites whereas the high encroached forest sites showed the lowest (21 cm) diameter at breast height in the Madhupur Sal forest (Table 2).

Table 2. Effects of forest encroachment on stock parameters in the Madhupur Sal forest.

Forest sites	Stand density (trees/ha)	Basal area (m^2/ha)	DBH
High encroached forest sites	75^c	4.77^b	21
Medium encroached forest sites	225^b	8.80^b	24
Low encroached forest sites	650^a	30.17^a	26
Co-efficient of variation	15.78	15.94	8.27
Level of significance	**	**	NS

Note: **= 1% level of significant; NS means non-significant

Effects of forest encroachment on soil chemical properties in the Madhupur Sal forest

Effects of forest encroachment on organic matter (OM)

The organic matter content of Madhupur Sal forest soils definitely influenced due to forest encroachment by the local people (Table 3). The present study revealed that the OM content of soils varied from 0.65 to 1.60% and the highest (1.60%) OM was found in the low encroached forest sites soil which was dissimilar to the OM content in the medium (1.11%) and high (0.65%) encroached forest sites soils (Table 3). The soil organic carbon was significantly affected by land-use changes of deciduous Sal forest in Bangladesh this was strongly supported by the present findings (Kashem et al., 2016). It was stated that the percentage of OM content was higher in the topsoil layer (0-15 cm) of well-stocked Sal (*Shorea robusta*) forest than the depleted Sal forest in Bangladesh which was supportive of the present findings of the study (Shahariar *et al.,* 2013).

Effects of forest encroachment on primary soil nutrients (N, P, K)

The Madhupur Sal forest soil contains statistically the very poor amount of total N due to changes in land-use practices through forest encroachment by the local people. The results indicated that the total N contents ranged from 0.09 to 0.18% from high to low encroached forest sites (Table 3). The total N content of the low encroached forest sites soil was the highest (0.18%) and the lowest (0.09%) in the soil of highly encroached forest sites (Table 3). The value of total N in the high encroached forest sites soil was a bit lower because of less vegetation and removal of the bulk of nutritive soil by erosion. While due to an excess collection of different fallen leaves of the tree there was a lack of chance to the additionof N in the soil in the medium encroached forest zone. The research found that the average total N (%) ranged was 0.11 to 0.15 in the soils of the Madhupur Sal forest in Bangladesh which was supported by the present study result (Hasan and Mamun, 2015). The mean value of available P in the soil of the low encroached forest sites was 12.96 ppm, bit lower 8.09 ppm found in the highly encroached Sal forest sites soils which clearly indicated that forest encroachment due to changing land-use practices in the Madhupur Sal forest had significantly influenced on soil nutrient status especially available P (Table 3). It was reported that the average available P range was 6.90 to 14.70 ppm of some selected soils of Madhupur Upazila under the Tangail district which was very much supportive of this study result (Rahman *et al.,* 2012). Similar results obtained in their respective studies which were supportive of the findings of the present study (Walpola *et al.,* 2007; Shahariar *et al.,* 2013; Hasan and Mamun, 2015). The exchangeable K content of Madhupur Sal forest soils is very poor due to the conversion of forest land to agricultural activities through human disturbances (Table 3). The average exchangeable K content in the soil of the study areas such as high, medium, and low encroach forest sites was recorded as 0.07 ppm, 0.15 ppm, and 0.25 ppm, respectively (Table 3). The results of the ANOVA revealed that there was a significant difference in the exchangeable K content of soil across the degrees of encroachment on the Madhupur Sal forest. It was revealed that the properties of the top soil of the Madhupur Sal forest are different in their responses to the varying land uses (Kashem *et al.,* 2016). Observation on similar lines was also made that exchangeable K was higher in the soil in the undisturbed sites or well-stocked Sal forest than disturbed Sal forest soils (Shahariar *et al.,* 2013). The exchangeable K in soils of the pure stand (less disturbed) was the highest which was statistically different from a mixed stand (medium disturbed) and plantation stand (highly disturbed) of the Madhupur Sal forest which strongly supported to the present study findings (Hasan and Mamun, 2015).

Effects of forest encroachment on secondary soil nutrients (Ca, Mg, S)

The secondary soil nutrients such as Ca, Mg, and S were significantly affected due to forest encroachment by local people in the Madhupur Sal forest (Table 3). The result showed that the available Ca, Mg, S contents were varied 1.09 to 3.38 ppm, 0.92 to 1.47 ppm and 10.60 to 20.34 ppm from high to low encroached forest sites soils in the Madhupur Sal forest and the variation among the sites was statistically significant (Table 3). The result revealed that the available Ca, Mg and S contents in the soils of low encroached forest site was comparatively higher (3.38 ppm, 1.47 ppm, and 20.34 ppm) to that of lower corresponding values (1.09 ppm,0.92 ppm, and 10.60 ppm) which were obtained in the soils of high encroached forest land (Table 3). Relevant results also found that Ca, Mg and S contents of well-stocked Sal forests were higher compared to that of depleted Sal forests in the study of physicochemical properties of soil under two different land use management in tropical moist deciduous Sal (*Shorea robusta*) forests in Bangladesh (Shahariar *et al.,* 2013). The available Mg content of Madhupur Sal forest soil was 0.90 ppm to 1.22 ppm, which was very much supportive of this study (Hoque *et al.,* 2009).

Effects of forest encroachment on soil micronutrients (Fe, B, Zn)

Table 3 showed that available micronutrients such as Fe, B, and Zn were significantly affected due to forest encroachment by a settler in the Madhupur Sal forest (Table 3). The available Fe, B, and Zn content were varied 180.85 to 234.06 ppm, 0.28 to 0.66 ppm and 1.22 to 2.35 ppm at 0-15 cm depth in the soils of the Madhupur Sal forest area (Table 3). From this result, it was observed that the available Fe, B and Zn contents in the soils of the low encroached forest site was higher (234.06 ppm, 0.66 ppm, and 2.35 ppm) compared to that of lower values (180.85 ppm, 0.28 ppm, and 1.22 ppm) which were found in the soils of high encroached forest site of the Madhupur Sal forest (Table 3). Similar results found that the Fe status in different soil series of Madhupur was 70-290 mg kg^{-1} (Khan *et al.,* 1997). It was reported that exchangeable Fe was higher in the soil in the well-stocked Sal forest than depleted Sal forest in Bangladesh which was also supportive to present findings (Shahariar *et al.,* 2013). The B status in different highland, medium highland,and medium lowland under the Madhupur Upazila were 0.61 µg g^{-1}, 0.63 µg g^{-1} and 0.55 µg g^{-1} soil, respectively which was supportive of the study findings (SRDI, 2014).

Table 3. Soil nutrient status affected by forest encroachment in the Madhupur Sal forest.

Forest sites	OM	Macronutrients						Micronutrients (ppm)		
		Primary nutrients			Secondary nutrients					
		N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	S (ppm)	Fe	B	Zn
HEFS	0.65^{c}	0.09^{c}	8.09^{c}	0.10^{c}	1.09^{c}	0.92^{c}	10.60^{c}	180.85^{c}	0.28^{c}	1.22^{c}
MEFS	1.11^{b}	0.12^{b}	9.90^{b}	0.15^{b}	2.65^{b}	1.21^{b}	17.73^{b}	200.70^{b}	0.46^{b}	1.53^{b}
LEFS	1.60^{a}	0.18^{a}	12.97^{a}	0.25^{a}	3.38^{a}	1.47^{a}	20.34^{a}	234.06^{a}	0.68^{a}	2.35^{a}
CV	8.32	12.63	4.11	11.55	10.7	8.24	3.47	4.42	14.04	9.08
Level of sig.	**	**	**	**	**	**	**	**	**	**

Note: HEFS= High encroached forest sites, MEFS= Medium encroached forest sites, LEFS= Low encroached forest sites; CV= Co-efficient of variation; sig.= significant; **= 1% level of significant; CV= Co-efficient of variation

Conclusions

From this study, it has been found that the effects of forest encroachment by local people had significantly affected tree stock parameters and soil nutrient status in high encroached forest sites compare to low encroached forest sites in the Madhupur Sal forest. The recurrent anthropogenic activities which are occurring in the Madhupur Sal forest declining the soil nutrient status and decreased the stand density. Therefore, it can be concluded that for increasing forest coverage prior need to conserve our natural forest through sustained soil fertility as well as the appropriate stand density and growth of trees.

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